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The Proceedings of ESERA 2021 is an electronic publication for revised and extended papers presented at the ESERA 2021 conference organised by the University of Minho, Portugal, from 30 August to 3 September 2021. All papers in the e-Proceedings correspond to communications submitted and accepted for the ESERA 2021 conference. All proposals to the conference went through a double-blind review process by two or three reviewers before being accepted to the conference. A total of 739 proposals (out of which 33 were symposia) were presented at the conference, and 158 papers are included in the ESERA e-Proceedings, 5 of them from symposia.

The authors were asked to produce updated versions of their papers and consider the discussion that took place after the presentation and the suggestions received from other participants at the conference. The e-Proceedings presents a comprehensive overview of ongoing studies in Science Education Research in Europe and beyond. This book represents the current interests and areas of emphasis in the ESERA community at the end of 2021.

The e-Proceedings book contains seventeen Parts representing papers presented across 17 strands at the ESERA 2021 conference. The strand chairs for ESERA 2021 co-edited the corresponding Part for each strand 1 to 17. All formats of presentation (single oral, interactive poster, demonstration/workshop and symposium) used during the conference were eligible to be submitted to the e-Proceedings.

The co-editors reviewed the updated versions of the papers submitted after the conference at the end of 2021. ESERA, the editors and co-editors do not necessarily endorse or share the ideas and views presented in or implied by the papers included in this book.

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WITHIN THE PROCEEDINGS:

Part 1 / Strand 1

Learning Science: Conceptual Understanding

Co-editors: *Ana Sofia Afonso & Massimiliano Malgieri*

Part 1. Learning Science: Conceptual Understanding

Theories models, and empirical results on conceptual understanding, conceptual change and development of competences; methodology for investigating students' processes of concept formation and concept use; strategies to promote conceptual development.

Part 1: Learning Science: Conceptual Understanding

Editors: *Ana Sofia Afonso & Massimiliano Malgieri*

Introduction

Conceptual understanding is at the heart of science education, as the main motivation for its initial development and, even today, a central topic with many different facets. Identifying student difficulties and alternate models, evaluating the effectiveness of instructional approaches, and developing models of conceptual change are among the research themes researchers have discussed in the various sessions of Strand 1 at the ESERA 2021 conference. The contributions we received offer a wide research perspective, and in this Chapter, we present the articles in an order loosely based on the increasing level of instruction to which the study refers or is most useful. The contribution by Mafra, Carvalho and Lima, which opens the Chapter, identifies and classifies pre-instruction ideas about microorganisms of ten-year-old children by analyzing their drawings. The authors find a prevalence of drawings with anthropomorphic or animal shapes, often with negative connotations, and propose classifying children's ideas into emerging, transitional and expanded models. Borghini and coauthors, in their study, ask ten-year-old children to explain the finding of a sedimentary rock containing fossil shells on a mountain cliff. The authors find that children's explanations are dominated by the idea that the sea once covered the whole earth, and when it withdrew, the mountains emerged. However, the authors also note that at this age, explanations implying that mountains have formed over time start to appear. Neofotistos, Starakis and Halkia investigate the ideas of 10–12-year-old students about the nature of the moon's luminosity. They find that about one-quarter of students believe that the moon is self-luminous, a conclusion often supported by the idea that the sun cannot illuminate the moon since the two objects are always on opposite sides of the earth. Even for students correctly stating that the moon is hetero-luminous, they find several misconceptions concerning astronomical facts and the mechanism of vision. In the next contribution, Campillos and coauthors use an Arduino-based device to study the consistency of perceived temperature scales for different subjects. They find that people consistently detect a transition in perceived temperature (for example, from "cold" to "neutral") at similar physical temperatures but also consistently misjudge the temperature of such transitions. Coming to the secondary school curriculum, Glatz, Teichrew and Erb examine the effectiveness of different interactive computer-based experiments in promoting 14–15-year-old students' understanding of various aspects of the particle model of matter. They find that the experiments considered differing in terms of educational gains, and in particular, that experiments requiring a higher cognitive effort are less effective. Also, in the context of chemistry, Diniz Júnior and collaborators built a semantic matrix in which themes and categories related to a chemical reaction are articulated and characterized according to epistemological, ontological, and axiological commitments. This matrix – drawn upon the theory of conceptual profiles, history of chemical reactions, science education literature and empirical data – highlights the plurality of meanings attributed to a chemical reaction. Zarkadis and Papageorgiou analyzed 17-18 years old students' misconceptions about quantum numbers through verbal and pictorial representations. Findings suggest that students hold several misconceptions, some of which were only identified by pictorial representations. The authors highlight the complementary role of the two representations in studying students' expressions of quantum numbers and the corresponding representations of the atomic structure. Hull, Jansky and Hopf drew attention to the context dependence of high school students’ conceptual understanding of radioactivity, particularly half-life. This context-dependency was further explored via a survey that contains isomorphic problems. Particularly, the authors aimed to understand to what extent students’ confidence correlates with consistency across the isomorphic prompts. The fact that there was no statistically significant correlation suggests that: while using isomorphic prompts requires additional testing time, asking for confidence ratings is not an effective substitute. In a follow-up study, Hull, Kitagawa, Abe, Yokotani, and Funahashi assessed an instructional unit on radioactivity for high school students. Based on Hypothesis-Experiment Class, this unit considered that students’ ideas about radioactivity could shift fluidity from one context to another. The authors concluded that in a learning environment in which students’ ideas are encouraged, the fluidity of students’ reasoning is enabled, and students appreciate the freedom to think fluidly as they learn science. Souza and Neto’s study focuses on Special Relativity Theory in high school. Grounded on Cognitive Networks Mediation Theory, the study aims at understanding what levels of mediation are more effective in facilitating the development of the relativistic zone of the conceptual profile of the reference frame. Results suggest that hypercultural mediation contributed to the construction of mental images and, then, to the development of a conceptual profile zone. Taken together, these studies illustrate that while much has been written on conceptual understanding, more research is still needed to support students’ development of conceptualizations that are closer to the scientific one.

MODEL OF ACCESS TO CHILDREN'S PREVIOUS IDEAS ABOUT MICROORGANISMS

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Detecting alternative conceptions that children bring to the classroom is crucial when promoting conceptual change. There are several strategies to detect these previous ideas different from scientific knowledge, which can be obstacles to learning. The drawing technic is a strategy shown to be very effective since it allows children to externalise their mental models more easily than written expression. Several authors have identified uncorrected scientific ideas about microorganisms, not only in initial grade children but also in more advanced grades. Thus, microorganisms are often imagined as animal mini-versions of beetles or earthworms and, in many cases, with anthropomorphised characteristics having heads, facial expressions and limbs. In general, children consider microorganisms as tiny living beings and tend to relate them to animal species familiar to them and express negative emotional connotations. If these previous ideas are not tackled in the first years of schooling, they may become resistant to change and later make it difficult to learn thematic issues related to microorganisms' benefits and understand their beneficial importance in ecosystems and biotechnology. This study presents a model for detecting children's alternative conceptions about microorganisms by using children's drawings. Drawings of 187 children who completed the four-years primary school were analysed and subject to a subsequent categorisation. Several categories emerged concerning the "shape" (real, anthropomorphic, animal, others) and "emotional connotation" (positive, negative, and with no emotional connotation). Thus, a model of analysis was obtained, which can be a tool of great importance, contributing to the teacher's knowledge about the students' previous ideas before starting the teaching of these contents and then s/he can move forward with strategies that promote conceptual change effectively.

Keywords: Conceptual Models, Science Education, Primary School

INTRODUCTION

Detecting children's previous ideas should be the first step to promote conceptual change in a teaching-learning process. Several strategies can be used to detect these previous ideas, which often are different from scientific knowledge and can be obstacles to learning (Mafra et al., 2013). Such children's previous ideas are representations of a mental model that can be accessed through drawing, writing and oral speech (Buckley and Boulter, 2000). Drawing is one of the strategies that can be used to access children's ideas. Being a preliminary phase of writing (Vygotsky, 1997), children that do not feel secure in expressing their feelings and the interpretation of their lived or imagined experiences through writing can do it through by drawing, which results in a deep connection with what they feel and is endowed with significant meaning in their mind (Luquet, 1987; Vygotsky, 1997). In addition, they present a reflection on the message they want to convey, being, in this way, a powerful learning tool (Krees and Van Leeuwen, 2006). Several studies have demonstrated that children can more easily express their beliefs or thoughts on science topics through the use of drawings (Barbosa-Lima and

Carvalho, 2008; Ehrlén, 2009; Sylla et al., 2009; Byrne et al., 2009; Byrne, 2011; Mafra, 2012; Mafra et al., 2015).

If we want to use drawings to know children's conceptions about a specific subject, we need to know how children represent their conceptions in these drawings (Ehrlén, 2009). Indeed, drawings can represent an explicit model of a particular phenomenon that can be externalised. Considering that these models are related to mental models, they provide a very useful guide to know children's ideas, concentrating a large amount of data with some ease, and helping to understand children's representations, especially when combined with other methods of analysis (Hayes et al., 1994; Reiss et al., 2002).

An explicit model allows clarification of the child's mental model as he/she experiences direct or indirect learning, perceptions phenomenon change, or alters his/her initial explicit model (Byrne, 2011). The combination of several techniques for accessing children's ideas about microorganisms, in order to define the mental model that children have at different ages about them and to identify the nature of children's understanding of the topic, allowed Byrne (2011) to elaborate a three-level model of children's understanding of microorganisms (Emerging model, Transitional model, and Expanded model), according to the items Morphology, Size and Scale, and Living/Non-living organisms (Table 1).

Table 1. Mental model of children's ideas about microorganisms (Adapted from Byrne, 2011).

Item	Model		
	Emerging	**Transitional**	**Expanded**
Morphology exterior appearance and characteristics/ connotation	Small animals, usually invertebrates and often anthropomorphised or with human characteristics, with a geometric or abstract shape. Anthropomorphic appearance may illustrate a malicious aspect.	Amorphous cell or recognisable plant/animal cell. May have recognisable external items such as eyelashes.	Isolated cells, some recognised as bacterial cells. They may have external items such as cilia or flagella.
Size and Scale	Small. Natural/actual size not understood. Size sometimes related to virulence (the more virulent, the larger the microorganism).	Small/microscopic. Size explained using everyday objects or specific vocabulary as a reference point.	Microscopic. Requires magnification to be seen. Size often referred to incorrect measurements, but not necessarily understood.
Living/Non-living	Not alive / possibly alive	Alive, evidence-based on processes normally observed in living beings, such as movement and reproduction. Anthropocentric ideas, highlighting the harm that microorganisms cause to humans.	Alive. Presence of cellular structures/organelles as proof of being alive.

The use of these models also helped develop a vision of the progression of ideas across three age groups. Her results indicate that the progression between models (in the sense of more elaborate models) occurs significantly in children between 7 and 11 years old. Considering that this age group corresponds to the primary school age range, it becomes evident the importance of developing this theme at these early school ages and exploring children's ideas to understand their thinking about microorganisms better.

This study intended to identify categories of 11-12 years-old Portuguese children's ideas about microorganisms expressed in their drawings and present a handy model to detect children's alternative conceptions of microorganisms.

METHOD

This research used a qualitative methodology. Children's drawings and content analysis were used to detect their ideas about microorganisms. They were asked to draw a microbe and add captions. After the drawing analysis, the categorisation process was carried out to find categories and subcategories to obtain a model for detecting children's conceptions about microbes.

Drawings of 187 children who completed the four-years primary school (11-12 years old) were analysed and subject to a subsequent categorisation, which was based on microorganism shapes (Byrne et al., 2009) and the mental model connotations about microorganisms (Byrne, 2011). The characterisation regarding the positive and negative emotional connotation to microbes took into account drawing and caption elements, identifying emotions or intentions.

RESULTS, DISCUSSION AND IMPLICATIONS

The description of the categories and subcategories found in the drawings and their characterisation is shown in Table 2.

Table 2. Categories and subcategories of children's drawings and their characterisation

Categories	Subcategories	Characterisation
SHAPE	Real	A drawing that approaches the real, just as we see microorganisms under a microscope.
	Anthropomorphic	The drawings show humanized features, such as the presence of upper and lower limbs and other humanized elements.
	Animal	Presence of elements that approximate the drawings to animals (e.g., insects, rodents, reptiles, etc.).
	Others	Irregular/undefined/meaningless shapes.
CONNOTATION	Positive	In the drawings and/or captions, there are elements that show a positive/beneficial connotation.
	Negative	In the drawings and/or captions, there are elements that show a negative/harmful connotation.
	No Connotation	Drawings with no evidence of any connotations.

As for microorganisms' shape, most of the 187 children (59%) drew them far from real: 38% of them drew microorganisms as *animals* (Figure 1-A), 17% with *anthropomorphic shapes* (Figure 1-B), and 4% with *other shapes* (Figure 1-C). On the other hand, about 41% of the 187 children drew microorganisms similar to the real ones (Figure 1-D). These results agree with those reported by Byrne (2011), who has found that alternative microbe shapes predominate in this age children's conceptions.

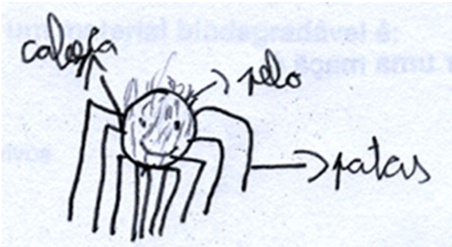
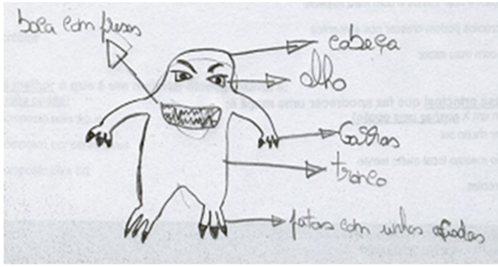
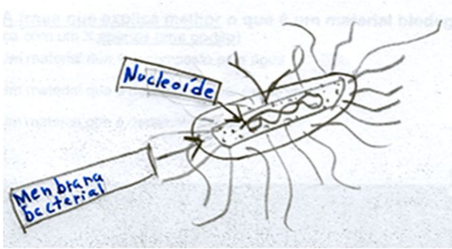
A	B
 Shape: ***Animal***. Emotional connotation: ***Positive***.	 Shape: ***Anthropomorphic.*** Emotional connotation: ***Negative***.
C	**D**
 Shape: ***Other.*** Emotional connotation: ***No connotation.***	 Shape: ***Real.*** Emotional connotation: ***No connotation***.

Figure 1: Examples of children's drawings classified according to shape and emotional connotation.

As for *emotional connotations* about microorganisms, children showed a higher expression to the negative connotation than to the positive one in all the *shape* subcategories: in *Animals*: 42% with a negative connotation; in *Anthropomorphic*: 59%; and in *Other shapes*: 71%. Furthermore, even children who drew microorganisms with their real appearance, 22% gave a negative connotation as indicated in image and caption elements, classifying the microorganisms as something ugly and harmful. In brief, positive connotations to microbes were scarce. Moreover, a considerable proportion of drawings (51%) did not express any emotional connotation (neither positive nor negative).

After the global drawing analysis, a model was created (Figure 2) that facilitates analysing children's drawings and identifying their alternative conceptions regarding microorganisms.

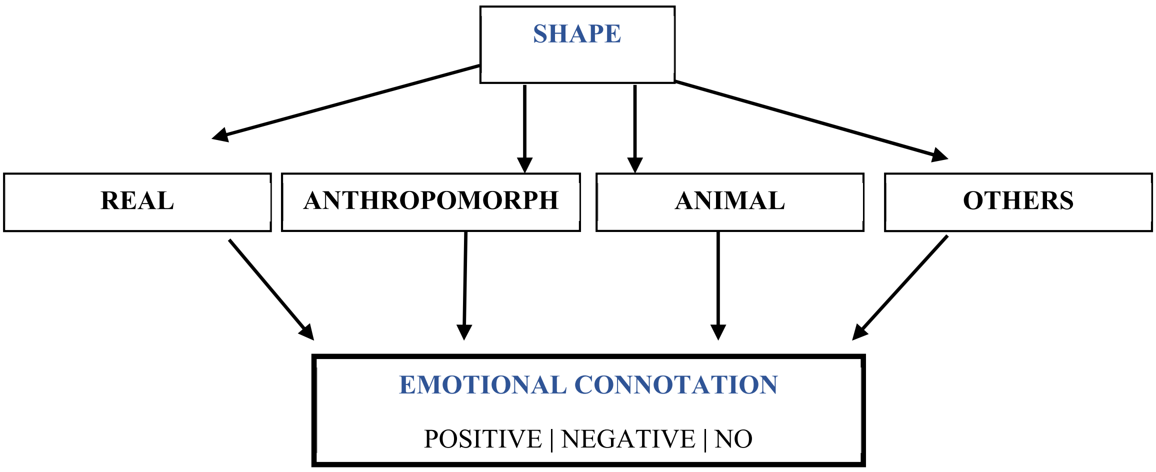


Figure 2: Model of analysis of children's alternative conceptions about microorganisms.

The results indicate that primary school children express alternative conceptions about microorganisms and that it is possible to access them in a prompt way using children's drawings. Primary school teachers (and others), using this model, can quickly and effectively detect children's prior ideas. The model developed in this study can be validated in further studies with the same age children from other regions and countries. Using this model by primary school teachers will help them improve their teaching to promote children's conceptual change to more scientific conceptions and increase microbiology literacy.

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"ONCE UPON A TIME IT WAS ALL SEA": TEN-YEAR-OLD CHILDREN'S REASONING ABOUT ROCK FORMATION

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The presence of fossil shells in a sample of sedimentary rock collected in the mountains was the starting point for the construction of educational research on children's concepts about rock formation.

Data were collected through semi-structured interviews with a sample of ten-year-old children. In the study, we ask the children to describe the rock and to give us an explanation for the presence of shells in a rock collected in the mountains. The interviews were analysed to look for common features and for the emergence of ideas about the transformations of the natural environment in time.

The purpose of the study was to gain information on children's reasoning on rock formation and related topics such as geological time and past changes in the environments. The information collected in this research can be useful for the improvement of didactic activity and the design of the science curriculum.

Keywords: Science Education, Primary School, Student's Reasoning.

INTRODUCTION

The comprehension of the processes that lead to the formation of rocks is linked to two of the most important concepts for geosciences: the idea that the Earth is continuously undergoing changes and the idea that the Earth has a long history (deep time).

As for many other science concepts, students develop their own ideas also from non-formal and informal education (Eshach, 2006; Maarschalk, 1988). The study of students' spontaneous ideas and the identification of misconceptions that may be present behind these ideas are important steps for the design of effective teaching activities.

In this study, we investigated the ideas about rock formation in a group of 123 ten-year-old students through semi-structured interviews. Each interview started from the observation and the description of a sample of sedimentary rock containing fossil shells; to trigger the reasoning by the children about its origin we introduced a cognitive conflict between the presence of shells in the rock and the fact that the rock was found in the mountains. This work follows other two studies on the same topic regarding five- and seven-year-old children (Pieraccioni et al., 2018; Bonaccorsi et al., 2019).

THEORETICAL FRAMEWORK

Several authors investigated the presence of alternative concepts about the rock formation present in pupils and students (Dove, 1998; Gosselin & Macklem-Hurst, 2002; King, 2008; Dal, 2007, 2009; Libarkin & Schneps, 2012). Such alternative concepts, including pebbles that grow, human involvement in the rock formation, and sedimentary rocks forming as puddles dry up, are rooted also in preservice teachers that have completed a college-level course in Earth science (Kusnick, 2002).

Within a constructivist framework, taking into consideration the ideas of children is a fundamental step that can help teachers to promote more effective learning. Furthermore, misconception and incorrect ideas present in students' pre-instructional knowledge can become an obstacle to conceptual change (Delserieys et al., 2018).

Research work on students' spontaneous ideas on rock formation traces back to the work of Piaget (1929) described in "The child's concept of the world"; more recently other authors worked on this subject (e.g., Russell et al., 1993; Ford, 2005; Blake, 2005). This work fits into this research field: the aim is to collect information about the spontaneous ideas of pupils in the early school years, about the processes of rock formation. The results of this study can be used as a reference in the design of more effective educational activities on this subject.

Research questions

How do ten-year-old children describe a sedimentary rock with fossil shells?

If we inform the children that the rock comes from a mountain, how do they explain the presence of shells?

Do they refer to transformations of the natural environment in time?

RESEARCH DESIGN AND METHODS

Semi-structured interviews were carried out on a group of 123 students attending the 5° class of five different Primary schools (ten-year-old students) in Italy. The interviews were about the description and the origin of a sedimentary rock bearing fossil shells and were performed by the class teachers following a shared protocol.

Each interview starts with the observation of a large sample of sedimentary rock with evident shell remains (Figure 1).

Figure 1. The rock sample examined by the children; the size of the sample is approximately 28 x 23 x 15 cm (compare with the grid in the background).

During the interviews, the teacher asks the pupils to help her figure out something about a rock which a friend gave her: "*Please, look at this piece of rock that my friend found in the mountain. My friend asked me to make some guesses about how it is made so I thought to bring it to school for you to help me. What do you see in this rock, collected in the mountain?*".

In the instructions for the interviewers, it is highlighted that it is important to use the words rock, stone, pebble, etc. to correctly suggest that the sample was a natural, not man-made object; moreover, the interviewer should clearly specify that the place of discovery is a mountain.

After the pupil indicates the occurrence of shells in the rock, the teacher invites the child to guess a possible explanation: *"In your opinion, since the rock was found in the mountain, why are there shells in this rock, if shells are usually found at the sea?"*.

The recorded interviews were transcribed and a qualitative analysis was carried out. The conversations were analysed separately by the four authors and the detected features were discussed together.

RESULTS

The results of the analysis can be divided into two parts: the description that the pupils give of the rock and the explanations for the presence of shells in a rock that was found in the mountain.

Regarding the rock description, all the 10-year-old students address the presence of the shells in the rock and 38% of them also use the term "fossil" to describe them. From the analysis of the interviews, it is not possible to assess whether this term is used just as a synonym of *"ancient remnant"* or whether some pupils have a more scientific understanding of the term. Nevertheless, it is plausible that the pupils that use the word "fossil" recognize the shells as something old that belongs to a past time. 31% of the students also describe other natural elements of the rock such as sand and gravel.

Regarding the explanations of the presence of the shells in a rock collected in a mountain environment, 85% of the students provide an explanation, and 18 students are able to elaborate more than one explanation. On the other hand, 15% of the pupils do not explain the presence of the shells in the rock during the interview.

The qualitative analysis of the pupil's explanations led to the identification of eight categories: no explanation; human intervention (e.g., *"maybe someone brought them there"*); the presence of a lake or a river in the mountain (e.g., *"There is a river"*); the mountain is near the sea (e.g., *"I think they took the rock from a cliff");* transported by sea (e.g., *"maybe when the sea is rough the sea reaches the mountains");* weather agents (e.g., *"a strong wind brought these shells on the rock*"); catastrophic events (e.g., *"perhaps it is with a tsunami that they moved"); the presence of an ancient sea* ("*it comes from when the sea covered all our mountains and so the shells remained attached to this rock*"; "*once upon a time it was all sea*").

In Table 1 the results of the qualitative analysis following the eight categories are reported.

Table 1. Results of the qualitative analysis of the 10-year-old children's answers, according to the eight categories individuated for the explanation of the presence of shells in a rock found in the mountain.

	Total	
Category	**total**	%
No explanation	19	15.4%
Human intervention	3	2.4%
Link with lake or river	7	5.7%
The mountain is near the sea	6	4.9%
Transported by sea	15	12.2%
Weather agents (e.g., wind)	7	5.7%
Catastrophic events	7	5.7%
Presence of an ancient sea	72	58.5%

The results show that only 2% of the students held the idea that humans are the cause of the presence of the shells in the mountain (*"maybe someone brought them there")*. A small number of the students (6%) suggest that the shells do not come from the sea but from a lake or a river in the mountain, and 5% of the students think that *"maybe the mountain was near the sea"*, suggesting that the presence of the shell is due to the proximity of these two environments.

A different role of the sea is suggested by 15 students (12%), that in the interviews talk about the sea actively bringing the shell to the mountain (*"A very strong wave could have carried them up to the mountains"; "I think that the seawater carried this stone with shells up to the mountains"*). Other active agents that are suggested to explain the presence of the shells are weather agents (6%); e.g., some pupils suggest that *"a big storm could have brought them as there" or "maybe [the shells arrived] with the wind"*. Another suggested explanation (6%) is the occurrence of catastrophic events, e.g. *"Perhaps it is with a tsunami that they [i.e., the shells] have moved"*. All these different explanations have in common the attempt to overcome the cognitive conflict by imagining that a single event occurred to bring shells into the mountain.

The most common explanation individuated in the interviews (59%) is related to the idea of the presence of an ancient sea (*"once upon a time there was the sea"* and *"all the water went away and they [i.e., the shells] remained")*. This group of explanations remarkably differs from the previous ones, because the attempt to overcome the cognitive conflict is based on figuring that the environment could be different in the past.

Most of the answers in this category are quite vague and the pupils don't actually explain the processes that led to the presence of the shells in the rock, whereas some of the students are able to give a more detailed explanation. Some pupils held the idea of sea-level changes in time (*"the sea level has risen so much ... and it has also managed to reach certain levels of height* *that could bring things that are in the sea even in the mountains"*). Some of them also attempt to give a reason for this change (*"it [i.e., the seabed] was submerged, then with rising temperatures, it dried and a piece of the seabed remains with the shells attached"*). Other ideas that are present in the pupils' explanation are that this ancient sea once covered all the planet (*"Because once the sea was much higher and slowly it began to sink [...] Now there are many more points that are uncovered than before; once it was almost all submerged, maybe even all …", "once the world was covered by water", "Because the whole planet was full of water, even the mountains"),* and that mountains under the sea were already modelled as they are now (*"perhaps this mountain was under the sea", "on that mountain perhaps there was seawater", "...when the sea covered all our mountains"*).

Another difference is between the students that think that the shells are placed only outside the rock as they somehow remained attached to a pre-existing rock (*"the sea which slowly dried up, but the shells remained stuck [to the rock]"*; *"... there was the sea and then the shells became ... let's put it this way, attached to the rock"*) and the students that recognize that the shells are also inside the rock. In some of these cases, the pupils sometimes struggle to figure out how the shells went inside the rock, and in their suggestions, the rock seems to have an active role in the shell incorporation (*"there are some shells left behind that were like… they were taken by the stone, ... and over time they fossilised"*; "*over time they were swallowed up [by the rock]"*). Some of the students eventually suggest that the shells are inside the rock because they were covered by sediment (*"when it [i.e., the sea] has withdrawn, there were shells that have remained on the seabed... when the sea retreated, the shells remained, then maybe some ground went over and covered them").*

A very interesting finding is that a group of students thinks that mountains (15%) or rocks (6%) have not always existed but they have formed over time: *"Because maybe there was the sea there before and it wasn't really a mountain [...] then it became a mountain, the ground became the mountain and there remained the fossil shells"; "... and some shells maybe ... are petrified over time and it has become a rock with shells inside.".*

The idea that modifications of the environment in time explain the presence of the shells within the rock is implied in the last category (*Presence of an ancient sea*). However, also some answers of the other categories point to events that happened in the past and even students that did not give any explanation state that *"maybe this rock is from a long time ago"*. To take the analysis of this a step further, the presence of expressions and words referring to time is analysed. The analysis shows that 28% of the pupils refer to time using words like *"before", "after", etc.;* while 21% refer to time using quantifying terms like: *"a long time ago", "million years ago"*, etc.

CONCLUSIONS AND IMPLICATIONS

Although rocks are a common topic in schools, the teacher's focus is often on the identification of rocks. The research in this field (e.g., Remmen and Frøyland (2020)) suggests how describing and identifying a rock is difficult for students. Apart from other aspects one of the crucial difficulties is that rock classification (sedimentary, igneous, metamorphic) is strictly related to the formation processes and therefore the discovery and reflection on these processes is an important part of what students should experience in school.

The analysis of the interviews with ten-year-old students put into evidence that most of the pupils figure out that the Earth was once covered by the sea, while the other explanations, at this age, are marginal. Some students go a step further by indicating the idea that rocks and mountains have not always existed, but they were formed. These findings suggest that at this age, in most of the children, there is the idea of some sort of changes that occurred over time to explain the presence of shells in the rock. One implication of this finding is that the age of ten begins to be adequate for teaching these concepts.

Nevertheless, the profound changes that occurred in geological time remain a delicate subject to be dealt with at school. In the analysis of pupils' answers, we find, for example, that in some of the ten-year-old students there is the idea that "all mountains that exist today formed when the Earth first formed", an idea reported as a common misconception in older students, also (Francek, 2013).

The obtained results can be useful to reconstruct the evolution of some of the main geological concepts in pupils. Moreover, the naive ideas that emerged during the interviews should be carefully considered by teachers to design their educational activities on this topic.

Finally, an implication stemming from the results of this study is that common and familiar materials, such as rocks and shells, can be effectively used to promote a discussion about the possible transformations of geological materials in time.

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PRIMARY SCHOOL STUDENTS' IDEAS ON THE SELF- OR HETERO- LUMINOSITY OF THE MOON

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The present research examines 10-12-year-old students' ideas on the self- or hetero- luminosity of the Moon. The main argument of students in favor of self-luminosity is that the Sun and the Moon are in antipodal points with the Earth between them and it is therefore impossible for the Moon to be illuminated. Students in favor of hetero-luminosity either place the Sun in such a position that it will be able to illuminate the Moon or understand that the relevant size difference between the Sun and the Earth makes it possible for the Sun to illuminate the Moon even if the Earth is between them. Both groups support their ideas by using naïve explanatory reasonings, based on alternative ideas about various astronomical phenomena.

Keywords: Students' alternative ideas, conceptual models, Moon's luminosity

THEORETICAL FRAMEWORK

According to Lelliott & Rollnick (2010), from 1974 to 2008, several papers in astronomy education research examine students' conceptions of Moon related issues. Very few of these papers however, even fewer in the years that follow, refer to the self- or hetero- luminosity question while dealing with students' ideas about other astronomical phenomena. Notably, none of them focus on the explanatory mechanisms the students employ to answer the concerned question (Osborne 1990: 12 – 16, 37, Vosniadou 1992: 8, Stahly, Krockover & Shepardson 1999, Benacchio 2001: 52, Barnett & Morran 2002, Lelliott & Kelfkens 2006, Sherrod & Wilhelm 2009, Wilhelm 2014). It is therefore very difficult to develop a learning pathway for teaching the luminosity of the Moon. In Greece, relevant research has been conducted and some of its results are being presented in this paper (Neofotistos, 2020 - in Greek). The main aim of this research is to investigate students' ideas on the self- or hetero- luminosity of the Moon, focusing on the explanatory mechanisms they provide. Furthermore, it was considered that the investigation of students' ideas on the lunar phases (an indication that they are aware –among other phenomena– of the relative movements of the Sun-Earth-Moon system) and the mechanisms of seeing hetero-luminous objects could provide evidence on why they support the self- or hetero- luminosity. Additionally, we investigated whether there were statistically significant differences in the students' ideas depending on their age (grade 5 or grade 6) to determine whether the teaching of the relevant ideas in the courses of science and geography had affected their views on the subject.

METHOD

The main research question was: «*What are the 10-12-year-old students' ideas on the self- or hetero- luminosity of the Moon?* », followed by three sub questions: a) «*Do students' ideas on the lunar phases affect their ideas on the self- or hetero- luminosity of the Moon?* », b) *Do students' ideas on how we see hetero-luminous objects affect their ideas on the self- or hetero-*

luminosity of the Moon? ». Sixth (6th) grade students are taught some relevant concepts in geography (e.g., Earth's rotation, Earth's orbit, planet, star) and science (e.g., light transmission, self-luminous and hetero- luminous objects). Thus, taking into consideration the knowledge background of students of different grades the third sub question was formed: c) *Are students' ideas on the self- or hetero- luminosity of the Moon affected by their knowledge background on astronomy and optics?* The (convenient) sample was consisted of 176 students (10-12 years old), 83 of which attended the 5th grade and 93 the 6th grade, from fifteen primary schools in the broader area of Athens (Greece). The research tool was an open-ended questionnaire aiming to investigate students' ideas on: 1) the self/hetero-luminosity of the Moon, 2) the lunar phases and 3) how we see hetero-luminous objects. Students could justify their views by text or/and by drawings. Data analysis was carried out using qualitative methods of content analysis (Erickson, 1998).

RESULTS

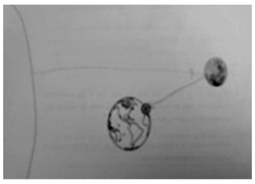
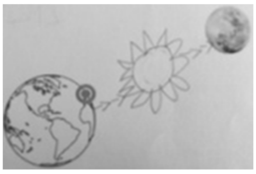
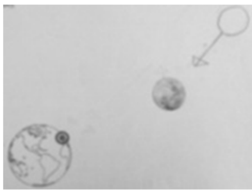
Is the Moon self-luminous or hetero-luminous?

An analysis of the students' answers showed that 25,6% are in favor of self-luminosity (N = 45) whereas 74,4% supported hetero- luminosity (N = 131). From tables 1 and 2, it can be deduced that students support their idea of self- or hetero- luminosity with naïve explanatory mechanisms that reveal several alternative ideas about the relative movements of the Sun-Earth-Moon system, their relative sizes, etc.

Table 1. Students' ideas on the self-luminosity of the Moon.

Basic argument	Students' explanations (Main categories)	Students' drawings	Alternative ideas	Percentages
The Moon is self-luminous because it cannot be illuminated by the Sun.	1) «*When the Sun is on the day-side of the Earth, it cannot illuminate the Moon*».		A) The Sun and the Moon are constantly diametrically opposed with the Earth between them and therefore the Earth is blogging the sunlight from reaching the Moon (confusion with lunar eclipse). B) The Sun, the Earth and the Moon are similar in size (size scale misconception). C) The Sun is much closer to the Earth than the Moon (distance scale misconception). D) The Moon is visible only during the night because of the antipodal positions of the Sun-Earth-Moon system.	27 (60%)
	2) «*The Sun is too far away for its light to reach the Moon*».	-	The distance of the Moon from the Sun is much greater that the distance of the Earth from the Sun, not allowing the sunlight to reach the Moon.	2 (4,5%)
	3) Non categorizable	-	-	16 (35%)

Table 2. Students' ideas on the hetero-luminosity of the Moon.

Basic argument	Students' answers (Main categories)	Students' drawings	Alternative ideas	Percentages
The Moon is hetero-luminous because it has one side constantly illuminated by the Sun.	1) *«The Sun is very big. It illuminates the Moon and so we can see it. The moon does not have a light of its own»*.		The Sun and the Moon are constantly diametrically opposed with the Earth between them. The Sun is visible only during the day and the Moon is visible only during the night.	50 (38,2%)
	2) *«For the Sun to illuminate the Moon, it must be somewhere in the middle between the Earth and the Moon and not behind the Earth»*.		A) In order for the Sun to illuminate the Moon they must not be in antipodal points with the Earth between them. B) The Earth and the Moon are in antipodal points with the Sun between them. C) The Earth is bigger than the Sun. The Sun and the Moon are similar in size (size scale misconception).	48 (36,7%)
	3) *«During the night the Sun is hidden behind the Moon therefore illuminates it without being observed»*.		A) During the night, the Sun is behind the Moon and illuminates it: a) The Moon's far side is dipped in sunlight, b) the Moon blocks the sunlight from reaching the Earth (day–night cycle is caused by solar eclipse). B) The Sun the Earth and the Moon are similar in size (size scale misconception).	19 (14,6%)
	4) *«Sunlight reaching the Moon during the day is stored and the Moon emits it during the night.»*.		The Moon acts like a battery: Sunlight charges it during the day; solar energy is turned into light during the night.	6 (4,5%)
	5) The Moon has phases: «*If the Moon was self-luminous, we should constantly (every day) see it as a full moon (in the phase of a full moon)* ».		-	4 (3%)
	DN/NO			4 (3%)

Content analysis of the two groups

Through content analysis of the students' answers and alternative ideas that they represent, as depicted on Tables 1 and 2, we were able to distinguish between the two populations. Specifically, students that support hetero- luminosity understand at least one of the following: a) the Sun and the Moon are not constantly diametrically opposed with the Earth between them, b) the relevant size differences of the Sun-Earth-Moon system (Table 2: categories 1 and 2, figures 1 and 2). So, despite a plethora of alternative ideas on the relative movements and in some cases on the relevant sizes of the Sun-Earth-Moon system, they understand that the Moon is illuminated by the Sun. On the other hand, students that support the self- luminosity simultaneously place the Sun and Moon as diametrically opposed with the Earth between them and draw all three celestial bodies as almost equally sized (Table 1, category 1).

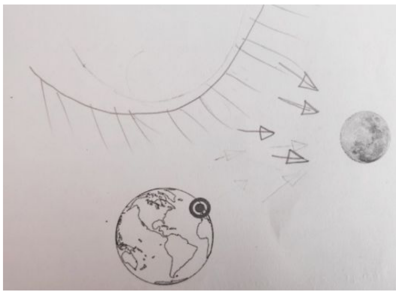


Figure 1: Appropriate placement of the Sun so it can illuminate the Moon - understanding of the relevant sizes (hetero- luminous Moon).

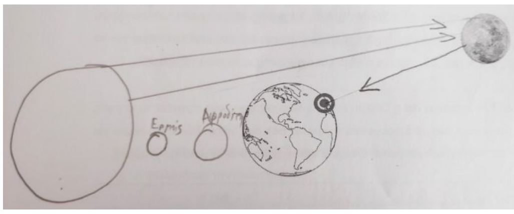


Figure 2: The Sun and the Moon are placed in diametrically opposed positions with the Earth between them, but the relevant size difference allows sunrays to follow the correctly designed path to the Earth (hetero- luminous Moon).

Students' ideas on the lunar phases

Table 3: Students' ideas about the lunar phases.

Ideas/explanations about the lunar phases	N (%) (Hetero- luminous Moon)	N (%) (Self- luminous Moon)
Lunar phases occur when an obstacle is entering in front of the Moon.	42 (32%)	17 (37,8%)
Specific parts of the Moon illuminate/ are illuminated.	34 (25,9%)	7 (15,6%)
Scientific view.	18 (13,7%)	3 (6,7%)
Each night, all lunar phases appear.	7 (5,3%)	6 (13,3%)
There is a variation in the amount of light that hits the Moon.	14 (10,7%)	-
Non categorizable	5 (3,9%)	7 (15,5%)
DN/NO	11 (8,5%)	5 (11,1%)

The the content analysis of the students' conceptions, as presented on Table 3, reveals that both groups share the same alternative ideas on the lunar phases but the explanation differs depending on their belief on the Moon's luminosity. E.g. a) Obstacle, b) specific parts of the Moon illuminate/are iluminated. Specifically:

EXAMPLE 1:

Self- luminus Moon: «When a planet passes in front of the Moon, Moon's light cannot reach the Earth.»

Hetero- luminous Moon: «When a planet happens to pass in front of the Moon, it hides a part of it.»

EXAMPLE 2:

Self- luminus Moon: «When the Moon has more brightness it looks more full.»

Hetero- luminous Moon: «The way the Moon looks depends on which part of it luminates the specific night.»

These answers suggest that students are attempting to interpret the phenomenon based on their view of the Moon's luminosity (self- or hetero- luminosity). This becomes more evident from the answers of some students that believe in self- luminosity but expressed ideas on the lunar phases that were close to the scientific view. Even though they understand that the lunar phases depend on which part of the illuminated Moon we can see, they do not change their views on the Moon's self-luminosity. Moreover, the majority of the students in favor of Moon's hetero-luminosity also expressed alternative ideas on the lunar phases. Students' answers were further categorised as seen on Table 4 (percentages refer to each population in total).

Table 4. Students' ideas on the lunar phases (percentages refer to the total percentage of the students in favor of self- and hetero- luminosity respectively).

Students' answers	Group 1: Self-luminous Moon	Group 2: Hetero-luminous Moon
Alternative ideas	35/45 (77,8%)	97/131 (74%)
Scientifically accepted view.	3/45 (6,7%)	18/131 (13,7%)
Non-categorizable answers.	7/45 (15,5%)	16/131 (12,3%)

Similar percentages of alternative ideas on the lunar phases were observed in both groups (self/hetero luminosity). As previously stated, some of these ideas were identical but each group provided a different explanation. Moreover, students' ideas on the lunar phases depended on whether they supported Moon's self- or hetero- luminosity. Additionaly, the scientific view was in a small percentage of students appeared in both groups and we can deduce that: a) the students that believe the Moon is hetero- luminous usually have alternative ideas on the lunar phases, b) even though some students that believe the Moon to be self- luminous understand that the lunar phases depend on which illuminated part we can see, they do not change their view. Thus, we conclude that students' ideas on the lunar phases do not affect their ideas on Moon's self- or hetero- luminosity. If they did, the percentage of students in favor of hetero- luminosity would be similar to the percentage of students that take into consideration the relevant movements of the Sun-Earth-Moon system to explain the lunar phases. In fact, depending on their view, the students explain the phenomenon on a different basis.

Students' ideas on how we see hetero-luminous objects

An analysis of students' answers to the questions regarding the mechanisms of seeing hetero-luminous objects is presented at Table 5.

Table 5. Students' ideas on how we see hetero luminous objects (percentages refer to the total percentage of the students in favor of self- and hetero-luminosity respectively).

Students' answers	Group 1: Self-luminous Moon	Group 2: Hetero-luminous Moon
Alternative ideas.	45/45 (100%)	104/131 (79,3%)
Scientifically accepted view.	-	20/131 (15,3%)
Non-categorizable answers.	-	7/131 (5,4%)

Alternative ideas were expressed from all students (100%) in favor of self-luminosity of the Moon and by 79,3% of those in favor of hetero-luminosity. These ideas include: a) «Single light emission (from the light source to the hetero-luminous object)», b) «Cooperative light emission (both from the light source and our eyes to the hetero-luminous object)» etc. Subsequently, we present the ideas of both groups of students (self- and hetero- luminosity) as they were detected in their answers to the question of how we see hetero- luminous objects.

Table 6: Comparing ideas on how we see hetero- luminous objects.

Εναλλακτικές ιδέες	N (%) (Hetero- luminous Moon)	N (%) (Self- luminous Moon)
Single light ray emission from the source to the object.	36 (80%)	85 (64,8%)
Double light ray emission from the source to the object and to the eye.	1 (2,2%)	-
Emission of light rays from the source to the eye or/and to the object.	3 (6,6%)	6 (4,5%)
Cooperative light ray emission (from the source and eye to the object).	4 (8,8%)	9 (6,8%)
Active eye involvement (eyes-light source-object).	1 (2,2%)	-
Assisted light emission (light source- eyes-object).	-	4 (3%)
Scientific view on how we see hetero- luminous objects (light source- object- eyes).	-	20 (15,3%)
Non-categorizable	-	7 (5,3%)

As shown on Table 6, most the students share similar alternative ideas. The scientific view, however, was only observed in the hetero- luminosity group which suggests that some students of this group are more likely to realize how we see hetero- luminous objects and possibly understand how the Moon is visible to an observer on Earth. On the other hand, students of the self- luminosity group mostly express the single light ray emission model (from the light source to the object). Therefore, we can assume that students' ideas on the self- or hetero- luminosity of the Moon are not affected by their ideas on how we see hetero-luminous objects. Additionally, taking Tables 3 and 4 into consideration, we can observe a small percentage of students in group 2 (approx. 14 %) that can explain both the lunar phases and the mechanism of seeing hetero-luminous objects through the scientifically accepted view.

Does the students' knowledge background on related concepts (e.g. solar system, optics etc.) affect their opinion on the luminosity of the Moon?

The content analysis of students' answers to the relevant questions revealed that their views differ depending on their knowledge background. We can attribute this to the fact that when this research took place, only 6th grade students had been taught some basic astronomy and optics concepts (science and geography) that are relevant to the subject we were investigating. These included: a) Earth's rotation and Earth's orbit around the Sun, b) concepts such as "star", "planet", "moon", "self- luminous", "hetero- luminous", c) the fact that light is transmitted in a straight-line d) how we see hetero- luminous objects, and e) reflection of light rays.

Table 7: Grade comparison.

N (%) 5th grade		N (%) 6th grade	
The Moon is hetero-luminous	The Moon is self-luminous	The Moon is hetero-luminous	The Moon is self-luminous
55/83 (66,2%)	28/83 (33,8%)	76/93 (81,7%)	17/93 (18,3%)

Statistical analysis of the students' answers for both grades through the x2 test (chi- square) showed that there is a statistically significant difference between the ideas of the 5th grade students and the 6th grade students on the self- or hetero- luminosity of the Moon ($p = 0,019 < 0,05$). In other words, a higher percentage of students in the 6th grade expressed the scientific view.

Based on this, it appears that students follow a different path of reasoning to support their view of the Moon's luminosity depending on whether they attend 5th or 6th grade. Specifically, 5th grade students are more likely to support the idea of self- luminosity, because they have not yet been taught any of the concepts that would help them to understand the phenomenon and change their views. On the contrary, 6th grade students that believe in self- luminosity, most likely do not adequately understand the relevant concepts they have been taught in relation to the subject (such as Earth's relevant movements, light reflection etc.) Another path of reasoning is also noticed in the group of students that support the hetero- luminosity of the Moon. The 5th grade students exhibit more frequently the idea that the Sun only appears during the day and the Moon during the night, not taking into consideration any of the relevant movements of the Sun- Earth-Moon system. On the other hand, most of the 6th grade students mention that the Moon is illuminated by the Sun, with no evidence for this specific alternative idea. This percentage decrease can be explained, if we take into consideration the fact that 6th grade students have been taught, even if only as declarative knowledge, that: a) the Earth rotates around its axis, b) the Earth orbits around the Sun, c) The Sun is the main light source in the solar system.

In support of the above, there is evidence that students often take into consideration the relative movements of the Sun-Earth-Moon system (or at least some of them) when they try to explain the phenomena that they are implicated in e.g., seasonal change, day-night cycle etc. (Starakis & Halkia, 2010, Starakis & Halkia, 2013). However, if it is not clear during teaching that the relevant movements do in fact occur, and suffice to explain the phenomenon, alternative conceptions might occur. As a matter of fact, this is one of the reasons that the teaching of concepts relevant to the luminosity of the Moon could be considered as insufficient.

DISCUSSION AND CONCLUSIONS

Students' view on the self- or hetero- luminosity of the Moon is depended on their knowledge and/or ideas on a) the Sun being the main light source in the solar system, b) how light is transmitted, and c) how we see hetero- luminous objects. Taking this into consideration and in order to clarify if students' ideas on the self- or hetero- luminosity depend on a coherent way of thinking, we investigated: 1) whether the explanatory reasonings utilized by the students that support the scientific view (hetero luminosity of the Moon) are based on scientific reasonings or alternative ideas and 2) whether they follow the same path of reasoning to explain other relevant phenomena that are based on the same mechanism (lunar phases, how we see hetero-luminous objects).

From this research, it is deduced that students' ideas on the self- or hetero- luminosity of the Moon, are supported by simplistic explanatory reasonings, based on alternative ideas for various astronomical phenomena (tables 1 and 2). Moreover, most students in both groups have similar ideas on the lunar phases and how we see hetero-luminous objects (analysis of tables 3-6). Thus, even these students whose answers are close to the scientific view, in most cases they support their views based on a superficial information and not to a coherent way of thinking. Very few of the students that believe the Moon to be hetero- luminous were able to provide a coherent explanation to support their views.

To summarize, from this research we can conclude the following:

1) Approximately one in four students of the sample believes that the Moon is self-luminous.

2) The main underlying alternative idea of students that support self- luminosity is that they believe the Sun and Moon are constantly in diametrically opposed positions with the Earth between them and so it is not possible for the Sun to illuminate the Moon. Consequently, for the students to understand that the Moon is illuminated by the Sun, comprehension of the relevant movements of the Sun-Earth-Moon system, relevant sizes and distances is necessary.

3) For students to be able to understand why the Moon is visible, it is necessary that they understand the following optics concepts: a) how hetero- luminous objects are visible/how we see hetero- luminous objects, b) how the eye works, c) definitions: self-luminous/ hetero- luminous objects, d) light is transmitted in a straight line. They also need to comprehend that the Sun is the main light source in our solar system.

4) Students' conceptions of the lunar phases do not affect their ideas on the self- or hetero-luminosity of the Moon. On the contrary, the explanations they provide for the lunar phases are influenced by their opinions on the self- or hetero- luminosity.

5) The opinions of students on the luminosity of the Moon, is related to the school grade they are in (5th or 6th). This can be attributed to the additional knowledge 6th graders have gained through teaching on concepts of astronomy and optics.

With this study as a starting point, we make suggestions for future research. Firstly, we propose that students' alternative ideas on the self- or hetero- luminosity of the Moon are further examined; the data available in the literature regarding this issue is insufficient. Furthermore, we suggest that future relevant research be carried out with a larger population sample and/or personal interviews. Additionally, a case study of 5th and 6th grade students that support hetero-luminosity might shed some light onto their reasons for doing so.

It would also be interesting, research-wise, to examine the students' learning pathways for attaining an understanding of the hetero- luminosity of the Moon. We believe that the data gathered through this study can be used as a basis upon which a constructivist teaching sequence approach can be built. In accordance with our results, the teaching of the relevant sizes, movements and distances of the Sun-Earth-Moon system would be an appropriate first step in such a teaching process.

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MEASURING OUR OWN TEMPERATURE SCALE(S). FROM THERMAL SENSATIONS TO THERMAL CONCEPTS

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Research has suggested that some characteristics of misconceptions are explained by the way we perceive the world. In this study, we investigated the relationship between thermal sensations, temperature estimations and the real temperature scale. To perform this experiment, we developed a novel device, which produces a thermal gradient. Participants had to slide one index finger along the thermal gradient. They were asked to indicate where they detected a change of sensation and to estimate the temperature. The temperature at which participants detected a change of sensation was consistent, whereas the spread of estimated temperatures was significantly higher. This suggests the existence of a common perceptual-qualitative scale and an agreement in how it is reported, but a lack of an appropriate representation of the temperature variable. The presence of this mismatch poses a challenge for teaching and learning concepts about temperature. We propose that this mismatch is a product of differences in the learning process. In this sense, teaching staff should understand the neuropsychological basis of misconceptions to tackle the learning difficulties of their students more effectively.

Keywords: Conceptual Understanding, Misconceptions, Learning and Neuroscience

INTRODUCTION AND THEORETICAL FRAMEWORK

Misconceptions are universal. They are found in people around the world regardless their age, education, gender and cultural background (Abrahams et al., 2015). Moreover, misconceptions seem very persistent and resistant to change (Chiappetta & Koballa, 2014). These characteristics suggest that there is a common basis. In this sense, research has proposed that some of their characteristics can be explained by the way our nervous system works (Vosniadou, 1994).

The fields of science education and psychology of learning have categorised misconceptions about the concepts of temperature and heat (Driver, 1989; Piaget, 2007). People conceptualise temperature as a discontinuous scale, which is divided in two by the great concepts of hot and cold and has a blurry neutral zone (Albert, 1978; Clough & Driver, 1985; Erickson, 1979; Tiberghien, 1985).

Temperature perception is vital for survival. Biological organisms need to monitor the temperature of their tissues for optimal functioning of metabolic processes. Beyond physiological reactions such as sweating and shivering, humans show a wide range of complex behaviours such as making fire or developing air conditioning systems. These behaviours are the expression of cognitive processes that necessarily imply the existence of a representation or conceptualisation of the temperature magnitude and its corresponding scale (Ezquerra & Ezquerra-Romano, 2018).

Thermal perception is supported by the thermosensory system (Figure 1). In the skin, temperature changes are transformed into neural activity by receptors which are called thermoTRPs. Interestingly, humans have a family of thermoTRPs that allow us to feel temperatures between 17 ºC and 30 ºC (innocuous cold range) and between 36 ºC and 43 ºC (innocuous hot range) (Ezquerra-Romano & Ezquerra, 2017; Patapoutian et al., 2003). However, each thermoTRP is only sensitive to a subrange within either the cold or warm ranges. Moreover, the response of thermoTRPs to thermal stimuli is not linear within their subrange.

ThermoTRPs are embedded in the membrane of thermosensitive neurons. Many of these neurons only express a type of thermoTRP. This means that they are only sensitive to a thermal subrange. Thus, cold and warm signals are transmitted separately. This separation is maintained in the spinal cord and these signals also arrive separately to different parts of the brain (Ezquerra-Romano & Ezquerra, 2017). Finally, thermal information is also integrated in the brain and the perception of temperature emerges from the synergistic interactions between different brain areas.

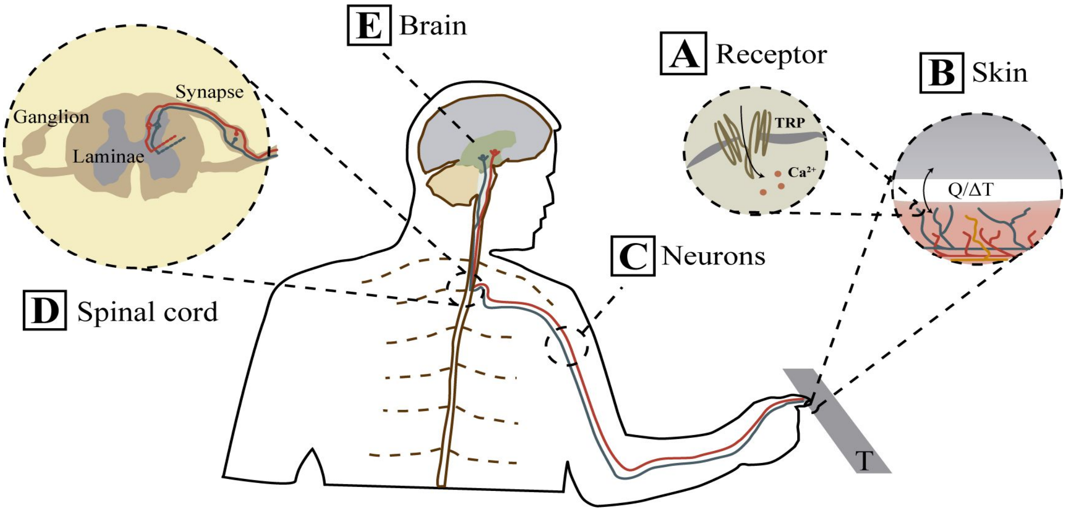

Figure 1. Schematic diagram of the neurophysiology of the thermosensory system. [A] Receptors (TRPs) sensitive to temperature changes. They are embedded in the membrane of neurons. As a result, these neurons become sensitive to temperature changes too. [B] The endings of thermosensitive neurons are located in the dermis. They are exposed to heat flux between tissues and objects. [C] Neurons sensitive to innocuous cooling (blue) and warming (red) carry thermal signals separately to the spinal cord. [D] The separation between cold and warm signals is maintained in the spinal cord. [E] Warm and cold sensations are encoded in different parts of the brain. Adapted from Ezquerra-Romano & Ezquerra (2017).

In summary, thermoTRPs have large, overlapping and non-linear response subranges within the whole thermal range. These receptors are expressed in different fibres, and this separation is maintained along the thermosensory pathway, but thermal information is integrated only in particular brain areas. Additionally, thermosensation not only depends on the temperature of objects, but other factors also contribute to the experience of temperature such as the materials' conductivity (Ezquerra-Romano et al., 2019). Thus, our thermosensory system does not work like a thermometer. Our thermal sensations are not represented like the measurement of a precise sensor which linearly measures a unique variable.

From a declarative perspective, we categorise thermal experiences in two wide ranges, cold and hot, which can be further subdivided with different terms (e.g. cool) and adverbs (e.g. very)

(Green et al., 2008). However, from a conceptual perspective (in Physics), temperature is defined as a quantity on a numeric continuous scale with 0 K (- 273.15º C) as a starting point. The concepts of hot and cold are straightforward, but subdivisions are blurry, and the sensations assigned to these categories do not seem to have a clear representation on the physical scale. All in all, there seems to be a mismatch between the way we talk about temperature (declarative perspective) and the way physicists think about temperature (conceptual perspective).

In the science education context, the integration of neuroscience and science education could allow us to study teaching and learning processes from a biological point of view. This knowledge would help science teachers and traineers dealing with students' misconceptions and cognitive processes more effectively (Ezquerra-Romano et al., 2019).

RESEARCH METHOD AND DESIGN

In this study, we investigated the mismatch between our thermosensory scale, which is dictated by our neurobiology, and the temperature scale, which is defined in Physics. We obtained the points at which people detected a change in thermal sensation and the numerical estimation of the temperature at these points. We compared these measurements between each other.

To deliver thermal stimuli to participants, we developed a novel device called *Termosensimetro* (Figure 2) (Spanish Patent No. 202030815, 2020). The device creates a continuous thermal gradient from 10 ºC to 50 ºC along a metal bar using Peltier modules. To track the position of the participant's fingers, there is a tactile sensor parallel to the metal bar. The temperature on the metal bar and the position of the finger on the tactile sensor are mapped with a one-to-one relationship. The device is equipped with different control elements which are driven by Arduino. Custom-written code was used to coordinate the electronic components and collect the data.

In each trial, participants had to slide one index finger along the metal bar. They were asked to indicate where they perceived a change of thermal sensation by touching the tactile sensor. After touching the tactile sensor, participants were asked to label the sensation and estimate the temperature.

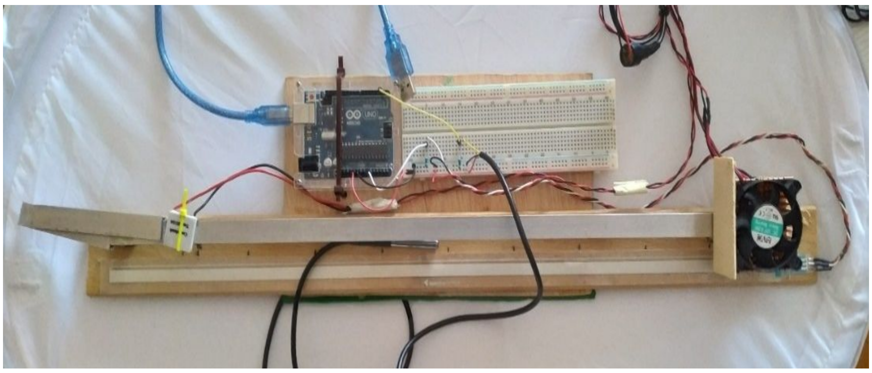

Figure 2. *Termosensimetro* prototype. Thermal stimulator that produces a thermal gradient along the grey metal bar. The thermal gradient is produced by Peltier modules at both ends of the grey metal bar. The tactile sensor is the white band below the metal bar.

To label the thermal sensations, the Labelled Magnitude Scale (LMS) was adapted from Green et al. (2008). The thermal range was divided into an ordinal scale: Painfully Cold (PC), Very

Cold (VC), Cold (C), Neutral (N), Hot (H), Very Hot (VH), and Painfully Hot (PH). The point at which participants indicated a change of thermal sensation was used to determine the *'perceptual change point'* (e.g., from VC to C). After labelling the sensation, subjects were asked to estimate the temperature. This numerical value (degrees Celsius, ºC) was called *'estimated numerical value'*. Both the labelled sensations (LMS) and the *'estimated numerical value'* (Celsius) were noted down by the researcher during the experiment. The 'perceptual change point' was automatically recorded by *Termosensimetro*.

The pressure between the skin and objects modulates thermal sensations. When the pressure is low, heat flux is inefficient or partially stopped. On the other hand, a high pressure would result in the mechanical sensations confounding the temperature ones. Therefore, we established a standard force of 12 g which participants learnt to apply with a pocket weight scale before each trial (Dyck et al., 1978). Moreover, to minimise neural fatigue, a 5-second waiting period was introduced between each trial.

All experiments were carried out individually, in a controlled room with a room air temperature of 25 ºC and a relative humidity of 30–40 % to keep thermal conditions constant and ensure participants' comfort.

When initialising the device, we had to perform some checks to ensure the device was performing correctly. Firstly, we measured the temperature of the metal at different points until thermal stability was reached. The warmup time was approximately 20 minutes. Secondly, we checked that our thermal gradient was approximately linear, so we could deploy the one-to-one mapping between the temperature on the metal bar and the position of the finger on the tactile sensor (Figure 3). For security reasons, we established physical limits on the metal bar to restrict accessibility to noxious temperatures. None of the participants were harmed during the procedure.

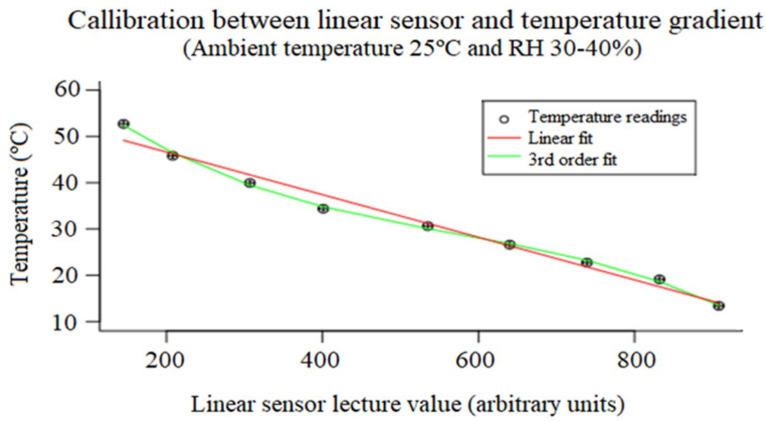

Figure 3. Linearity check of the temperature gradient along the metal bar. The x-axis represents the position on the linear sensor. This sensor is parallel to the metal bar, so the real length or position on the bar are not required to perform the mapping (Arduino analog-to-digital readings use 10 bits to store the readings —10 bits are 2^{10}, from 0 to 1024 values). The y-axis represents the local temperature in Celsius degrees (ºC). This was performed at a standard room temperature of 25ºC and with a relative humidity of 30-40%.

RESULTS

To understand the relationship between the reported sensations and the actual temperature of the device, we plotted the *'perceptual change points'* (e.g. from VC to C) against the temperature measured by the device at the points where people stopped sliding their finger (Figure 4a). As expected, we found a monotonic increase in the temperature at which people reported a change in sensation from Very Cold to Painfully Hot. None of the participants reported Painfully Cold (PC) sensations.

Interestingly, the standard deviations were low at each *'perceptual change point'*. They were between 1.5 and 4.0. This shows that participant responses were consistent when they determined the *'perceptual change points'*. This suggests that there is a common perceptual-qualitative scale across people.

To understand the relationship between the reported sensations and the estimated temperatures, we plotted the *'perceptual change points'* (e.g. from VC to C) against the *'estimated numerical values'* given by the participants at each point (Figure 4b). These values also follow a monotonic increase from Very Cold to Painfully Hot. The standard deviations were between 3.5 and 14, which are higher than in the previous case. There is a clear difference between the estimated temperatures and the real temperatures measured at the points in which people reported a temperature change.

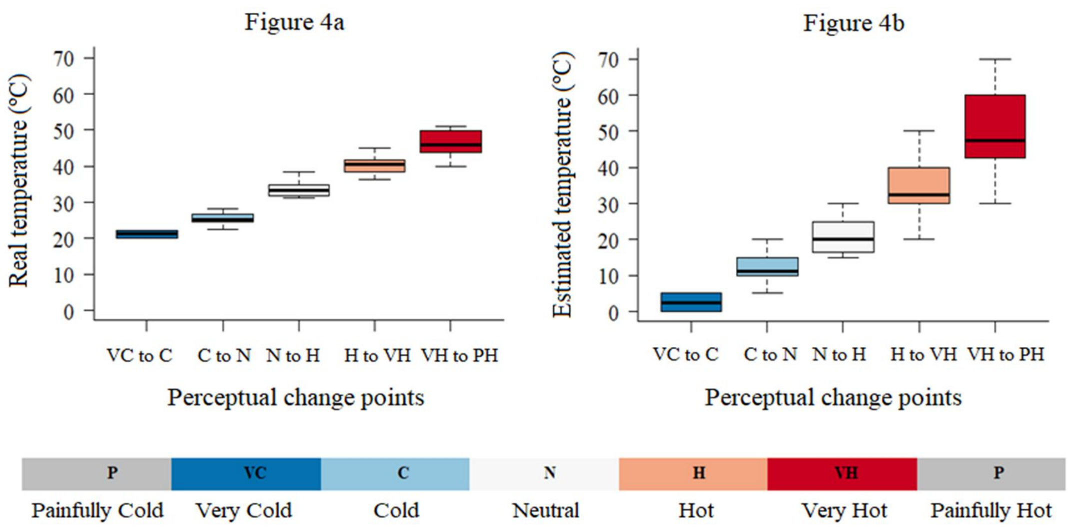

Figure 4. On the left, the Figure 4a: *'perceptual change points'* vs real temperatures. The x-axis represents the *'perceptual change points'* (e.g., from VC to C). The y-axis represents the temperatures registered by the device. On the right, the Figure 4b: *'perceptual change points'* vs estimated temperatures. The x-axis represents the 'perceptual change points' (e.g., from VC to C). The y-axis represents the 'estimated numerical values' in degrees Celsius given by the participants.

A closer statistical analysis was carried for each *'perceptual change point'* between the device temperature scale and the estimated temperature. First, the mean values were analysed with a student's t-test. In the cold and neutral range, the estimated values are significantly lower ($t(14)$, $p < .05$) than the temperatures measured by our device. This fact suggests that we tend to overestimate negatively the cold and neutral sensation range.

A second analysis about the precision of the estimated scale is made by comparing variance with Fisher's F-tests. The temperatures from the perceptual-qualitative scale and the estimated ones have a significantly different dispersion ($F(7,7)$, $p < .05$) in the hot range. In other words, the responses in the estimated numerical scale are much more spread.

DISCUSSION AND CONCLUSIONS

Our results show that the temperature at which participants detected a change of sensation was consistent (Figure 4a). This suggests the existence of a common perceptual-qualitative scale and an agreement in how it is reported. This perceptual categorisation of thermosensation (VC, C….VH & PB) is present in other perceptual systems (Ashby & Spiering, 2004), and is in line with research on thermoTRPs and thermosensitive fibres (Ezquerra-Romano & Ezquerra, 2017).

Interestingly, the numerical estimations follow a different pattern. Firstly, the estimations differ more significantly from the real temperature values in the cold and neutral ranges. Secondly, the spread of these estimations increases monotonically with temperature (Figure 4b). Therefore, people identify the *'perceptual change points'*, recognise the physical quantity temperature and its units, but they do not seem to correctly estimate their values. This means that they lack an appropriate representation of this variable. This is in line with the hypothesis that the ambiguity of the sensory signals is a contributing factor in the development of misconceptions (Ezquerra & Ezquerra-Romano, 2018; Kubricht et al., 2017).

The consistency of the *'perceptual change points'* indicates that we have a common perceptual-qualitative thermal scale. This perceptual categorisation arguably underlies our temperature estimations. However, there is a greater variability in the numerical estimation of temperature compared to the *'perceptual change points*. We propose that this mismatch is a product of differences in the learning process.

The presence of this mismatch poses a challenge for teaching and learning concepts about temperature. In this sense, teaching staff should understand the physiological and perceptual bases of misconceptions to tackle the learning difficulties of their students more effectively (Ezquerra & Ezquerra-Romano, 2019). Finally, we propose that teachers should develop activities to highlight the mismatch between thermal sensations and estimations. During these activities, students should connect the real temperature of objects with their thermal sensations and estimations. Thus, students would realise their difficulties in making thermal estimations and they would reflect on the way they developed concepts about heat, "cold" and temperature.

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ASSESSING THE PERSUASIVENESS OF EXPERIMENTS ON THE PARTICLE MODEL OF MATTER

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The particle model of matter is an integral part of secondary school science education. After having selected several experiments that are useful in conveying adequate conceptions about the particle model of matter, they are now being assessed in the form of interactive video experiments that can be carried out autonomously by secondary school pupils. The results of our pilot study (n = 47) show that experiments that are cognitively more demanding are less convincing.

Keywords: Multimedia and Hypermedia Learning, Conceptual Understanding, Secondary School

INTRODUCTION

Teaching the Particulate Nature of Matter

The secondary school science curriculum typically includes an explicit discussion of the particle model of matter. Yet, although there is consensus on the importance of this topic, it has long been debated how and when pupils should first be introduced to it (for a historical overview, see Rehm & Parchmann, 2009). One reason for this is that even a relatively simple particle model that is suitable for lower secondary school, is composed of numerous aspects that need to be understood (Hofmann & Erb, 2018). To help with this situation, we have selected several experiments that cover many of these aspects and are suitable for the introduction of the particle model of matter (see Table 1 for examples).

Table 1. Examples of selected experiments with aspects of the particle model they are intended to convey.

Experiment	Aspect of the Particle Model of Matter
Egg Floating in Salt Water	Between particles, there is empty space.
Growing and Dissolving Salt Crystals	The structures that the particles form determines the perceptible properties of the substances.
Brownian Motion of Smoke Particles	Particles are in constant motion.
Dye in Water	In the case of liquids and gases, the particles tend to distribute themselves evenly in space, as long as there are no external influences.
Electrolysis (Law of Constant Proportions)	The components of chemical compounds only occur in certain ratios. These are determined by the properties of the particles.
Electrolysis and Oxyhydrogen Test	Particles form certain structures. These structures can change due to physical or chemical processes.

Interactive Video Experiments

To enable better comparability between multiple aspects of the experiments and reduce the influence of the teachers' demonstration skills, the experiments were transformed into interactive video experiments. These are digitally edited videos of experiments in which users can significantly influence the presented content, taking on the role of virtual experimenter. This offers users the possibility to work on the experiments autonomously and at an individual pace. At the same time, the interactive elements provide an opportunity to engage with the subject matter and give the possibility to focus on aspects relevant to the learning process.

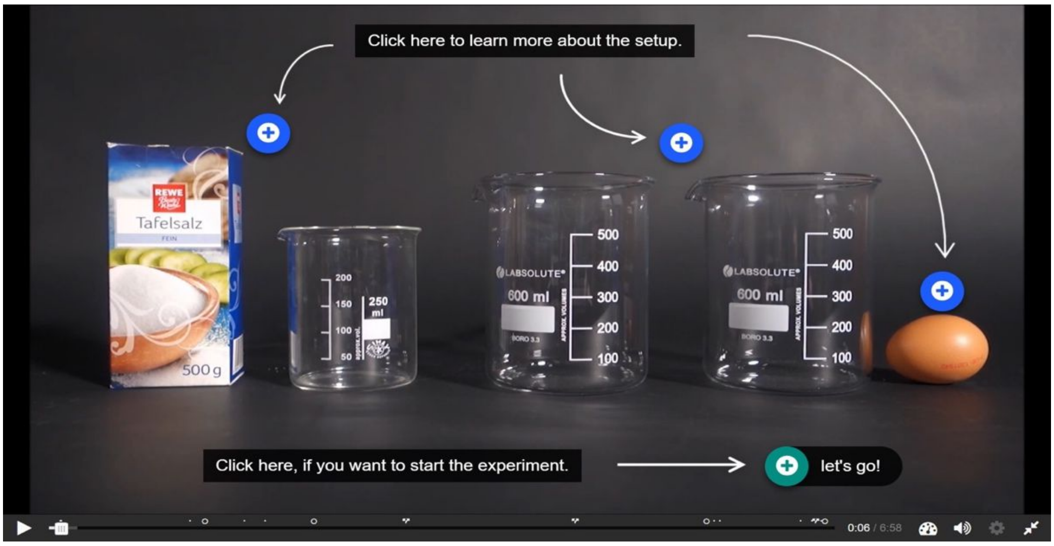

Figure 1. Screenshot from the interactive video experiment *Egg Floating in Water* (captions have been translated from German for the purpose of this paper).

To ensure a high level of quality, the interactive video experiments follow Mayer's (2009) design principles of multimedia learning and the principles of *Universal Design for Learning* (Meyer et al., 2014). Moreover, they each contain the same set of elements (see Table 2) for the purpose of ensuring a high level of comparability.

Research Questions

In order to evaluate the suitability of these experiments for conveying aspects of the particulate nature of matter, our research does not only focus on testing the pupils' learning gain but also on the persuasiveness of the experiments. Persuasiveness in this case denotes the experiments' ability of leading to a change in the pupils' acceptance of statements about the particle model of matter, from scientifically incorrect to correct ones.

Table 2. Elements that are part of each interactive video experiment and their purposes.

Element Appearing in the Video	Purpose
Aspect of the particle model of matter	Introduce the statement about the particle model of matter that will then be examined with the experiment (based on the *Cycle of Knowledge Acquisition*, Teichrew & Erb, 2019)
Aim of the experiment and its setup	Encourage a higher level of cognitive processing of the experimental setup (cf. Watzka et al., 2019, p. 26)
Possibility to choose an experimental hypothesis	Allow for a hypothesis to be tested using the experiment
Non-linear sequencing	Allow for the experiment to be carried out at an individual pace and its sequences in a selectable order

Questions and tasks	Avoid superficial processing of the experiment's contents (cf. Schaumburg & Prasse, 2019, p. 183)
Optional, additional help	Allow for internal differentiation
Interpretation of the experiment's results	Establish a clear connection to the particle model of matter

In other words, we would like to find out which experiments are comparably more convincing. This question is of particular interest, given that even the most tangible secondary school experiments allow only for indirect conclusions to be drawn about the particle model of matter.

With the aim of transferring our findings on persuasiveness to experiments of other subject areas, the experiments are grouped into categories that go beyond subject-related characteristics, such as cognitive and technical complexity. We thus aim to find generalizable characteristics that make school science experiments more convincing.

Consequently, the research questions guiding this study are as follows:

Q1: Which experiments on the particle model of matter are more persuasive?

Q2: Can the differences in persuasiveness be explained by general characteristics such as technical complexity or cognitive demand?

This paper will present the results of the pilot run, which had the purpose of examining the procedures, methods, and tests used in the study, as well as detecting first evidence of differences in the persuasiveness of the four piloted experiments.

METHODS

The ability of the interactive video experiments to support a conceptual understanding of the particle model of matter is assessed in an intervention design. The pretest and posttest are adapted from Hadenfeldt et al. (2016) and consist of 28 ordered multiple choice (OMC) items. With each item the participants can be assigned a level of understanding of the structure of matter, from naive conceptions (level 1) to systemic ones (level 3 to 5, depending on the item). The participants can thus reach a score between 28 and 94 points.

Each interactive video experiment is accompanied by two questionnaires, one before and one after, where the participants must decide between explicitly formulated statements about the particle model of matter. Along with one correct statement, which is the one conveyed by the respective experiment, two alternative statements are offered that often cater to common misconceptions (see Table 3 for examples). The pupils' choice of statement before and after the experiment, as well as the reported certainty of their choice, can be seen as a first assessment of each experiment's persuasiveness.

Table 3. Statements about the particle model of matter that are part of the questionnaire accompanying experiment *Egg Floating in Water.*

Correct Statement	Alternative 1	Alternative 2
Matter is composed of particles. Between particles, there is empty space.	Matter is composed of particles. There can be a substance between the particles (for example water or air).	Matter is not composed of particles. It is always a continuous entity that does not have any free spaces within.

The participants' reasons for accepting or not accepting these explicit statements are then the basis of the evaluation of how suitable the interactive video experiments are for leading to long-term attitude changes. To do this, we draw on parts of the *Elaboration Likelihood Model of Persuasion* (ELM), which have been positively assessed for their transferability to science education (Ludwig, 2017). They state that depending on the type of cues that are processed as part of the given information, receivers of that information process it peripherally or centrally, resulting in either short- or long-term attitude changes. In our study, we focused on the two cues "Data as Evidence" and "Intuition" (Ludwig, 2017).

Furthermore, comparisons between differently categorized experiments may provide clues as to what types of experiments are generally perceived as convincing. For this purpose, the experiments are categorized as either having a setup that mainly consists of everyday objects or of utensils found in a scientific context. Additionally, they are categorized as being cognitively more demanding or less demanding when it comes to adequately processing the experiment's key findings.

In order to determine these differences in cognitive demand, we drew on Sweller's et al. (2019) *Cognitive Load Theory* (CLT). According to the CLT, the intrinsic cognitive load of learning materials can be determined by identifying the interacting elements that need to be processed in order to successfully learn the material (Sweller & Chandler, 1994). The only additional information needed is the knowledge level of the learner working with the material, which in our study's case could be estimated using the school curriculum and information given by the teacher.

In addition to this prior categorization of the experiments according to how cognitively demanding they are expected to be, the intrinsic cognitive load was also measured during the intervention. For this purpose, an adapted version (Thees et al., 2020) of the *Cognitive Load Scale* by Leppink et al. (2013) was used, with minor adaptions to fit this study's research design.

Lastly, to measure the pupils' ease of use of the interactive videos, an adaptation of the *System Usability Scale* (Brooke, 1996) was used.

For the pilot run of the study, four experiments belonging to different categories (see Table 4) were used in two German 9^{th} grade classes (n = 47).

Table 4. Experiments used in the pilot run of the study.

	Experiment	Content	Cognitive Demand	Experimental Setup
1	Brownian Motion of Smoke Particles	Smoke particles' behaviour in a chamber is observed. It suggests that the submicroscopic particles matter is made of, are in constant motion.	Low	Scientific Utensils
2	Electrolysis and Oxyhydrogen Test	Electrolysis of water with subsequent oxyhydrogen test is carried out. It shows that matter (in this case water) can undergo reversable aggregate phase changes and that it is formed according to fixed component ratios.	High	Scientific Utensils
3	Egg Floating in Salt Water	An egg sinking in fresh water but floating in salt water is used as evidence for the salt water having a higher density. This in turn suggests that the particles salt water consists of have arranged in a more space-saving way. This means there must be empty space between particles.	High	Everyday Utensils
4	Dye in Water	The diffusion of dye in water is observed over a period of time. It suggests that in the case of fluids, particles tend to distribute themselves evenly in space.	Low	Everyday Utensils

RESULTS

The measured intrinsic cognitive load of the four experiments that are part of the pilot study corresponds with the categorization that was carried out beforehand, rating experiments 2 and 3 as cognitively more demanding than 1 and 4. However, these measured differences are not statistically significant, $F(2.51, 100.52) = .76$, $p = .496$.

The four experiments differ in their persuasiveness. As can be seen in Figure 2, more pupils switch to or keep an incorrect statement about the particle model of matter after having carried out experiments *Electrolysis and Oxyhydrogen Test* and *Egg Floating in Salt Water* (Experiments 2 and 3).

These two experiments are the ones that were categorized as cognitively more demanding. The ones that were categorized as comparatively less demanding (Experiments 1 and 4) have lower percentages of pupils switching to or keeping an incorrect statement about the particle model of matter.

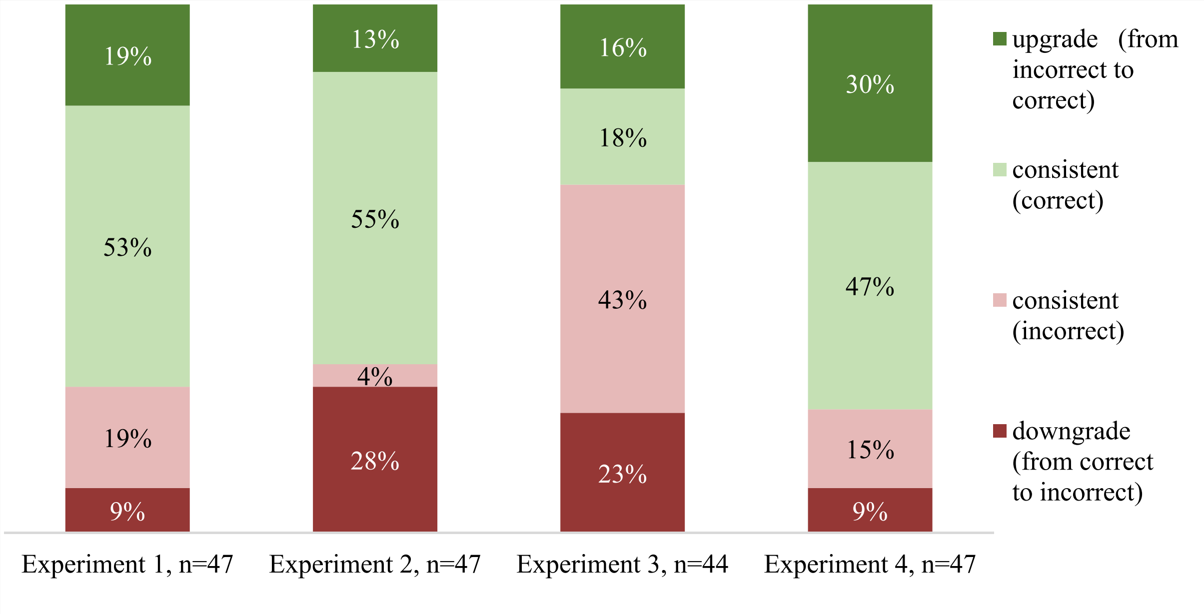

Figure 2. Percentages of participants agreeing with correct or incorrect statements about the particle model of matter before and after each experiment.

The different types of utensils used in the experiments do not seem to influence the experiments' persuasiveness in a significant way, as experiments 1 and 2 use a more scientific setup and 3 and 4 a setup consisting of everyday utensils.

When looking at the reasons for agreeing or disagreeing with statements about the particle model of matter, we found no significant differences between the experiments, $F(3, 123) = 1.35$, $p = .261$. It therefore cannot be stated that any of the four experiments is more likely to lead to long-term attitude changes than the others.

The mean system usability of the interactive video experiments was rated at 68.7, which according to Bangor's et al. (2009) single adjective scale falls into the range of "Ok", just short of "Good".

The overall conceptual knowledge, measured using the OMC-Test at the very beginning and end of the study, decreased significantly, $t(45) = -2.929$, $p = .005$, $d = 0.43$, with a mean pretest score of 69.5 ($SD = 7.4$) and a mean posttest score of 66.3 ($SD = 8.1$). Possible reasons for this are discussed in the following chapter.

DISCUSSION AND CONCLUSION

The results of this study's pilot run suggest that experiments demanding a higher cognitive strain for correctly processing their key findings are perceived as less convincing. Particularly striking are the relatively large percentages of participants categorized as "downgrade" in Experiment 2 and 3 and "consistent (incorrect)" in Experiment 3 (see Figure 2). Both experiments were categorized as cognitively more demanding, which is most apparent in experiment 2, the electrolysis and oxyhydrogen test requiring many procedural steps.

A possible additional explanation for the relatively high percentage of pupils choosing an incorrect statement about the particle model of matter after having carried out experiment 3 is that the incorrect statement addresses a common misconception that is difficult to abandon ("there is a substance between particles").

A possible reason for the overall decrease of conceptual knowledge over the course of the study is that the pretest scores were already relatively high. Additionally, the lack of an extensive break between the intervention and the posttest might also have contributed to poorer fatigue-related scores. Therefore, the research design of future implementations of this study will be adjusted accordingly.

The results of this study have shown that the interactive video experiments are generally suitable for conveying aspects of the particle model of matter. For following implementations of this study with more than four experiments, it will be of interest to see whether differences in the experiments' persuasiveness can be detected when factoring in individual system usability scores and the thoroughness with which the interactive video experiments are carried out. Moreover, a wider range of experiments should also allow for a more distinguished look at differences in the experiments' persuasiveness, not only in relation to their cognitive demand, but also to their suitability of leading to long-term attitude changes.

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PROPOSING A SEMANTIC MATRIX TO ORGANIZE DIFFERENT UNDERSTANDINGS ON CHEMICAL REACTIONS

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In this work, we aimed to analyze the plurality of meanings attributed to the chemical transformation or chemical reaction concept applied on different contexts to propose a semantic matrix constituted by themes, categories, and epistemological, ontological, and axiological commitments. We are guided by the theory of conceptual profiles in our intent of structuring the heterogeneity of verbal thinking as individuals expressed different ways of thinking on chemical reactions or transformations, in different settings and historical contexts. The methodological approach to building and analyzing data was qualitative in nature and resulted in a semantic matrix for the concept of chemical reactions. We collected data from three sources – history of science texts, science education literature and conceptions emerging in the students' speeches – to analyze different ways of thinking and epistemological, ontological, and axiological commitments which could be implicated in them. Our results showed a polysemy for the concept of chemical reactions, and we structured eight themes related to different contexts in a semantic matrix, based on distinct commitments. Categories and commitments were associated to each theme and the matrix seemed to constitute a productive tool for teaching and learning on chemical reactions.

Keywords: Semantic Matrix. Chemical Reactions. Plurality of Meanings

INTRODUCTION

This work aimed to analyze the plurality of meanings attributed to the chemical reaction concept in different contexts to propose a semantic matrix constituted by themes, categories, and epistemological, ontological, and axiological commitments. Learning on chemical reaction is important in the formal instruction and for citizenship formation as knowledge such as fuel burning and production, climate change, food conservation, recycling of materials, synthesis of medicines and vaccines are necessary to improve the quality of people' lives (see Rosa & Schnetzler, 1998, Yan and Talanquer, 2015).

The understanding on chemical reaction could help the students to know how chemical substances are implicated in numerous matter transformations processes, which have relevance in many real situations lived by them and are present in discourses emerging in social context and science classroom (Ahtee & Varjola, 1998). Weinrich and Talanquer (2016) highlight that the students must go beyond only mechanistic explanations and representations on chemical reactions building an integrated understanding on this concept with other ones, such as chemical bond, kinetics, and thermochemistry and improving the comprehension on natural phenomena and industrial processes.

The possibility and potentiality of building an integrated view on chemical reactions leads us to address the concept in a pluralist perspective. In this direction, we adopted premises from the conceptual profiles theory (Mortimer et al, 2014a) that deals with the heterogeneity of thinking and acknowledges that individuals can present different ways of thinking on a particular concept, which are related to their ways of speaking and can be associated to social experiences in diverse contexts. Distinct epistemological, ontological, and axiological commitments characterize zones in conceptual profiles, which are representative of the different ways of thinking and speaking on concepts, legitimized by the social language. According to Mortimer et al. (2014a), conceptual profiles can be understood as models that structure different ways of thinking on scientific concepts, expressed by the individuals as a form of signifying their social experiences.

Methodological bases to propose conceptual profiles in terms of zones include getting data from secondary historical sources on the development of scientific ideas, systematic review in science education literature on alternative conceptions and analysis of students' speeches in instructional settings. Data from different sources take part of a dynamical and dialogical process in which different ways of thinking could be identified and characterized to assemble in specific zones of a conceptual profile, according to their convergent commitments (Mortimer et al., 2014b).

In this process, data could be organized in a sort of matrix that have been differently addressed and named by distinct authors (see Sepulveda, 2010; Reis, 2018 and Pimentel, 2019). Reis (2018) and Pimentel (2019) supported on ideas proposed by Sepulveda (2010) organized data in a semantic matrix, in which themes and categories related to a concept are articulated and characterized according to epistemological, ontological, and axiological commitments. In this way, the semantic matrix highlights the polysemy of the concept making explicit the plurality of meanings attributed to it in different contexts.

Here, we present a semantic matrix as a preliminary step to propose a conceptual profile for chemical reactions in a further work. The semantic matrix was proposed with the goal to put together themes, categories, and commitments in a comprehensive and productive visualization. Themes represent a particular view on the concept that implies in specific assumptions on the nature, type of knowledge, and can involve subjective aspects in the comprehension on it. Categories entail specific definitions for each theme, bringing contributions to characterize in detail the set of ideas that constitute a theme and the commitments implicated on them. The commitments could be defined as follow: epistemological commitments concern to how and for what knowledge is addressed, for example, we are looking for how individuals know on transformations of matter and/or chemical reactions and how they act oriented by this specific knowledge; ontological commitments are related to the nature of the concept and we are supported by some categories proposed by Chi (1992), for instance, transformation of matter and/or chemical reaction can be addressed as a process, abstraction or even a material thing, which characterize an specific way of thinking on this concept; and axiological commitments represents ideas embedded in affections and values associated to the concept.

METHODOLOGY

This paper brings a qualitative approach for research (Guba & Lincoln, 2002), considering the descriptive and interpretative treatment given to data in order to reach our objective: proposing a semantic matrix on chemical reaction concept, constituted by themes, categories, and epistemological, ontological, and axiological commitments from the analysis of the plurality of meanings attributed to this concept in different contexts. This work is part of a doctoral research that aims to propose a conceptual profile for chemical reactions, and we present an initial data analysis on ideas related to this concept from a literature review on the historical development of ideas on transformation of matter and chemical reactions, students' conceptions on chemical reaction found in science education literature and the students' responses to a questionnaire applied for future chemistry teachers in formation course. Data were collected in order to envisage three genetic domains – ontogenetic (subjective/social process), sociogenetic (social/historical process) and microgenetic (interactional process) (Wertsch, 1993), according to the methodological design proposed in the theory of conceptual profiles (Mortimer et al., 2014b). In the Table 1, we illustrate the main works used to catch ideas from historical secondary sources and science education literature. We emphasize that these works contributed to understanding a dialogical articulation of data in the process of construction of the semantic matrix, considering that they could be potentially representative of the sociogenetic and ontogenetic genetic domains.

Table 1. Main sources used to get data from historical and science education literatures.

Source	References
Historical secondary sources	Vidal, 1986; Partington, 1989; Bensaude-Vicente; Stegers, 1992; Hudson, 1992; Maar, 2008; Rooney, 2019
Science education literature	Andersson, 1990; Rosa & Schnetzler, 1995; Lopes, 1995; Mortimer & Miranda, 1995; Solsona, 2002; Machado Jr. et al., 2005; Silva, 2008

Source: Research data.

In addition, we applied a questionnaire to find conceptions on chemical reactions expressed by 26 future chemistry teachers (S1 to S26) attending a formation course in a public university in Pernambuco, Brazil. They were aged between 19 and 25 years, studying in different stages of the course (6^{th} to 9^{th}), answered questions about general definitions and situations involving the occurrence of chemical reactions, such as, functioning of batteries, antiacids, oxidation of different materials and food conservation. For data analysis, we elaborated three tables to organize data from each source, pointing possible themes, categories, and commitments for each one, thus we proceed to a comparative analysis of the tables to find convergences, establishing common themes, selecting meaningful categories, and characterizing them by different commitments.

RESULTS AND DISCUSSION

For the results, we present a summary of main ideas identified in the different contexts, organized in three tables, following this order: ideas emerging from the historical context, students' conceptions found in the literature and the students' responses to the questionnaire. Then, we show the semantic matrix proposed from a comparative analysis of the tables.

Ideas from historical context

Firstly, we highlight that our intention was not to present a historiographic study, but some historical ideas that are important for the understanding of scientific view on chemical reactions in nowadays. In the early periods, transformations of matter were discussed not as chemical reactions but considering visible changes of materials occurring naturally or by using techniques developed in different periods, for example, heating or burning materials. Many ideas were proposed trying to explain different phenomena and the transformations of matter associated to changes in the four elements constituting all matter - fire, air, water, and earth – prevailed for a long time (Maar, 2008). In the alchemy period, most transformations were associated with spiritual purposes, as well as experimenters' values regarding with the vitality of the substances (Hudson, 1992).

According to Bensaude-Vicente and Stengers (1992), about the 14th and 15th centuries, transformations of matter were discussed based on affinity between different types of substances, and only between the 16th and 17th centuries they were discussed considering changes in the constituting substances of materials and particle combinations, respectively. Maar (2008) stated that chemical reactions was aligned to explanations about reversibility of different chemical processes by the 19th century onset, and over the years the concept embedded aspects related to heat release and absorption in reactions and to the spontaneity of processes, highlighting energetic aspects implicated in chemical reactions. In the Table 2, we summarize main ideas on transformations of matter and chemical reactions we selected from different historical periods to help us in elaborating a semantic matrix.

Table 2. Summary of ideas on transformation of matter and chemical reactions emerged from historical context.

Historical period	Main ideas on transformation of matter and chemical reactions
About 100-50.000 years ago	Human beings discovered fire as the main way to transform materials. Thus, the ability to change material and produce different objects was intuitive and there was no systematized knowledge at the first, but some techniques were developed along the time.
600 B.C	Based on spontaneous observations, philosophers argued that transformations occurred due to natural forces, which reinforce ideas on natural processes occurring due to the nature of matter and its components, an approach related mainly to the Philosophy.
380 B.C	According to the Aristotle's principles, the transformations were associated with the natural tendencies of change in the qualities of the four fundamental elements: fire (hot and dry); air (hot and humid); water (cold and wet) and earth (cold and dry).
300 B.C	From the beginning of alchemy, transformations of matter were associated with spiritual purposes, the changed material must acquire supernatural aspects based on the mystical powers of the alchemists. Everything was transformed due to the will of some deity.
1st Century	Transformations of matter were based on health and perfection level of the substances. There was an essence in matter, values and vitality were attributed to the substances and, if they could not decompose, a kind of appetite could made bodies unite.
Between the 14th and 15th Centuries	Studies on some types of metals contributed to ideas on affinity among different types of substances as an explanation for chemical reactions or transformations. Thus, substances reacted because they attract each other, and this is driven by attractive forces.
16th and 17th Centuries	Chemical reactions are addressed considering the interactions and transformations of substances. In this sense, materials came to be interpreted as something made up of substances, and they would be responsible for the transformations that occurred on them.
From 18th and 19th Century	Initially, it was believed that chemical reactions occurred by the combinations between elementary particles, and the multiple combinations between these primary elements was due to the distinct shapes and movements of the particles. The understanding on atoms put forward ideas on chemical reactions occurring due to a rearrangement of atoms. breaking and forming new chemical bonds between atoms e producing new substances.
Between the 19th and 20th Centuries	Chemical reactions explained from energetic parameters - equilibrium, reversibility, absorption and release of energy, spontaneity, and dissipation of heat. Representation and classification of different types f chemical reactions.

Source: Research data.

Student's conceptions on chemical reactions in literature

In science education literature, we found numerous research dealing with the students' conceptions on chemical reactions (Andersson, 1990; Rosa & Schnetzler, 1995; Mortimer & Miranda, 1995; Ahtee & Varjola, 1998; Weinrich & Talanquer, 2015; and others). The authors pointed conceptions on chemical reactions, such as: associated with will or feelings from materials; undifferentiated of physical changes; as disappearance, modification, transmutation, and interaction of the materials/substances; as something natural occurring spontaneously to produce new substances; characterized only considering perceptible changes; and others. Few students explain chemical changes as something dynamic related to the corpuscular nature of matter that involves rearrangement of atoms.

Table 3. Summary of the students' conceptions found in science education literature.

Source	Main conceptions of students about chemical reactions
Andersson (1990) Mortimer e Miranda (1995), Lopes (1995)	Chemical reaction as a process that involves will or feelings from the materials. Changes occur because materials have a natural tendency to change, or it is an intrinsic property of them. Chemical reaction as something natural. Thus, a chemical phenomenon can be observed and occurs spontaneously to produce new substances.
Andersson (1990)	Chemical transformation as transmutation – in a chemical reaction, fundamental particles of elements can change in another type of particles or elements.
Mortimer e Miranda (1995) and Rosa & Schnetzler (1995)	Chemical reactions understood from the changes in the macroscopic properties of the substances, it is possible to distinguish substances from their specific chemical and physical properties.
Solsona (2002) and Silva (2008)	Chemical reaction as a process involving interaction between substances and their constituents. A chemical reaction is something dynamic related to the corpuscular nature of matter.
Lopes (1995)	Chemical reactions involve both reversible and irreversible processes. Physical changes are always reversible processes or phenomena.
Rosa e Schnetzler (1995), Machado Jr. et al. (2005)	Chemical reactions understood from the perceptible changes that occur after mixture of the substances, for instance, changes in the physical state, in color, with formation of gases, precipitated, heating or cooling, etc.
Andersson (1990), Rosa & Schnetzler (1995)	Chemical reactions as rearrangement of atoms. Thus, the transformations that occur at the submicroscopic level (bonds, atoms, interactions) and macroscopic level (properties of substances, visible effects)

Source: Research data.

Students' answers for the questionnaire

In the answers for the questionnaire, the future teachers expressed different ways of thinking on chemical reactions, such as: visible evidence used to characterize changes, changes in the properties of materials/substances, general ideas on reactants turning in products, and changes occurring due to interactions. The set of data show a plurality of meanings for chemical reactions, and that similar ideas can emerge even if individuals are in the different contexts. In the Table 4, we summarized the main ideas found in the answers of the future teachers.

Table 4. Some ideas expressed by the future teachers on chemical reactions, answering the questionnaire.

Future Teacher	Main ideas extracted from the answers
S1	Chemical reactions are transformations that happen at microscopic levels occurring breaks of bonds between molecules, as well as the formation of new bonds, effective shocks. So that from the reagents is forming products and by-products.
S3	A reaction can be defined as a quantitative and qualitative change from a substance or element to other substances, in which occurs changes in the properties, and physical changes at the atomic level.

S4	(...) identified by the evidence of these reactions, such as color change, precipitate formation and gas release.
S8	Chemical reactions are processes that involve matter in which the chemical identity of bodies changes.
S2	(...) where there is electron transfer and there is the transformation of chemical energy into electric energy.
S7	In contact with air, the fruits go into oxidation process.

Source: Research data.

From the data presented in the three tables above, we proposed themes, categories, and commitments for the semantic matrix (Table 5)

Semantic matrix on chemical reactions

From a comparative analysis of the ideas presented in the three previous tables, we proposed a preliminary semantic matrix for the transformation of matter and/or chemical reactions concept.

Table 5. Semantic matrix for the concept of chemical reactions.

Themes	Categories	Commitments
Changes related to the nature of matter	Matter changes for natural tendency	Material ontology (living or inert). Ingenuous realism
Changes related to mistical endeavor	Matter changes for mystic or spiritual reasons	Abstract ontology. Beliefs and affects guiding changes (axiological commitment)
Changes occurring naturally	Matter changes without interferences	Events ontology - change as a natural process. Ingenuous realism
	Matter changes for natural forces	Events ontology. Causal and Naturalist view based on affects (axiological commitments)
Chemical changes associated to visible evidence	Physical features evidence changes in materials	Material/Process ontology. Empirical epistemology
	Physical and chemical changes are not differentiated	Process ontology. Empirical epistemology
Chemical change associated to affinity between substances	Matter is composed by substances that could change by affinity with each other.	Material/Process ontology. Rationalist epistemology
Chemical change related to the use of techniques and practical work	Matter changes from intentional intervention, under specific conditions, sometimes by using techniques and technology	Process ontology. Theory based empirical epistemology
Chemical change related to interactions between substances	Chemical reactions occur as interactions between two substances form a new product	Process ontology. Rationalist epistemology.
Chemical change is associated to reorganizations of atoms or elements	Matter changes as atomic particles get new arrangement.	Process ontology. Rationalist epistemology

Source: Research data.

According to Table 5, it was identified eight themes related to the concept of chemical reactions, which present different categories and different ontological, epistemological, and axiological commitments. The first theme, **Changes related to the nature of matter**, was proposed considering mainly ideas from the historical context (Vidal, 1986; Bensaude-Vicente & Stengers, 1992), in which we identified as a category the idea on transformations of matter explained from a natural tendency. Similar ideas also appear in the literature and classroom contexts. For us, there is a centralization of the understanding on the matter and its resources, thus, we considered this category aligned with a material ontology (Chi, 1992) as the transformation is linked to a potential force from the material (living or inert). In addition, we observe indicatives of the realist epistemological commitment, in which the transformations are explained from naive and generalist perspectives.

For the second theme, **Changes related to mystical endeavor**, we are also supported on ideas emerging from historical and instructional contexts (informal conceptions), in which chemical reactions are related to supernatural issues. Thus, this theme comprises only one category that suggests an abstract ontological commitment as the transformation of matter is attributed to mystical or spiritual reasons, according to subjective beliefs and affects. For Vidal (1986) and Maar (2008), the transformations of matter over a long period of human history were explained through virtues and powers, and therefore, we evidenced an axiological commitment in which beliefs could influence the forms, leading individuals to explain changes in a subjective way.

Regarding to the third theme, **Changes occurring naturally**, we grouped ideas from historical and instructional contexts in which the conceptions are aligned with spontaneous processes and natural forces (Vidal, 1986; Bensaude-Vicente & Stengers, 1992). This theme is divided in two categories: the first one related to the idea that materials transform without interference, that is, transformations occurs because things are in this way, as there is a natural tendency for it, and the second category is related to the idea that materials transform under action of some natural forces. In this sense, we found clues of an ontological commitment that transformations are like the occurrence of events, sometimes without a specific reason, in other way for natural cause. In the first category, we consider the idea linked to a naive realism in which the idea of spontaneous occurrence could be supported by individuals' ingenuous experiences, the second one seems to be based on naturalistic views, based on beliefs and values internalized by social subjects related to natural forces guiding events. It is aligned with an axiological commitment.

In the fourth theme, **Chemical changes associated with visible evidence**, we pointed out ideas from the historical and instructional contexts, and we propose two categories. The first one is associated with changes in materials that could be evidenced by physical characteristics, such as, visible effects evidenced in observations, perceived in a macroscopic way (Solsona, 2002 and Silva, 2008), and the second one related to the idea that physical and chemical transformations are not differentiated. In this sense, both categories are linked to an empirical epistemology, when it is aligned with more practical view of transformations, however it is not clear that such transformations effectively represent a chemical reaction, for example, color changes and gases release not necessarily indicate a chemical reaction. And it is necessary that the students learn to differentiate physical from chemical transformations. In this theme, we identify an material ontology, linked to empirical evidences, but also some notion about a process occurring behind the visible observations.

The fifth theme is **Chemical change associated with affinity between substances**, again we gathered ideas identified in the historical and instructional contexts, in which the concept of chemical reactions is aligned with a preliminary model of explaining reasons for the substances interact with others - affinity. Along the historical context, affinity between substances did not encompass necessarily a scientific or rational view, sometimes it was linked to feelings as attraction, or linked to a principle of forces appointed from Newtonian models. Thus, we assumed a meaning associated to a category in which the students are conscious that materials are composed by substances that could interact with others by affinity (without stress on the meaning for it). In this way, the idea is linked to a material ontology and presents indications of a rationalist epistemology (Vidal, 1986). For example, according to Rooney (2019), in the history of chemistry, copper and arsenic alloys were formed due to the affinity between these substances through heating the mineral.

On the sixth theme, **Chemical change related to the use of techniques and practical work**, we grouped ideas based on historical and instructional contexts, in which the concept of chemical reactions is addressed from the perspective of forms of operationalization and practical activities. For this theme, we proposed one category as we identify ideas on the transformation of materials from an intentional intervention (Solsona, 2002; Rosa and Schnetzler,1995; Machado Jr. et al., 2005; Silva, 2008) by using techniques and technologies to generate products through different processes and practical actions. These ideas include explanation about the use and application of the chemical reactions in human activities and technological process for social development, as well as, raising some questions on consequences that such processes and activities should provoke for life and environment. It is aligned with an ontology of processes and an empirical or pragmatic epistemology, considering a theory based empirical perspective.

In the seventh theme, **Chemical change theme related to interactions between substances**, we point to ideas mainly found in studies about informal conceptions (Andersson (1990), Rosa & Schnetzler (1995)) that explain the generation of products from interactions between substances. Therefore, we indicate a category in which chemical reactions occur due to the interaction between two substances forming a new product, demonstrating an ontological commitment of process and a rationalist epistemology from the understanding of the occurrence of the chemical reaction. The eighth theme, **Chemical change is associated with reorganizations of atoms or elements**, is an expansion of the seventh theme, as we consider ideas on chemical reaction that include an understanding on different rearrangements of atoms in the process of the transformations of materials, starting from the interactions of substances. Thus, we propose a single category that explains the transformation of materials considering that atomic particles in a previous arrangement change to another configuration forming new substances. It is based on a rationalist epistemological commitment and a process ontological commitment, which corroborate with a scientific view of the concept. According to Solsona (2002), these commitments support the view that the chemical reaction is understood as a rearrangement of particles and establishes a balance of mass and energy between reactants and products.

FINAL COMMENTS

In this study, we examined diverse ideas on transformation of matter and/or chemical reactions gathered from different sources of data – historical texts, students' conceptions in science education literature, and a questionnaire applied to future chemistry teachers. From data analysis, we verify the polysemy for the concept of chemical reactions, since historical to nowadays contexts. Supported by the theory of conceptual profiles, we believe that it is important to promote the consciousness of the heterogeneity of thinking and language in the science classroom in order to reach meaningful understanding on scientific concepts. For this propose, we structured different ways of thinking on chemical reactions in a semantic matrix, elaborated in eight themes and ten categories. Commitments for each category were discussed and we believe that the semantic matrix can be useful for discussion on chemical reactions in instructional settings. For further investigations, the themes point for potential conceptual profile zones of chemical reactions, as a wider contribution for discussions and practical actions related to so relevant concept in science education.

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IDENTIFYING STUDENTS' MISCONCEPTIONS OF THE QUANTUM NUMBERS THROUGH VERBAL AND PICTORIAL EXPRESSIONS

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The study investigates students' misconceptions regarding 'quantum numbers' through both, their verbal descriptions and pictorial representations of the atomic structure. Participants were 192 secondary students (grade 12, age 17-18) from Northern Greece. Results reveal the existence of a number of misconceptions concerning their verbal descriptions that can be categorized in seven distinct categories, as well as, four additional categories of misconceptions identified through the corresponding pictorial representations of the atomic structure.

Keywords: Misconceptions, Representations, Secondary Education

INTRODUCTION

Students' conceptual understanding of the 'quantum numbers' is often accompanied by several ideas and misconceptions (e.g., Ardac, 2002; Temel & Özcan, 2018). Such misconceptions are associated either, with students' verbal explanations of electron configurations and the quantum state of the electron (e.g., Ardac, 2002; Temel & Özcan, 2018), meaning of quantum numbers (e.g., Sunyono et al., 2016; Temel & Özcan, 2018) and relations between orbital characteristics and quantum numbers values (e.g., Sunyono et al., 2016) or with their pictorial representations of the atomic structure (e.g. Dangur et al., 2014).

According to existing literature evidence, students' relevant misconceptions are numerous and could be organized in a number of particular categories. Thus, in a first category of misconceptions, students seem to approach quantum numbers through a deterministic/macroscopic perspective, which is characterized by the effects of the Bohr's model on their conceptualization and the confusion between quantum numbers and the characteristics of the atom (e.g., Özcan, 2013; Papaphotis & Tsaparlis, 2008; Taber, 2002, 2005; Temel & Özcan, 2018). For instance, students often visualize the spin as a classical rotation of the electrons/particles around their own axis (Özcan, 2013) and ascribe characteristics of quantum numbers to the characteristics of the whole atom considering, for instance, that the '*principal quantum number'* (n) shows the size of the atom (Özcan, 2013; Papaphotis & Tsaparlis, 2008; Taber, 2002, 2005). In the second category of misconceptions, students' conceptualization of quantum numbers takes place with the engagement of other quantum concepts such as the concept of orbital (e.g., Ardac, 2002; Papaphotis & Tsaparlis, 2008; Taber, 2002, 2005; Temel & Özcan, 2018). In this category, students' conceptualization of the first three quantum numbers is associated with the conceptualization of the concepts of 'shell', 'sub-shell', 'energy level' and 'orbital' which often are used interchangeably or as synonyms (e.g. Nakiboglu, 2003; Nicoll, 2001; Stevens et al., 2010; Sunyono et al., 2016; Taber, 2002, 2005) and often are affected by the Bohr's model ideas (e.g. Allred & Bretz, 2019; Papaphotis & Tsaparlis, 2008; Park & Light, 2009; Tsaparlis & Papaphotis, 2009; Zarkadis et al., 2017). The third misconception category concerns confusion in-between the characteristics of quantum numbers (e.g., Ardac, 2002; Papaphotis & Tsaparlis, 2008; Temel & Özcan, 2018). For instance, students often confuse characteristics of the *angular momentum quantum number* with those of the *magnetic quantum number* attributing the direction of an orbital to the *angular momentum quantum number* (Papaphotis & Tsaparlis, 2008). The fourth misconception category indicates confusion concerning the quantum number values, showing difficulty in interpreting these values during electronic configuration problems (e.g. Ardac, 2002, Temel & Özcan, 2018). Thus, students use 'self-generated-rules' (Ardac, 2002), considering, for instance, that the energy level of orbitals increases along with the increase of the corresponding l or m_l values (Ardac, 2002).

However, the above categorization results by literature evidence where either, verbal or pictorial relevant students' representations are studied. Taking also into account that students' difficulties in conceptualizing quantum numbers are numerous and they are associated with the probabilistic nature of orbitals and electron clouds, it would be important to study more systematically such students' misconceptions through their both verbal and pictorial relevant expressions in association with the representation of the atomic structure.

RESEARCH QUESTIONS

The present study is a part of a wider research project regarding students' conceptualization of the quantum numbers and their association with the representation of the atomic structure. Research questions were:

1. What do students' misconceptions concerning quantum numbers exist and how can they be categorized, when they verbally describe quantum numbers?

2. What do further significant student misconceptions concerning quantum numbers arise when they draw corresponding pictorial representations of the atomic structure?

METHODOLOGY

Subjects and Procedure

A total of 192 students [105 (54.7%) male, 87 (45.3%) female] of the 12th grade of secondary schools from Northern Greece participated voluntarily in the present study, being aware of its purpose and that their performance in the study will not affect the evaluation of their performance in school. Students were from various socio-economic levels and attended mixed ability classes of the 'science and mathematics direction' in regular public schools using the same textbook and following the National Science Curriculum for Greece (Greek Pedagogical Institute, 2003). Data were collected during the last semester of the school year by means of an anonymous paper-and-pencil test.

Instruments

Students' verbally expressed descriptions (written) of the 'quantum numbers' were measured along with their pictorial representations (drawings) of the atomic structure through an anonymous paper-and-pencil test especially designed for the purpose of the present study. Its completion by the students lasted 45 min. In each of the four tasks, one of the four quantum numbers was under study, respectively, where students were asked to describe the quantum number and to draw the corresponding atomic structure for a given value of it. Tasks concerning the present study are presented in Table 1. A pilot study (n = 72) was carried out in order to detect and correct possible errors - no problems were found and thus, no changes were made to the final tool. Internal consistency reliability was found acceptable, with a Cronbach's alpha of 0.79 for the verbal descriptions and a Cronbach's alpha of 0.81 for the pictorial representations.

Table 1. Descriptions of the tasks.

Tasks		Description of the task
1		For $n = 2$, students were asked to:
	a.	describe the 'principal quantum number'
	b.	depict the corresponding atomic structure explaining what they depict
2		For $l = +1$ of the principal quantum number $n = 2$, students were asked to:
	a.	describe the 'angular momentum quantum number'
	b.	depict the corresponding atomic structure explaining what they depict
3		For $m_l = +1$ of the principal quantum number $n = 2$, students were asked to:
	a.	describe the 'magnetic quantum number'
	b.	depict the corresponding atomic structure explaining what they depict
4		For $m_s = +1/2$ of the principal quantum number $n = 2$, students were asked to:
	a.	describe the 'spin quantum number'
	b.	depict the corresponding atomic structure explaining what they depict

RESULTS

Students' verbal descriptions were initially grouped into the three following categories:

a) Category 'SciA' (*Scientifically accepted responses*), where only answers including components consistent with the scientific view (one or more) were categorized, such as, what each quantum number represents and specifies, or what are the values of each quantum number, whether also other additional specifications are reported or not (e.g., that is about solutions of Schrödinger equation, report of forces between subatomic particles, etc.).

b) Category 'Mis' (*Misconceptions*), where answers including misconceptions were categorized.

c) Category 'NR', where unclear answers or no responses were categorized.

Figure 1 summarizes the distribution of student percentages in tasks dealing with verbal descriptions (tasks T1a to T4a). Note that, numbers 1 to 4 in each task T represent the corresponding quantum number, whereas the 'a' indicates that is about a verbal description.

Figure 1. Percentages of students' written descriptions per task.

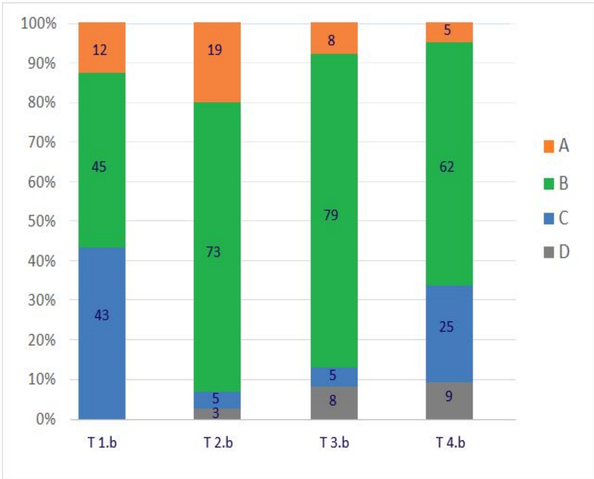

Figure 2. Percentages of students' drawings per task.

However, a further analysis of students' responses of Category 'Mis' revealed seven additional sub-categories of specific misconceptions (Mis 1 to Mis 7), which were coded as distinct and mutually exclusive categories, as Table 2 shows.

Table 2. Distribution of students' misconceptions across the four tasks - Frequencies f and percentages (%).

Categ.	Description of categories	T1a	T2a	T3a	T4a
Mis 1	No distinction between different quantum numbers - interchangeable use or use as synonyms	2(1%)	14(7.3%)	5(2.6%)	3(1.6%)
Mis 2	Quantum numbers are confused with other quantum concepts such as orbital, electron cloud, subshell and probability	10(5.2%)	3(1.6%)	5(2.6%)	24(12.5%)
Mis 3	Confusion concerning quantum numbers values (e.g. m_s=-*n*..0..+*n*, *l*=-*l*..0..+*l*, *n*= -*n*..0..+*n*, *l*=-*l*...+*l*)	5(2.6%)	3(1.6%)	-	1(0.5%)
Mis 4	Deterministic/Macroscopic characteristics are attributed to quantum numbers	-	6(3.1%)	17(8.9%)	22(11.5%)
Mis 5	Quantum number characteristics are attributed to the whole atom	-	2(1%)	-	7(3.6%)
Mis 6	Forces between the subatomic particles are attributed incorrectly to different quantum numbers	-	4(2%)	2(1%)	1(0.5%)
Mis 7	Incorrect set of quantum numbers (values) contribute to the electrons energy state	-	2(1%)	-	-

As for the students' pictorial representations, they were evaluated taking into account the correctness and completeness (including complexity) of a number of components (see also Zarkadis & Papageorgiou, 2021) and spatial characteristics such as position, alignment, relative size and scale (Tang, Won & Treagust, 2019), and they were grouped into the four following categories:

a) Category 'A' (*Quantum model*), where representations with complete and correct quantum number characteristics of orbitals/electron clouds (size, shape, orientation, spin) were categorized.

b) Category 'B' (*Quantum model with misconceptions*), where representations with both correct and incorrect quantum number characteristics of orbitals/electron clouds, or cases of mixed characteristics between naïve and quantum models, were categorized.

c) Category 'C' (*Naïve model*), where representations with deterministic approaches of quantum number characteristics were categorized.

d) Category 'D', where unclear drawings, wrong drawings, or even no drawings were categorized.

Figure 2 summarizes the distribution of student percentages in tasks dealing with pictorial representations (tasks T1b to T4b, where the 'b' indicates that is about a drawing).

However, a more elaborated analysis of Category 'B' revealed four specific sub-categories of misconceptions *(Drawing Subcategories - DS)*, which were also coded as distinct and mutually exclusive categories, as Table 3 shows.

Table 3. Distributions of students drawing subcategories across the four tasks T - Frequencies f and percentages (%).

Categ.	Description of categories	T1b	T2b	T3b	T4b
DS 1	Orbitals (or sub-shells) co-existing with the deterministic characteristics such as orbits/shells or/and the macroscopic view of (spin) movement	5(3%)	14(7%)	5(3%)	10(5%)
DS 2	Electron clouds co-existing with the deterministic characteristics such as orbits/shells or/and the macroscopic view of (spin) movement	8(4%)	-	4(2%)	4(2%)
DS 3	Orbitals and/or electron clouds in which some types/shapes are missing	61(32%)	89(46%)	98(51%)	70(37%)
DS 4	Incorrect (spatial) depiction of orbitals and/or electron clouds using incorrectly quantum number values	11(6%)	38(20%)	45(23%)	36(19%)

DISCUSSION AND CONCLUSIONS

Although Figure 1 shows that the majority of students provide scientifically accepted verbal responses ('SciA') in all tasks, Figure 2 shows that a large percentage of students holds misconceptions within Quantum model (Category B) for all tasks, especially for T2b, T3b and T4b. This indicates the existence of a possible inconsistency between students' verbal expressions and pictorial representations.

Furthermore, the misconception categories of Table 3 can shed light to the extent of such an inconsistency, indicating also possible relations with the categories presented in Table 2. Thus, as Table 3 shows, category DS3 seems to hold true for quite high percentages of students in all tasks, indicating that a significant part of students' misconceptions is possibly due to their insufficient view of the atomic structure through the role of quantum numbers. Also, the deterministic characteristics that are expressed through categories DS1 and DS2 could be associated with the way in which students attribute such characteristics to verbal descriptions of quantum numbers (see Mis 4), whereas the increased percentages of students' misconceptions in DS4 regarding incorrect use of quantum number values could be associated with the low percentages in Mis 3 and Mis 7. Therefore, it can be concluded that pictorial representations can provide additional evidence for students' misconceptions, which only verbal descriptions could not deliver, highlighting the complementary role of the two methodological approaches in studying students' expressions of the quantum numbers and the corresponding representations of the atomic structure.

The above could be taken into account in both the research and the teaching methodologies. Future relevant teaching procedures could take into account the misconceptions found in the present work, whereas further investigations regarding students conceptual difficulties in quantum numbers could focus on analyzing both relevant verbal descriptions and pictorial representations, including also possible effects of the corresponding textbook representations of the atomic structure.

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TWO APPROACHES TO ANALYZING FLUIDITY OF STUDENT REASONING ON A MULTIPLE CHOICE SURVEY ABOUT HALF-LIFE

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For several years, we have been studying the conceptual understanding of high school students about radioactivity, particularly regarding half-life. It is difficult for learners to grapple with the idea that random behavior of individual atoms can give rise to predictable patterns in the collective, and many students have said both in interviews and surveys that, if you are looking at an individual atom, half of the atom will have fissioned after one half-life. Our findings have indicated, however, that this idea (of individual atoms fissioning in a predictably continuous manner) is often not a robust and intact mental structure; rather, in other contexts, the same students correctly discuss fission as being instantaneous and unpredictable. We are exploring this context-dependency via a survey that contains problems that are isomorphic (that is, the questions require the same physics principles to be answered correctly). Since adding isomorphic prompts to a survey naturally increases the survey length, we are also considering the use of a surrogate measure to determine fluidity of student reasoning; namely, our survey also asks respondents to rate their confidence after each item. Our preliminary research findings suggest that there is no significant correlation: more (less) confident students are not more likely to be (in)consistent.

Keywords: Conceptual understanding, Physics, Quantitative methods

INTRODUCTION

To date, researchers have documented a number of student naïve ideas regarding radioactivity (*e.g.*, Eijkelhof, 1990). Specific to the lifetime of radioactive materials, many students assume that if half of a radioactive substance has transformed after one half-life, then half of each individual atom making up the sample must have transformed (*e.g.*, Klaassen, Eijkelhof, & Lijnse, 1990). It has been argued that part of the underlying difficulty could be a failure to understand the random nature of radioactivity (Eijkelhof, 1990; Hull, Jansky, & Hopf, 2021). We have also argued that, particularly regarding ideas about the timing of the fission of an individual atom, the difficulty could arise in part because of a failure to understand radioactivity as an emergent process (Hull & Hopf, 2020). Wilensky *et al.* (*e.g,,* Wilensky & Resnick, 1999) discussed how students demonstrate a "level confusion" when they assume that the agent level (in this case, individual nuclei) and the system level (the overall radioactive sample) share the same property (being half-transformed after one half-life). In our prior work, we have documented that this "level confusion" is not necessarily a stable and rigid cognitive structure; students often seem to have myriad ideas available to them simultaneously, including ideas about the random nature of individual nuclei, and different ideas come to the fore depending upon the specific context (Hull, 2019; Hull & Hopf, 2020). In this paper, we will discuss two features that we have incorporated into our survey: 1) isomorphic problems and 2) confidence ratings. We will use these features to attend to our research question "to what extent does student confidence correlate with consistency across the isomorphic prompts?".

METHOD

Our work involves analysis of student responses to two types of items on a multiple choice survey about half-life to assess how robust and intact their ideas are. First, we use isomorphic problems, problems that require the same conceptual understanding to answer, but have different surface features that may result in a given student answering only some of the problems correctly. This fluidity in reasoning appears because "problem context with distracting features can trigger the activation of knowledge that a student thinks is relevant but which is not actually applicable in that context" (Singh, 2008). The second tool we consider for indicating the robustness of a learner's ideas is that of confidence ratings. After each item in our survey, we ask the respondent how confident he or she is with the answer to that item. Lemmer (2013) has argued that expressing confidence can "confirm the existence of stable existing [knowledge] structures." Although reporting of confidence is an indirect measure of how stable a student's ideas are, it takes little time for a student to report confidence, as opposed to answering additional (isomorphic) questions. If there is great correlation between consistency across isomorphic prompts and reported confidence, then confidence ratings could be used alone to indicate stability or fluidity of student ideas.

Our survey, which we have named the "Fission as a Random Occurrence Survey" (FAROS), consists of 3 isomorphic prompts written in German, which we have described elsewhere, CAGE (Jansky, 2019), Many vs One (MvO) (Hull, 2019; Hull & Hopf, 2020), and ANT (Hull, Jansky, & Hopf, 2020). CAGE and MvO ask students to consider the behavior of a single unstable nucleus, in comparison to the behavior of a large collection of such nuclei. ANT is similar, in that it asks students to compare the radiation emitted from a stone containing "a very small amount" of a radioactive isotope (ANT: TRACE) with that from a stone containing "a huge amount" of the same isotope (ANT: HUGE). For each of these prompts, we looked to see if students made the error of saying that the individual atom (or "very small amount" of atoms) behaves in the same way as the large collection of atoms, indicating a "level confusion" (*e.g.,* Wilensky & Resnick, 1999). For example, MvO begins by defining half-life using the example of I-131, that "if one begins with a large number of [I-131] atoms, then half of the atoms would transform into another kind of atom after 8 days". MvO:MANY presents the situation of beginning with 100 million atoms and asks how many atoms would have not yet transformed after 8, 16, and 24 days. MvO:ONE then presents the situation of beginning with just a single I-131 atom and asks "how much I-131 would have not yet transformed after 8, 16, and 24 days?" Students generally answer MvO:MANY correctly. Such students who also incorrectly answer MvO:ONE that, after 8 days, half of an atom would remain, are coded as "indicating a level confusion" (LC). If a student receives an LC code on each of the three isomorphic prompts, then we can consider his or her reasoning to be fairly robust and context-independent. Overall, we would code this student as "consistent".

After each question, students were asked to rank their confidence from 1 to 5 with the prompt "How confident are you with your answer? On the scroll bar below, clicking farther to the right indicates that you are more confident. (No false modesty, please!)" Generally, our approach is to look for correlation between responses on the isomorphic prompts and these confidence ratings to see if the students we coded as "consistent" are also more likely to report confidence.

The design and validation of MvO and CAGE in FAROS have been discussed already elsewhere (Hull, 2019; Hull & Hopf, 2020), but the process was similar to what we will now describe for ANT. For additional details on MvO and CAGE, we refer interested readers to our prior publications. Unlike CAGE and MvO, we wanted ANT is to assess student reasoning about the timing of nuclear decay without thinking about half-life. ANT consists of a Concept Cartoon (Keogh, Naylor, & Wilson, 1998) (see Figure 1 below) where four students are having a discussion about the radiation reaching an ant standing near a radioactive stone for a duration of 10 minutes. Survey respondents are asked which of the four statements they agree with, which they disagree with, and why. These statements are intentionally ill-defined, and it is ambiguous what exactly a "huge amount" or a "very small amount" of I-131 in the stone entails. What is relevant for our analysis is whether language about "very small" and "huge" amounts cues in student's ideas about the law of large numbers and if they hence say that there would be differences in their answers or not.

Qualitative content analysis of ANT

Like CAGE and MvO, ANT existed first as a free response prompt whose quality was confirmed by three survey validation interviews (SVI#1, 2, and 3). Responses were collected from N = 55 students visiting the University of Vienna in the spring semester of 2019 who had not yet learned about half-life and from N = 37 students during their regularly scheduled high school class in the spring semester of 2020 who had already learned about half-life. Hull and Jansky coded the responses to ANT using qualitative content analysis (Mayring, 2014). These codes were then turned into options for a two-tier multiple-choice test form.

When ANT was administered in 2019 as a free response prompt, students were asked to first consider the situation of the stone being "weakly radioactive" and to then say how their answers would change if the stone were instead "strongly radioactive". The four statements students could agree or disagree with were (translated from English into German) were:

A: The ant will get the same radiation every moment. It is like a stream of water from a hose—it is always the same flow.

B: One cannot predict when an atom will send out radiation. Therefore, we also cannot guess how much radiation the ant receives.

C: The ant receives approximately the same amount of radiation in the first five minutes as in the last five minutes.

D: The ant receives a different amount of radiation every second. In some seconds, the ant might receive absolutely no radiation at all!

Unfortunately, casual examination of the free response data made it clear that ANT was not yet ready to be made into a multiple-choice form. In particular, we saw a need to specify what is meant by "weak". Many students had written that there would be no change whether the stone was weakly or strongly radioactive in terms of timing of emitted radiation. The difference would just be that the radiation itself would be more or less strong in some way. With the interpretation of "weak" meaning that the radiation energy released from a single fission event is less, these responses would be correct. What we wanted to convey by "weak" is that radiation is sent out less frequently. We hence decided to change our wording to talk about the stone containing I-131 (previously we had not specified this), which is radioactive. Instead of a "weak" stone in the first situation, we instead wrote that the stone contains only a small amount of I-131. Instead of a "strong" stone in the second situation, the stone now contained a huge amount of I-131. With this change, the argument becomes clearer that, when students say that there is "no change" in terms of which statements they (dis)agree with, that this is indication of a level confusion. Since we were making such a large change, we decided to keep ANT in a free response format to collect additional data in 2020 and to conduct a second round of coding before generating the MC version of the prompt.

Before the second round of free response data in 2020, we came to the consensus that additional changes should be made as well.

The four statements used in the 2020 free response version of ANT that resulted from these discussions are shown in Figure 1 below. ANT was then administered online to N = 37 respondents who had already learned about half-life.

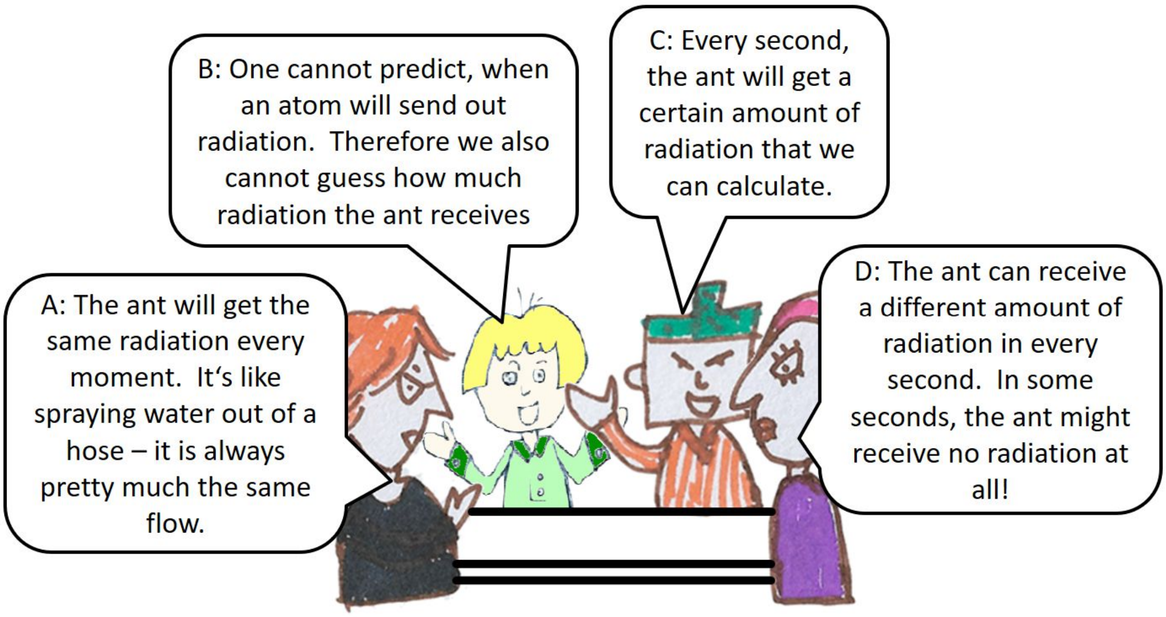

Figure 1. ANT involves the discussion of four students regarding the radiation received by an ant standing beside a radioactive stone for 10 minutes, first where the stone contains "a very small" amount of radioactive substance (ANT: TRACE) and then when the stone contains "a huge amount" (ANT: HUGE).

To code the 2019 and 2020 free response datasets, 6 and 4 responses (~10%) were chosen from each dataset, respectively, to discuss coding labels. Our final set of labels and their frequencies in both the 2019 and 2020 free response data sets are below in Table 1.

Despite clarifying what we had originally meant by "weakly radioactive" and "strongly radioactive" with the rewording of the prompt, students continued to respond that their answers would not change (AHA9 in Table 1), indicating that we had been correct about this problem being useful for indicating a level confusion. Furthermore, the change we made to statement C was not only more aligned theoretically with our intended survey construct, but more students responded to it (specifically, many students agreed with the statement in the context of ANT: TRACE, as can be seen in ATA3 in Table 1). As such, we decided that we had sufficient free response data to proceed in making a multiple-choice version of the prompt. We did this by turning the coding labels into multiple choice options.

RESULTS

Our research question is "to what extent does student confidence correlate with consistency across the isomorphic prompts?" To address this research question, we administered FAROS (including the MC form of ANT) as an online survey in between Nov. 9th 2020 and March 24th 2021. After data cleaning (removing, for example, students who obviously were not reading the survey prompts or who did not complete the survey), N = 234 responses remained. To code ANT for a level confusion ("LC"), we considered several possibilities, both from Tier 1 responses (discussed above) and Tier 2 responses. The following selections could indicate a level confusion:

- Agreeing with Student A in the context of ANT: TRACE (especially if the respondent also agreed with Student A in the context of ANT: HUGE)
- Disagreeing with Student B in the context of ANT: TRACE (especially if the respondent also disagreed with Student B in the context of ANT: HUGE)
- Agreeing with Student B in the context of ANT: HUGE (especially if the respondent also agreed with Student B in the context of ANT: TRACE)
- Disagreeing with Student D in the context of ANT: TRACE (especially if the respondent also disagreed with Student D in the context of ANT: HUGE)
- Agreeing with the following Tier 2 response in the context of ANT: TRACE: "How much and when an atom sends out radiation can be calculated, otherwise the concept of half-life would not make sense"
- Agreeing with the following Tier 2 response in the context of ANT: HUGE: "How much and when the stone sends out radiation is unpredictable"
- Selecting as Tier 1 response on ANT: HUGE "My answers would not change" or "Nothing changes except that the stone now sends radiation out longer".

Almost all respondents satisfied at least one of these conditions. We considered that the clearest indicator for a level confusion, however, was the last criterion, which we had used in our previous work (Hull et al., 2020). With this criterion alone, 196 of the N = 234

Table 1. Agreed upon codes for free response data from ANT in 2019 (where ANT: TRACE did not actually specify that only a trace amount of I-131 was present; rather it just described the rock as being weakly radioactive. Likewise for ANT: HUGE) and in 2020. "N of C" represents the total number of codes assigned for that label and "% of P" indicates percentage of respondents who received the label.

	Free Resp. 2019 (N = 55)				Free Resp. 2020 (N = 37)		
ANT:TRACE, Code 1 (Answer)							
	N of C	% of C	% of P		N of C	% of C	% of P
ATA1: Agree with A	23	21	42		11	17	30
ATA2: Agree with B	7	7	13		3	5	8
ATA3: Agree with C	15	14	27		19	29	51
ATA4: Agree with D	19	18	35		7	11	19
ATA5: Disagree with A	4	4	7		7	11	19
ATA6: Disagree with B	14	13	25		8	12	22
ATA7: Disagree with C	8	7	15		2	3	5
ATA8: Disagree with D	15	14	27		5	8	14

NONE	2	2	4		4	6	11
ANT:TRACE, Code 2 (Reason)							
ATR1: Stone keeps radioactivity level	6	10	11		5	13	14
ATR2: Radioactivity decreases with time	3	5	5		1	3	3
ATR3: Always sends radiation	4	7	7		1	3	3
ATR4: Level confusion	7	12	13		3	8	8
ATR5: Unpredictable	6	10	11		1	3	3
ATR6: Can calculate	0	0	0		2	5	5
OTHER	6	10	11		4	10	11
NONE	28	47	51		22	56	59
ANT:HUGE, Code 1 (Answer)							
AHA1: Agree with A	5	9	9		2	5	5
AHA2: Agree with B	1	2	2		0	0	0
AHA3: Agree with C	2	4	4		1	3	3
AHA4: Agree with D	2	4	4		0	0	0
AHA5: Disagree with A	0	0	0		0	0	0
AHA6: Disagree with B	0	0	0		0	0	0
AHA7: Disagree with C	0	0	0		0	0	0
AHA8: Disagree with D	0	0	0		0	0	0
AHA9: No change	39	71	71		26	68	70
AHA10: Radiation lasts longer	1	2	2		0	0	0
NONE	5	9	9		9	24	24
ANT:HUGE, Code 2 (Reason)							
AHR1: Stone keeps radioactivity level	2	4	4		1	3	3
AHR2: Radioactivity decreases with time	0	0	0		2	5	5
AHR3: Always sends radiation	1	2	2		0	0	0
AHR4: Level confusion	0	0	0		1	3	3
AHR5: Unpredictable	0	0	0		0	0	0
AHR6: Can calculate	2	4	4		0	0	0
AHR7: Probability gets higher	2	4	4		2	5	5
OTHER	1	2	2		0	0	0
NONE	48	86	87		31	84	84

respondents were coded as having a level confusion. To be consistent with our previous work, we hence used only the last criterion (the strongest one).

On CAGE, if, on Tier 2, the respondent selected “the atom transforms continuously” AND/OR “after the half-life, half of the atom has transformed” AND/OR “the atom transforms on the day of the half-life”, then the respondent was coded as LC. On MvO: ONE, respondents received an LC code if they selected “Half an atom” as their Tier 1 response for 8 days (one half-life) AND/OR selected “After the half-life, half of an atom will have transformed” as a Tier 2 response. Furthermore, we added a final possibility for the LC code informed by an additional survey validation interview (SVI#8). Specifically, SVI#8 selected “1, 0, 0” as Tier 1 responses with the justification that “one cannot have half an atom.” The interviewee explained that you would normally have half of your sample gone after one half-life, but since you cannot have half of an atom, the single atom must be all gone. Since one atom has transformed, the interviewee selected “1”. At the point of the second half-life, there would be none left to transform, and so the interviewee selected “0”. When the instructions were read slowly to the respondent, SVI#8 changed the first-tier answers to “0, 0, 0”. The difficulty seems to have been that the student interpreted the prompt at first to mean “how many atoms transform in between

0 and 8 days", "in between 8 and 16 days", and "in between 16 and 24 days."[1] Hence, respondents who responded to Tier 1 on MvO: MANY with "50, 25, 12.5" AND on answer tier for MvO: ONE with either "1, 0, 0" OR "0, 0, 0" AND, on the reason tier of MvO: ONE, selected "One cannot have half an atom" were also coded as LC. We coded a respondent as consistently indicating a level confusion ("Level Confusion Consistent", or LCC) if, on each of the three isomorphic prompts, the respondent received an LC code.

We are interested if the dichotomous variable (LCC = 0 or 1) depends upon confidence. We create the hypothesis H1: "Students with more confidence are more likely to consistently indicate a level confusion on the isomorphic prompts in comparison to less confident students" and corresponding null hypothesis H0: "The likelihood of being consistent will not depend upon confidence".

The confidence rating items are on a 5-point Likert scale labeled at the endpoints with "1. Not at all" and "5. Very", but as is frequently done with Likert scale data in physics education research, we collapsed this into three levels. The results from all three prompts are in Table 2. Out of N = 234 respondents, 102 respondents consistently received an LC code on all three isomorphic prompts. We coded these students as "level confusion consistent" (LCC = 1). Focusing on ANT, we see that the odds for a respondent with an LC code being consistent (LCC = 1: LCC = 0) are 51:47 (1.09) for unconfident students, 35:25 (1.4) for neutral students, and 16:22 (0.73) for confident students. That is, the odds first increase and then decrease as confidence increases. We will now investigate whether or not these changes are statistically significant.

We avoided treating the Likert scale as interval data (where the points on the scale would be considered uniformly spaced, making it possible to calculate average scores). We did this because there is controversy in the literature about whether it is appropriate to treat Likert-scale data as interval data (*e.g.,* Jamieson, 2004; Norman, 2010). Instead, we treated the Likert scale as ordinal data, where the options are discrete categories. For these conditions, logistic

Table 2. Confidence level of students who were assigned a level confusion ("LC") code. The confidence ratings in the left-most columns were from ANT: HUGE, in the middle columns from CAGE, and from the right-most columns from MvO:ONE.

	"LC" on ANT				"LC" on CAGE				"LC" on MvO		
Confidence	LCC = 1	LCC = 0	Total		LCC = 1	LCC = 0	Total		LCC = 1	LCC = 0	Total
1 (unconfident)	51	47	98		55	35	90		56	24	80
2 (neutral)	35	25	60		24	8	32		23	13	36
3 (confident)	16	22	38		23	9	32		23	4	27
Total	102	94	196		102	52	154		102	41	143

regression is an appropriate choice, with the predictor, confidence, being the X variable. The increase in odds from unconfident to neutral respondents on ANT (indicated by the positive

[1] It is possible that, had we used less accurate language of "how many atoms remain" that this difficulty would not have occurred. Although it does not change the fact that the response is incorrect, it does have an effect on our coding scheme.

sign of β_1 in Table 3) is what we would expect if more confidence predicts a greater likelihood to answer consistently. However, the decrease in odds from unconfident to confident students is opposite of what we would expect (indicated by the negative sign of β_2 in Table 3). As shown in Table 3, neither of these changes in odds are statistically significant. The estimates (log odds ratios) and associated p-values were calculated using the **glm** command in R Studio with the "family" set to "binomial" (since the dependent variable is dichotomous).

Table 3. Estimated coefficients and associated p-values for the logistic regression model for consistently demonstrating a level confusion as predicted by confidence on ANT: HUGE, CAGE, and MvO:ONE. No *p*-values are significant (<0.05).

Estimates	ANT	CAGE	MvO
β_1	0.255	0.647	-0.277
	0.441	0.162	0.514
β_2	-0.400	0.486	0.902
	0.300	0.279	0.129
$^{***}p < 0.001$	$^{**}p < 0.01$	$^{*}p < 0.05$	

Considering the p-values, we find that all results are statistically insignificant. Therefore, we do *not* reject the null hypothesis H0: "the likelihood of being consistent will not depend upon confidence".

CONCLUSION

In this paper, we have presented findings from the Fission as a Random Occurrence Survey (FAROS). FAROS consists of three isomorphic prompts, which can all be answered appropriately with the same underlying physics principle that fission is considered to take place at random. All three prompts also allow students to respond in a way indicating the naïve idea that what is true for the radioactive sample is true also for the individual nucleus. Our results are consistent with what we and other education researchers investigating student understanding of radioactivity have reported elsewhere. In particular, many students think that after one half-life, since half of the radioactive sample has fissioned, it follows that half of each atom in that sample has fissioned [21,23,25]. A total of N = 234 responses from 17–18-year-olds survived our data cleaning process (students who said they had not yet learned about half-life, for example, were removed). On one of the three isomorphic prompts (MvO:ONE), 114 (49%) said that, after a half-life had passed, half an atom would have not yet transformed. Across all three isomorphic prompts, 224 (96%) showed evidence of a level confusion on at least one prompt. Clearly, the idea of "what is true for the radioactive sample is true for an individual unstable nucleus" is salient for many students. However, only 102 respondents (44%) exhibited a level confusion consistently across all three prompts. Our first finding, then, is that most students who show evidence of a level confusion do not do so consistently.

This paper has expanded on our previous findings by considering whether or not stability of reasoning can be predicted by confidence. Lemmer (2013) argued that expressing confidence can "confirm the existence of stable existing [knowledge] structures." In the case of our study, a "stable existing structure" would correspond to stably modeling the decay of a single unstable nucleus in terms of half-life (for example, that it is half-gone after one half-life). To the best of our knowledge, however, until our work, this argument had not been tested in the sense of seeing if students who are more confident in an incorrect answer are actually more likely to have a "stable existing structure" or not. Although Lemmer *et al.* found that students with robust cognitive structures expressed confidence in those answers, they did not compare with students of lower confidence. Whereas they wrote that the majority of students "were sure or very sure that they responded correctly… for all the questions," that was not the case in our study. We found a distribution in confidence, with most students being unconfident. This allowed us to see how patterns change as confidence increases. We have found that, in the case of the three isomorphic prompts that we used, that increased confidence in an incorrect answer does not, generally, indicate less context-dependency of naïve ideas.

The answer to our research question "to what extent does student confidence correlate with consistency across the isomorphic prompts?" is "there is no statistically significant correlation". Although our study was specific to three prompts regarding student understanding of half-life and fission as a random occurrence, we suspect our findings are relevant to researchers investigating student naïve ideas in other fields as well. Our findings suggest that, although isomorphic prompts require additional testing time, asking for confidence ratings is not an effective substitute, despite saving time.

Limitations

Although we have conducted a total of 9 survey validation interviews throughout the creation process of FAROS, we suspect that there is future room for improvement in terms of survey design and in terms of our interpretation of student responses.

In administrating FAROS, we have deliberately avoided asking demographic questions to maximize anonymity of survey respondents. Based upon our findings that increased confidence does not imply greater stability of reasoning, we are left with only speculation regarding what confidence on these prompts *does* imply. Leppavirta [41] found that female students tend to be less confident about their abilities in science. Since we have no demographic information, we cannot say whether the less confident students in our study tended to be female. Interest in physical science in general and radioactivity in particular is an additional factor that we speculate may influence confidence. Future studies should include demographic and interest-related questions to investigate why some students are more confident in their responses to FAROS.

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RESPECTING FLUIDITY OF STUDENT IDEAS: STUDENT-CENTERED LESSONS ABOUT RADIOACTIVITY

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Interview and survey data collected by the first author in the last three years have indicated that student naïve ideas about radioactivity can shift fluidly from one context to another. We encourage instructors to consider this context-sensitivity when helping students learn about radioactivity. In this paper, we will assess an instructional unit on radioactivity, Yamamoto's "The Radiation Around Us" (abbreviated "TRAU"), to investigate the extent to which this curriculum accounts for the fluidity of student reasoning. TRAU is an instructional unit in Hypothesis–Experiment Class (HEC), the educational approach proposed by Itakura. HEC is built upon the expectation that individual students may simultaneously have multiple ways of thinking about a given situation, and several measures are put in place to support students in drawing on these various views. Via textbook analysis and in-class observations of instructor and students, we will show that TRAU is designed to create a learning environment where simultaneous ideas of students are both respected and encouraged, enabling fluidity of reasoning. We will also investigate, via in-class observations, student interviews, and surveys, the extent to which this intention to foster fluidity in student reasoning actually has an effect on students.

Keywords: Nature of Science, Curriculum, Learning Theory, HEC

INTRODUCTION

Ionizing radiation is utilized around the world for energy, industrial, and medical purposes. However, many students are unaware that radioactive nuclei are ubiquitous, and consider radioactivity to be unnatural and/or dangerous (*e.g.,* Alsop, 2001; Boyes & Stanisstreet, 1994; Eijkelhof, Klaassen, Lijnse, & Scholte, 1990; Henriksen & Jorde, 2001; Neumann & Hopf, 2012; Rego & Peralta, 2006). The results of recent research conducted by the first author suggest that student ideas about radioactive decay need not be rigid and robust cognitive structures; rather student reasoning can change fluidly depending on the context of which question is being asked (Hull & Hopf, 2020; Hull, Jansky, & Hopf, n.d.).

We argue that if student reasoning about radioactivity is indeed fluid and context-dependent, then instruction which expects such fluidity of student ideas is desired. In this paper, we will present results from the first implementation of an English translation of Miyuki Yamamoto's curriculum "The Radiation Around Us" (Yamamoto, 2011), which we will abbreviate "TRAU" in this paper.

TRAU is an instructional unit in Hypothesis–Experiment Class (HEC), the educational approach proposed by Dr. Kiyonobu Itakura (1930-2018) in 1963 (Itakura, 2019). Since that time, a number of HEC curricular materials have been developed to teach students a wide range of topics in both natural and social sciences, and HEC is well-known by teachers throughout Japan. The "Itakura method", as some people call it, was originally introduced to the Western world in 1977 by Inagaki and Hatano, who discussed it as a practical example of "how individual cognitive mechanisms can combine with sociocultural constraints to promote instruction induced conceptual change" (Vosniadou, 2007, p. 52). Initially the term HEI (Hypothesis-Experiment-Instruction) was used, but now HEC is the official name given by Association for Studies in Hypothesis–Experiment Class. The new name matches better with the Hypothesis–Experiment concept because it is crafted "as a group-based 'class' for science education in school and not as a 'program' for an individual learning science." (Itakura, 1966, 2019 p. 18).

The curricular materials of HEC are comprised primarily of a "Classbook", which students receive from their instructor page by page. These pages contain multiple-choice questions pertaining to an experiment. Students discuss in the whole-class setting after making a personal prediction. Once the discussion has come to a close, the actual experiment is conducted or the next page which contains the results of the experiment is distributed. Note that HEC does not, generally, emphasize the importance of students actually carrying out an experiment themselves; rather, "the crux of an experiment is holding some specific expectation regarding an object or phenomenon and checking that expectation against reality." (Itakura, 2019, p48). After the results of the experiment have been observed, the next question is revealed. It has been argued by HEC practitioners that the Classbook is an indispensable component of HEC. Teachers and curriculum developers inspired by HEC who aim for conceptual change via student-driven ideas but do *not* use Classbooks should not claim that they are teaching in the HEC style. This is because, as Saburo Takeuchi says, HEC Classbooks "contain problems carefully ordered to guide the understanding of scientific concepts underlying each problem set" (Itakura, 2019, viii).

Official Classbooks are recognized as achieving the following three goals: (Itakura, 2019, p.19): "Goal 1: Make sure each and every student gains the ability to use the central theory or concept"; "Goal 2: Structure the class so that most students report that they like both science and these science classes"; "Goal 3: … any teacher sufficiently passionate about education… will be able to" achieve the above goals. Behind the Classbooks that produce the above positive results are meticulous preparations, a large number of trial classes, and revisions in order to satisfy the above goals.

In 1981, Itakura expanded his definition of HEC to accommodate new Classbooks that were developed (Itakura, 1982, 1988). Whereas earlier Classbooks had featured a series of experiments, some newer Classbooks included no experiments at all. In the Classbook "The Road to Space", for example, students should develop an image of the relative sizes of the Earth, Moon, and Sun and the distances between them. These Classbooks also aimed to have students "not confuse fundamental facts with exceptional facts" (Itakura, 2011, p.96). In the case of the "The Road to Space", this includes recognizing that the Earth is more spherical than ellipsoidal. Most Classbook users (ourselves included) subsume such newer Classbooks in the phrase "HEC Classbooks"; however, when one desires to distinguish the Classbook styles, many refer to this latter style of Classbook as an "Image–Verification Class" (IVC) Classbook. The most successful IVC Classbook is "If You Could See an Atom", which captures the fundamental facts about atoms in the air around us. It's success has been vividly documented in case studies (*e.g.*, Ito, 1998; Nakamura, 2022). TRAU, which is the focus of this paper, is also an IVC Classbook. (FOOTNOTE: Actually, in light of the new style of Classbook, Itakura described Hypothesis–Experiment Class as a subgroup of the more general Image-Verification Class (IVC) (Itakura, 2011, p.95). Practitioners, however, generally do just the opposite, considering IVC as a subgroup of HEC.)

To focus our presentation, we frame our work in terms of two research questions: 1) To what extent does TRAU account for the fluidity of student reasoning? and 2) How do students perceive TRAU? In particular, do the features identified in answering research question 1 have any noticeable effect on students?

To address these research questions, we will begin by elaborating on what we mean by "account for fluidity of student reasoning". Scherr (2007) compares and contrasts the "Misconceptions" and the "Pieces" models of student ideas and what features are characteristic of corresponding curricula. Whereas the former model (often only tacitly!) attributes a stable, rigid, and context-independent character to student ideas, the latter model explicitly treats student ideas as being potentially fluctuating, pliable, and context-dependent. The "elicit, confront, resolve" model utilized, for example, in the University of Washington's Tutorials in Introductory Physics (McDermott, 1991; McDermott & Shaffer, 2002) is a well-known instructional agenda consistent with the "Misconceptions" model. In contrast, curricula that expect students to have fluid reasoning do not elicit and confront "misconceptions", because it does not assume that students' naïve ideas are intact knowledge structures in the first place. Arguably the most well-known framework utilizing a "Pieces" model is that of "phenomenological primitives", or "p-prims", established by diSessa (diSessa, 1993, 2009). DiSessa writes that instruction which assumes students to have myriad ways of thinking about a given situation should "Attend to [student] ideas and help them build on the best of them" (p. 41 of diSessa, 2009). An example of what this can look like in practice is offered by Burde and Wilhelm's electricity curriculum which uses the electron gas model to teach voltage before current by drawing upon students' everyday ideas about pressure differences (Burde & Wilhelm, 2017). The approach does not focus on eliciting incorrect student ideas so that they can be confronted and rejected, because the curriculum assumes that students have multiple ways of thinking about electrical circuits that they can fluidly switch to.

METHODOLOGY

In the fall semester of 2019, we taught TRAU over the course of one week to a class of 18 high school students at a private school in Japan. These classes were video recorded and field notes were taken by the authors. These observations together with textbook analysis of both TRAU itself and of seminal writings about HEC by its founder Itakura (Itakura, 2019) were used to answer the first research question. In-class observations were also used to address the second research question regarding the effect of TRAU on students. To go into more depth regarding this question, three of the 18 students were interviewed and these interviews were video recorded and analyzed by the research group.

To extend beyond the 18 high school students, two survey items were created and administered at the end of the semester to 50 nonscience majors at Kyoto University finishing a course of introductory physics. Although this course did not use TRAU, it did utilize HEC for more than

75% of the content. Thus, although this survey data does not gain us deeper insight into TRAU specifically, it does help us see student views about HEC in general. The first item was:

In a previous year, I received the following student comment about this class:

"... there were times when we were making predictions that I didn't have any physics knowledge about the problem, so all I could do was guess without a justification, but I liked the atmosphere of an answer like that being acceptable. It is more enjoyable to be able to think freely and be able to base your answers on a gut feeling, than to feel the duty of having to come up with a reason."

What is your feeling about this? Looking back on this half year…

Students were asked to respond with a 5 for "I thought so very much", 1 for "It absolutely was not enjoyable, nor was it fun", and 3 for "Neither".

An additional survey prompt was also created and given to these students in this same survey:

We have devoted a lot of time in this class to discussing the reasons behind student predictions and everybody's thoughts about those reasons, regardless of whether they were physically correct or not. Regarding discussion of the ideas that were not physically correct, looking back on the semester,

Students were asked to respond with a 5 for "I think that was also very helpful", 1 being "I think that was a total waste of time", and 3 being "Neither".

RESULTS

This paper concerns two research questions: 1) "To what extent does TRAU account for the fluidity of student reasoning?" and 2) "How do students perceive TRAU? In particular, do the features identified in answering research question 1 have any noticeable effect on students?" We will present results relating to each of these two questions in turn.

TRAU respects and encourages fluidity of student reasoning

We read the TRAU instructional unit with painstaking care to ensure an English translation as true in spirit to the original as possible. Nowhere does TRAU use the "elicit, confront, resolve" approach characteristic of the "Misconceptions" model. Like Burde and Wilhelm's electron gas curriculum, TRAU does not reject student ideas. This is consistent with "Hypothesis–Experiment Class" (HEC) learning units in general (see Introduction, above). HEC is founded in the assumption that an individual student may simultaneously have multiple ways of thinking about a given situation, as reflected in Itakura's quote "Even students with minimal knowledge of the topic at hand will nonetheless probably have, at least, some naïve ideas regarding the topic. These may not be very logical and may even be an **amorphous understanding with fluid interpretations**." [emphasis ours] (p. 11 of Itakura, 2019)

In our observations of students engaging with TRAU, two student ideas appeared consistently throughout the questions of the Classbook, that "some things emit more radiation than others" and that "radiation is absorbed or blocked". We can consider these ideas to be "primitive" in the sense that they require no explanation themselves (they are seen by students to just be the way the world is), but they can be used to explain a wide range of situations themselves. The idea of radiation being "blocked" for example, may come from everyday student experience with things that block other things, like a parent blocking a child from running out of the store into the street. One of the p-prims described by diSessa (diSessa, 1993) is "Interference" and it is used to describe this kind of situation, in which "influences that do not directly aid or conflict may still interfere." Similarly, on two of the later questions, the idea that "radiation decreases farther from a source" was voiced by students. This idea may stem from Ohm's P-Prim, that increased resistance leads to less result.

As expected by the "Pieces" model, the ideas that students raised during the questions of the Classbook were not rigidly held. Rather, individual students switched back and forth from one argument to another from one question to the next, and even within a given question. As stated above, student understanding is perceived by HEC to be "amorphous with fluid interpretations", and several measures are put in place to support students in drawing on and considering these various interpretations. For example, during the discussion, in accordance with the teacher guide to TRAU created by the last author, we invited students to share "any other ideas that have not been heard yet? Maybe you chose A but you were kind of thinking B at first? What was attractive about B in the beginning?" Similarly, an explicit step of the discussion is dedicated to giving space to students who have changed their mind, such that they can share what made sense to them about the other perspective. Just as important as what the teacher is instructed to do during the discussion is what the teacher is instructed NOT to do. The teacher should not correct the errors in the reasoning of the students, but rather leave them as they are, waiting for students to accept the new information through a succession of experimental results.

It is a goal of HEC to have students consider a given problem from a variety of perspectives and to bring in various bits of knowledge in the debate. Itakura explicitly writes that such an occurrence should be considered commonplace: "One of the predictions proves true, but more than one interpretation or reason is possible." (p. 31 of Itakura, 2019) Itakura is also quite explicit in writing against teachers prematurely settling unresolved issues for students: "Despite being presented with a new experimental fact, the student will often spin out a newer interpretation based on their everyday understanding just to incorporate the new fact. And yet the teacher and textbook pay no heed, simply concluding, 'So we can see that these facts lead to such and such.' In cases such as this, the teacher has **brutally forced a theory on the student**" [emphasis ours] (p. 11 of Itakura, 2019).

It is for this reason that minimal explanation, if any, is given between experiments in a Classbook. Instead, the questions are carefully arranged such that students gradually come to a canonical understanding of the content material in a way that feels organic to them and that they are personally convinced of. Question 6 of "The Radiation Around Us", for example, asks students how they would expect the gamma radiation level to change as one climbs Tokyo Tower to a height of 140 m. We observed a wide range of student ideas during this question, for example that cosmic rays increase with height, that cosmic rays are completely blocked by the atmosphere, that concrete of the tower emits radiation, and that the humidity of the air between the ground and the observation deck absorbs radiation. However, after seeing the result of the experiment (that the radiation decreases), students move right on to Question 7 without additional narrative. Teachers unfamiliar with HEC may be tempted to add discussion here about ideas that are incorrect and/or would have led to the incorrect prediction. Such additions to the original are discouraged, however, as they are seen as rejecting student ideas and "brutally forcing a theory on the student".

In consideration of what we have presented so far, we turn our attention to directly answering our first research question, "To what extent does TRAU account for the fluidity of student reasoning?" TRAU, like HEC in general, respects the fluidity of student reasoning, as seen clearly in Itakura's stance against "brutally forcing a theory on the student". All ideas are respected, in that incorrect ideas are never rejected by the teacher, but by the students themselves in interpreting the results of scientific experiments. What's more, TRAU encourages fluidity of student reasoning in the design of the Classbook and in the way that instructors are told to facilitate the lesson. By providing minimal information between questions and by encouraging students to share ideas that they considered, even if they were not the final idea, they used to make a prediction, the teaching method preserves student ideas. At the same time, the questions of the Classbook are carefully chosen and arranged such that potentially productive student ideas, for example about distancing oneself from a radioactive source, are cued. As students see the results of successive experiments, they develop an understanding built upon these ideas. As such, at least in theory, TRAU serves as an example of diSessa's call to "Attend to [student] ideas and help them build on the best of them" (pg. 41 of diSessa, 2009).

Students recognize that TRAU respects and encourages diverse ideas

Now that we have answered our first research question, we turn our attention to our second research question: "How do students perceive TRAU?" In particular, do students feel that their diverse ideas are being respected and encouraged? Or is it just philosophy of the curriculum developers that has no actual influence?

One of the three students interviewed, "Ai-kun", expressed a preference for the HEC style of learning in comparison to "traditional" science instruction he had previously experienced, characterized by the teacher just reading out of a book and the students memorizing by rote. In particular, Ai-kun said that the experiments are enjoyable: "I think that the process of repeating an experiment to check things other people consider to be true can make a person enjoy science." Note that Ai-kun is saying that experiments are enjoyable not because it is fun to do things with one's hands and move around. Rather, Ai-kun enjoys experiments because it is an opportunity to see which ideas are right. At the same time, however, as revealed in the following quote, it is not the case that Ai-kun only values the one "correct" answer. Rather, Ai-kun finds it important for students to have multiple ways of thinking at a given time, as it is more true to the actual nature of science: "I don't think we can assume that answers that science gives us are definitely correct... They can be disproved by new experimental methods, as has already happened in history. [Awareness of that] is necessary for science to develop further. But … many people just believe that the knowledge of the textbook is correct." Ai-kun also discussed how having multiple ways of thinking at a given time is important because it encourages a spirit of inquiry in people: "By our recognizing... that we are not necessarily right, our inquiring mind towards science increases, I think. [That recognition] nurtures the inquisitive mind, that is, the heart to conduct more scientific research."

In contrast, Ai-kun resists science instruction that forces knowledge on students:

But, … my view, is: if you all, being human, can't perfectly understand the world, how, then, can you tell me that what you are claiming is 100% true? … Even if someone tells me "Believe this answer", I think to myself… "why should I have to blindly accept that this human perception of the world is correct?" Because science is not the same as brainwashing, even if people order me to believe, I am not going to do so.

Similar to Ai-kun, "Glen", an additional interviewee, contrasted HEC with classes that emphasize memorization for material to be recalled on an exam. Glen said

(HEC) asked for the opinions and exchanged opinions, did debates based on the opinions … I thought that was pretty nice because … it helps you see other points of view that you didn't see … I try to look at… problems, from different places to see if there is any other better way to solve the problem or if there is something wrong with my conclusions based on what I said earlier … when my friends have a fight … and then if they ask me to help … I would get as much information as possible so that I don't make a wrong conclusion.… you want to see as much different points as possible because sometimes you would ignore a point, but from some other perspective … that would be a really important point …

When asked, Glen was able to elaborate and give an example of "ignoring an important point":

When it was about the tower, I made a prediction that it would be weaker… some people said it was stronger because of things like cosmic radiation… there is concrete maybe on the observation which is affecting the outcome but … the person is close to the observatory room, but actually not: they were in the middle between the base and the observatory room…

In summary, both Ai-kun and Glen were aware that multiple views were present during the lesson, and they saw this as a positive feature. Although they are aware that some of the ideas being voiced (including their own) were incorrect, they did not discuss a need to have these wrong ideas elicited and confronted. Rather, they reported appreciating the environment created by HEC, an environment in which their ideas could shift fluidly from context to context in response to classroom discussion and experimental results.

The students at this high school, perhaps Ai-kun in particular, are exceptional in many regards and, as such, should not be considered to represent the typical student learning in a HEC classroom. However, the interviews serve as existence proof that the HEC philosophy of "allowing experimental results to guide students as they navigate together between myriad concurrent ideas" can be noticed and appreciated by students taking HEC classes.

Although not specific to TRAU, there is additional evidence to suggest that students notice that HEC respects and encourages diverse ideas. Let us now turn our attention to the results of the two survey questions described above in the Methods section. Out of 50 students, 31 students completed the survey. In response to the first survey question, 4 of these 31 students selected "3". The remaining 27 selected either "4" or "5".

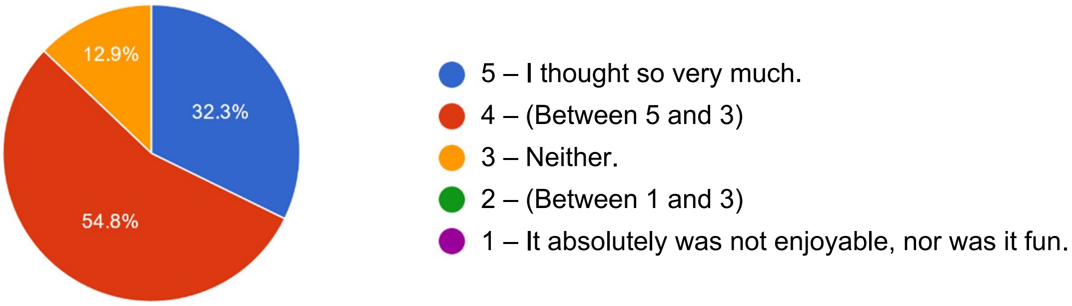

Figure 1. Responses to the first survey prompt: "…It is more enjoyable to … be able to base your answers on a gut feeling, than to feel the duty of having to come up with a reason."

Students were also asked to explain, and 25 did so. Here some responses from the students who selected "5. I thought so very much":

- …our statements were not suppressed by the environment… I think it is important in the academic world.
- It was considered important to think freely without the pressure of having to answer correctly. I felt that this was the thing that our university had to inherit, in keeping with its liberal culture.
- …It was very nicely organic…
- Not having relevant knowledge and thus having to seek answers using only logical thinking and intuition was an extremely interesting experience that I had not been able to enjoy while preparing for university entrance exams.

On the second item, of the 31 students who completed the survey, 7 responded with "3". The remaining 24 students selected either "4" or "5".

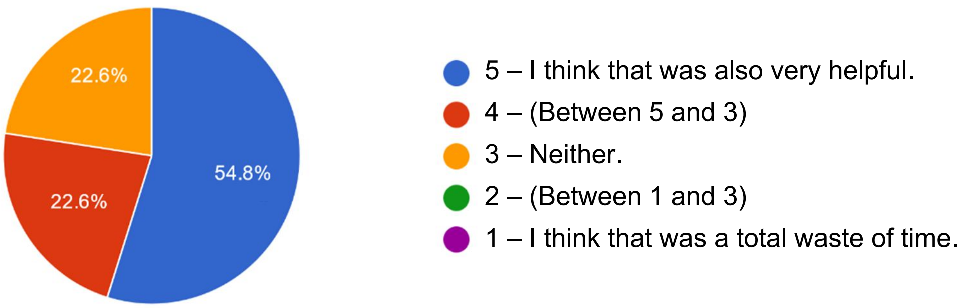

Figure 2. Responses to the second survey prompt: "…discussing the reasons behind student predictions and everybody's thoughts about those reasons…".

Although these statements are not specific to TRAU (and, indeed, these students never saw that Classbook), the sentiment is similar to what was expressed in more detail in the interviews with Ai-kun and Glen. Students of HEC report enjoying the educational approach because their "statements are not suppressed" and they can learn in a "nicely organic" way. They see the value of considering even ideas that turn out to be incorrect. This is consistent with Ai-kun and Glen valuing the fact that HEC provided encouragement for myriad concurrent ideas to coexist in the classroom.

DISCUSSION AND CONCLUSION

Researchers have documented naïve ideas of students pertaining to radioactivity. However, preliminary data exists to suggest that student reasoning about radioactivity is not necessarily rigidly fixed, consisting of "Misconceptions". It may be that these naïve ideas are better modeled as being "Pieces"-like, as they fluidly shift depending on the context at hand. TRAU is an example of a curriculum that takes into account such shifting of student reasoning by respecting and encouraging many simultaneous ideas. In HEC, unless an idea is proven wrong by experiments, the idea must be respected. Teachers both respect and encourage diversity in student ideas (and hence fluidity of student reasoning) by adhering to the Classbooks and the corresponding classroom management principles. There is evidence to suggest that these principles are not just empty philosophy: students can notice and appreciate the freedom to think fluidly as they learn science.

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USING DIFFERENT MEDIATIONS TO FOSTER THE DEVELOPMENT OF RELATIVISTIC ZONE IN CONCEPTUAL PROFILE OF REFERENCE FRAME

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The importance of Modern Physics themes in basic education is recognized. However, as these are complex issues, it is necessary to develop and use resources that can facilitate its learning. In this way, this research relates the use of four different resources that use, each, the four levels of mediation according to the Cognitive Networks Mediation Theory (CNMT) to facilitate the development of the relativistic zone in the conceptual profile of reference frame for understanding the Special Relativity Theory (SRT) by high school students. The results obtained indicate that the use of different mediations, especially hypercultural mediation, can contribute to the construction of mental images and then the development of this conceptual profile zone.

Keywords: Special Relativity; Conceptual Profile; CNMT.

INTRODUCTION

Modern Physics knowledge is of great relevance in the context of basic education. These topics are crucial for a better understanding of the current world since most of the emerging technologies are explained by them. One of the cornerstones of Modern Physics is undoubtfully Einstein's Special Relativity Theory (SRT), through which the emergence of the largely used technology, of the *Global Positioning System* (GPS) was made possible. However, it is a complex theory, which requires a high level of abstraction for its understanding,

Moreover, as relativistic effects are imperceptible in everyday life, students tend to believe that any changes in time intervals or size of objects for different reference frames are related to perception, optical illusions, or measurement failure, believing that relativity is not a real phenomenon (Kim & Kim, 2011). Among the main difficulties presented by students, imagining the relativistic situations seems to be of critical importance (Ünlu Yavas & Kizilcik, 2016) and the acceptance of the consequences of the SRT, such as time dilation and space contraction (Dimitriadi & Halkia, 2012; Velentzas & Halkia, 2013). There is also a difficulty with the exchange of reference frame, which causes difficulties in understanding SRT (Gousopoulos, Kapotis, & Kalkanis, 2015).

Conceptual Profile

These obstacles to learning Special Relativity Theory may be associated with the lack of development of new regions in the conceptual profile. The idea of a conceptual profile brought up by Mortimer (1995) explains why certain misconceptions remain in the student's cognitive structure, even after he/she has learned new scientific concepts. Mortimer defines his idea of conceptual profile as “a model to describe changes in individual thoughts as a result of the teaching process” (Mortimer, 1995, p. 6).

According to Mortimer, the profile of a concept has different regions with increasingly explanatory ranges that carry both epistemological and ontological differences. Therefore, during the teaching-learning process of a concept, new regions of its conceptual profile are developed. It is important that the student learns how to carry over these regions of the profile to use the more suitable definition for each situation.

Since SRT brought deep changes in the nature description, even though the student comprehends correctly Newtonian Physics, it is necessary to develop new regions in the conceptual profile to understand SRT. A crucial concept regarding the theory is of reference frame, therefore, in order to student comprehend it, it is necessary that he/she develops a new region on reference frame's conceptual profile. Ayala Filho and Frezza (2007) constructed a conceptual profile for the concept of 'reference frame' containing three different zones: *the common sense, Newtonian Physics,* and *the relativistic zone*. Therefore, the student must develop a 'relativistic zone' in his/her conceptual profile of reference frame.

Cognitive Networks Mediation Theory

Seeking to stimulate the development of the relativistic zone of the conceptual profile of reference frame, different types of mediations, according to the Cognitive Networks Mediation Theory (CNMT) (Souza, Silva, Silva, Roazzi, & Carrilho, 2012) can be used during the activities with students. According to the theory, the human brain naturally uses external organized resources to complement and expand its natural, biologic, information processing capacity. Moreover, the use of Information and Communication Technologies (ICT) has caused changes in cognitive structure of individuals.

So, the interaction with external resources takes place through essentially four different levels: psychophysical mediation, with the use of physical objects, stimulating sensorimotor schemes; social mediation, through interaction between individuals in a group, it can occur directly or indirectly; cultural mediation, using symbolic schemes, such as language; and *hypercultural* mediation, which occurs using technological tools, as ICT.

In the process of interaction with the external resources, new internal features are developed, called *drivers*. These drivers act as "virtual machines" (Souza & Roazzi, 2009) and translate inputs and outputs between the brain and the external resource. Therefore, the usage of different mediations could stimulate the development of new regions in the conceptual profile, specially the *hypercultural* mediation dealing with SRT, as found in previous studies (Souza & Serrano, 2020).

Research Question

Considering the theoretical background presented here, the present research relied on the use of the four types of mediations when dealing with SRT with third-year high school students from a public school in Brazil aiming to stimulate the development of a relativistic zone in conceptual profile of reference frame. Our research question is "What levels of mediations are more effective to facilitate the development of the relativistic zone of the conceptual profile of reference frame?", we sought not only to investigate whether students were able to develop the relativistic zone of the conceptual profile of reference frame after the activities, but also which mediations were most effective in this process.

METHODOLOGY

The present research was developed with 82 students of the third year of high school from a public school in Brazil, during the curricular classes of Physics. The activities were carried out in the second half of 2019, so before the Covid-19 pandemic, using the four levels of mediation during the SRT approach.

Therefore, a presentation of 63 slides[2] (containing images, videos, and animated gifs), a questionnaire[3] for being used as pre-test and post-test, two mock-ups and two computer simulations[4] were developed.

During the activities with students, social mediation occurred through the interaction with the teacher (as the teacher explained using speech, gestures and the chalkboard both temporal expansion and spatial contraction) and between students during activities; cultural mediation was used by watching videos explaining relativistic models; psychophysical mediation, occurred with the use of models representing the space-time diagrams for relativity by the mock-ups; and, finally, *hypercultural* mediation occurred with the use of computer simulations by the students, representing time expansion and space contraction.

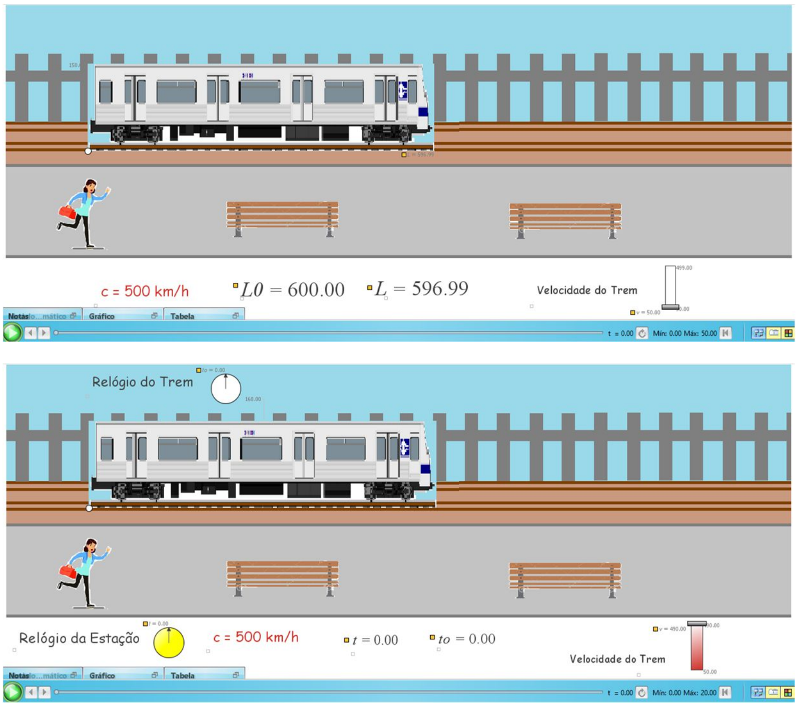

Figure 1. Computer simulations showing space contraction (above) and time dilation (below).

The students answered the pre-test and post-test questionnaires immediately before and after the activities. The researchers analysed all answers to both the pre-test and post-test and selected a subset of 14 students to be interviewed. The interviews were conducted by the teacher-researcher individually through the *Report Aloud* protocol (Trevisan, Serrano, Wolff, & Ramos, 2019), by a constant dialogue between interviewer and interviewee, while the student explains what he/she thought and of what he/she remembered during the activities developed.

All interviews were recorded on video and transcribed for the analysis carried out through Depictive Gestural Analysis (Clement & Stephens, 2010; Monaghan & Clement, 1999), looking for the connection between the depictive gestures performed by students and their mental images, as well as investigating the

[2] Available in; https://drive.google.com/drive/folders/1F1TqAjsVc7Ovj7Vle9YObg4kAIUGmsnr?usp=sharing.
[3] Available in: https://drive.google.com/drive/folders/11gkBQaHKsV2La1QVIZ2w06ALUv16mf7j?usp=sharing.
[4] Available in: https://drive.google.com/drive/folders/1sMg20libFq6urAUtL3e0b1xZdHy-cIB3?usp=sharing.

origin of these images. These gestures can be considered a parallel "speech" that happens while the verbal speech is made, allowing the identification of mental simulations used during the activities.

RESULTS AND DISCUSSION

Among the students interviewed, there are signs of the development of the relativistic zone of the conceptual profile of reference frame in four students: A14, A15, A18 and D23. These students showed a good comprehension of Special Relativity Theory considering the space contraction and time dilation as real phenomena. All four students also showed evidence of similar mental simulations for relativistic situations during the interviews, precisely for situations involving space contraction. The following are excerpts from the interviews where the four students showed evidences which suggest the development of the relativistic zone of the conceptual profile of reference frame after the activities developed.

Regarding the phenomenon of space contraction, there were two questions on tests dealing with the same situation: two trucks, one at rest in relation to the ground and the other getting close to it. The question 1 asked about the measured distance between the trucks when the moving truck has the speed 80 km/h and question 3 when it moves at 0.7c. When talking about these questions, the four students demonstrated to understand that this phenomenon is real, as well as its relationship with the speed of the reference frame. These excerpts are presented below.

Student A14

When explaining the answers to the questions of the test, student A14 states that the distance measured by the reference frame of the moving truck would be "less than 100 m" due to its speed:

> [13:34] A14: [...] I think it would be less than 100 m. Being at a very high speed, I think that here I got a little confused. Yeah, I think I got confused. Now seeing better, I think it is less than 100 m.
>
> E: And when you think about [it] being smaller, what image comes to mind, what do you remember?
>
> A14: Ah, I don't know, I can't imagine a truck at that speed, but I imagine, I don't know, like a [#FOG 14:13] rocket, something like that, it's very fast.

It is important to note that the student treated the difference as real, as she said, "it is less than 100 m" and not that the distance "seems smaller" (like other interviewed students declared). This acceptance suggests the existence of a new region on the conceptual profile of reference frame, which treats the space as a relative physical quantity.

Student A14 also performed the static depictive gesture #FOG when talked about a imagined rocket in this situation. The slides used during activities presented some animated gifs with rockets and ships. Possibly, the rocket remembered by the student is an internal resource, a static mental image, constructed by the interaction with this mediation.

Figure 2. The static gesture #FOG performed by student A14.

This internal resource helped the student to comprehend SRT and, possibly, supported the develop of a relativistic region of her conceptual profile.

Student A15

Similarly, also talking about the questions dealing with space contraction during the interview, student A15 states that "speed can distort the distance", as she remembers an animated gif of a rocket, which was used on slides in class during activities:

[16:11] A15: Yes, because after being seen in class, we saw that speed can distort the distance, then.

E: And when you answered here in the post-test, what did you remember to mark that answer?

A15: I do not remember exactly what it was, but you showed a slide that was distorted, I think. I don't know if it was a rocket, what it was. [...] That, as you moved [#NAV2 16:41], the little thing it distorted itself like that.

As student A15 said, "speed can distort the distance", which suggests that she considered the changes in space as real. This acceptance of these changes indicates the existence of a relativistic region in her conceptual profile of reference frame.

Figure 3. The dynamic gesture #NAV2 performed by student A15.

Moreover, this student performed the dynamic depictive gesture #NAV2 when remembered of a gif used in slides during classes. This gesture is evidence of the construction of an internal resource, a dynamical mental image by the interaction with a hypercultural mediation which helped the student to comprehend the theory.

Student A18

Student A18 also showed evidence of the development of the relativistic zone of conceptual profile. Talking about the questions during interview, he stated that "the higher the speed, the shorter the distance will be", indicating the understanding of the contraction of space as a real phenomenon:

[19:27] A18: [...] That the speed is high, so the higher the speed, the shorter the distance will be.

E: So, in which of the two cases (50 km/h and 0.7c) would be the shortest distance?

A18: In both, I think ... Ah, what would be smaller, in question 3 (0.7c) because it is faster.

E: [...] What if it was a speed of 0.2c, for example?

A18: Then it would be between (questions) 1 and 3, I think.

E: And do you imagine that?

A18: Yes, I imagine [#NAV4 20:09] the path [travelled distance] literally getting smaller you know, as if it were in the gif, but then the path and not the spaceship, right.

This student also presented evidence of a complete understanding when demonstrated to comprehend the gradual relation between the speed and the changes in space saying that for a speed of 0.2c the measured distance "would be between (questions) 1 and 3". This complete understanding and the acceptance of the space contraction indicate the existence of a relativistic region on is conceptual profile.

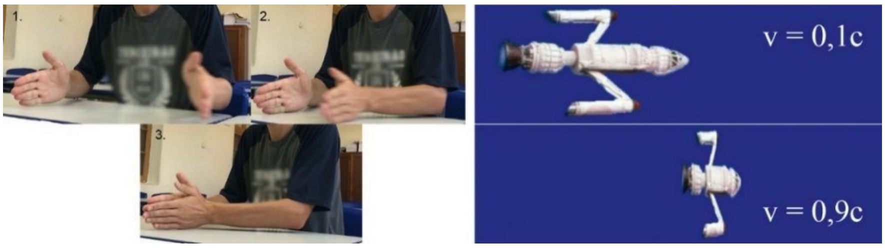

Figure 4. The dynamic gesture #NAV4 performed by student A18.

Moreover, he performed the dynamical depictive gesture #NAV4, remembering the same animated gif used in slides that student A15 also remembered:

> [17:32] A18: So, I remembered the slides. I remember that there was a spaceship and all. What impressed me the most was that the spaceship was [#NAV4 17:50] decreasing in… And I believe that a have thought on it, because so [NAV4 18:14] its size decrease how faster it was. So, the faster it (truck of question) was, the smaller the path would be.

This gesture indicates the existence of an internal resource, a dynamical mental image, developed by the interaction with *hypercultural* mediation which helped him to comprehend the Special Relativity Theory and develop the relativistic zone in his conceptual profile of reference frame.

Student D23

Finally, student D23, also saw a relation between the phenomenon of space contraction with the speed of the reference frame, as well as showed signs of believing that the phenomenon is real, for example, when talking about his answers to the questions:

> [15:24] D23: This one I already, I already agree, as it is at a higher speed [#DIS 15:30], it will arrive, it will contract a little, the length, and it will arrive faster than that he really thinks it's arrived.
>
> E: What if the speed there instead of 0.7c, for example, was 0.9c? Was it going to change anything?
>
> D23: Only the length, right. It was going to be [#DIS 15:50], it was going to be one, less length was going to be like [#DIS 15:54], it was going to increase the length, that is, it was going to increase the ... The distance, the distance was going to decrease, even more than he thought he really is. I don't know if it was clear.

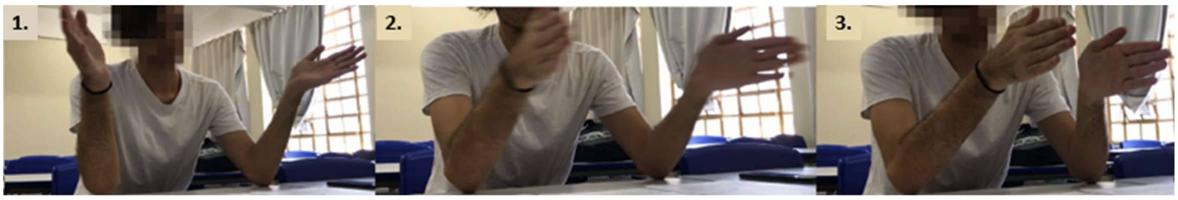

Figure 5. The dynamic gesture #DIS performed by student D23.

Despite of showing some difficulty in expressing himself, the student treated the changes in space as real, saying that length "will contract a little". This suggests he could develop the new relativistic region in his conceptual profile of reference frame.

He also performed a dynamical depictive gesture of approximating both hands, showing he has an internal resource, a dynamical mental image, which helped him to comprehend the situation. Even though, the student didn't mention the mediations used during activities, his gesture is very similar to the gestures performed by the other students.

CONCLUSION

The present research aimed to investigate the development of the relativistic zone in the conceptual profile (Mortimer, 1995) of reference frame of third year high school students dealing with the Special Relativity Theory (STR). Therefore, activities involving STR and contemplating the four levels of mediations according to Cognitive Networks Mediation Theory (Souza et al., 2012) were developed, as well as individual interviews with students.

Of the four students presented in this study, three said they remembered a rocket/spaceship present as an animated gif in one of the slides used in class. Also, the four students performed similar gestures, indicating that they have similar internal resources – mental images – that also seems to have not only from the animated gif as their only source, but also very similar to the computer simulation used to deal with the space contraction.

Answering the research question, the excerpts from the interviews and the gestures performed by students are indications that the use of different mediations, especially *hypercultural* ones, may have facilitated the development of internal resources, mental images, which helped the comprehension of the theory and the construction of a new zone of their conceptual profile of reference frame, apparently the relativistic one.

So, the use of the four mediations according to the CNMT, highlighting *hypercultural* mediation through computer simulations and animated gifs, proved to be a valid resource to facilitate the construction of new zones in the conceptual profile of reference frame, with indications that it is the relativistic zone of the profile. Therefore, we would recommend using the same type of resource with other subjects of Modern Physics, so to trigger the development of the corresponding (new) zone of conceptual profile to the many Modern Physics main concepts.

ACKNOWLEDGEMENTS

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Part 2 / Strand 2

Learning Science: Cognitive, Affective, and Social Aspects

Editors: *Florence Le Hebel & Vanessa Kind*

Part 2. Learning Science: Cognitive, Affective, and Social Aspects

Cognitive, affective, and social dimensions in learning science. Design of in-school and extra school learning environments and study of teaching/learning processes. Representational languages and knowledge organisation. Collaborative construction of knowledge.

HOW CONSTRUCTED EPISTEMIC EMOTIONS FACILITED AN ELEMENTARY STUDENT'S PARTICIPATION PATTERNS IN SMALL-GROUP SCIENCTIFIC MODELING

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In this qualitative case study, we purposively selected a Korean female elementary student, anonymously named Susan, and explored which epistemic emotions she constructed during her participation in small-group scientific modeling of the human respiratory system. With six lessons, students in small groups discussed and formulated arguments in order to construct a scientific model that will make them understand the organ structure, mechanisms, and functions of the human respiratory system. Our data were derived from video-recordings, semi-structured interview guides, and emotion diaries. Our data analysis showed that Susan constructed three epistemic emotions namely: frustration, anxiety, and joy while in the group. While frustration and anxiety were negative epistemic emotions that facilitated her non-participation and passive participation to their small group modeling activity, the positive epistemic emotion of joy facilitated her active participation. She constructed frustration in the Lesson 1 because of combined feeling of self-incompetence, thus, having the fear of being judged by her groupmates. However, this was changed to anxiety in Lesson 2 which was attributed to her lack of confidence to share her scientific knowledge. Nonetheless, she was able to passively participate when she started to feel the sense of belongingness as her groupmates emphatically provided her opportunities to participate. When the third lesson ended, she was reminded by the teacher to just continue interacting as she had great improvement from the first lesson. Thus, she was able to construct the epistemic emotion of joy from Lesson 5 that extended until Lesson 6. With joy, her cognitive and social engagements with the group were filled with fun which changed the group atmosphere.

Keywords: constructed epistemic emotions, epistemic emotions, scientific modeling

INTRODUCTION AND RATIONALE OF THE STUDY

Early constructionists claim that emotions are linked to the relationships between and among interacting individuals which can affect their participation in the social system (McCarthy, 1994; Wallbott & Scherer, 1986; Parkinson, Fischer, & Manstead, 2005). While Boiger and Mesquita (2012) mentioned that there are various contexts in which emotions are constructed, they specifically mentioned the social construction of emotions within three contexts namely, moment-to-moment interactions, developing and ongoing relationships, and sociocultural contexts. The prominence of small-group activities in science classrooms allows these three contexts to exist that trigger students' momentary construction of epistemic emotions. However, despite the growing number of studies on emotions and cognitions, research in this area especially in scientific modeling is scant.

We draw the importance of this study in that epistemic emotions have significant roles in the students' cognitive lives by influencing various aspects in the learning process such as their actions, behaviors, and motivations when they are engaged in knowledge construction (Arango-Muñoz & Michaelian, 2014). From the previous claims on epistemic emotion and learning, we hypothesize that students' participation in scientific modeling depends on the various epistemic emotions they construct that facilitate their performance in the epistemic practice. With gaps in the research on how epistemic emotions can be constructed in specific social situations, we investigated how an inherently passive student would eventually participate while constructing certain epistemic emotions. These epistemic emotions were explored in terms of how they influenced Susan's pattern of participation in scientific modeling by focusing on the following questions:

1. What epistemic emotions were constructed by Susan across the scientific modeling lessons?
2. How was her participation in the small group activities influenced by her constructed epistemic emotions?

METHODS

To investigate our research question, we explored a fifth-grade classroom taught by one of the authors in a public elementary school in one of the cities of Gyeonggi-do Province in South Korea during the 2018-2019 academic year. The teacher has been teaching in this school for 12 years and was using scientific modeling as one of the strategies in science class. Prior to the study, Susan's homeroom teacher conducted observations on her cognitive and social participation in classroom activities for 10 months not only in science classes but also with other subjects. In our initial analysis, Susan was mostly active in other subjects except in science. When we documented their group interactions across the six lessons on scientific modeling of the human respiratory system, we also noted that she constructed three different emotions which facilitated three different patterns of participation when they were accomplishing the required tasks of the activity. These served as the unique characteristics of Susan as our case student.

The scientific modeling of the human respiratory system consisted of six lessons where students were asked to work and interact in small groups. The cognitive tasks in the scientific modeling activity that were performed by students in this study were designed to understand what kinds of epistemic emotions they constructed during the moment-to-moment interactions while they develop and establish on-going relationships with each other. They were then expected to cognitively participate by articulating their claims, grounds, and rebuttals towards their group members' explanations and eventually construct a model for the structure, functions, and mechanisms of the human respiratory system.

Using video-recordings, semi-structured interview guides, emotion diaries, and field notes, we investigated what epistemic emotions Susan constructed while performing the cognitive tasks of the lesson with her groupmates. These were analyzed and interpreted on how they influenced her participation in the group social and cognitive tasks. Analysis was conducted through iterative viewing of the video-recordings paying attention to the facial expressions, gestures, tone of voices, and words she used (Jaber, 2014). We noted her repetitive behaviors she displayed as a product of her constructed epistemic emotions while in the small group. These were then verified using other data such as the interview and the emotion diaries.

RESULTS AND DISCUSSION

From across the six lessons of their scientific modeling activity, Susan constructed the epistemic emotion of *frustration* (Lesson 1), *anxiety* (Lesson 2 to 3), and *joy* (Lesson 5 to 6). These constructed epistemic emotions facilitated the different patterns of her participation during their scientific modeling class. It is important to note that we were not able to report results for Lesson 4 because their tasks were mostly illustrating and tracing the path of air on the different organs of the human respiratory system.

According to her emotion diaries, Susan constructed *frustration* as an epistemic emotion in Lesson 1 which facilitated her feeling of disinterest in interacting with the other members of her group. During the post-lesson interview, she expressed difficulty on the tasks which made her frustrated (Excerpt 1). Another factor which contributed to Susan's construction of *frustration* was her low perception towards her cognitive ability relative to the other members of her group. We were able to note this from the transcript of the post-lesson interview when she said that she is not as good as them in science.

Excerpt 1	
1	Teacher-researcher: *(After watching the video recording)* Susan, you rarely talked in Lesson 1, when Jenny asked your arguments, you just spoke out without confidence. Is it because you felt frustrated as you have written in your emotion diary?
2	Susan: Yes. I think it was hard on several tasks.
3	Teacher-researcher: Can you tell me what was difficult?
4	Susan: I think it is difficult for me to tell my arguments based on claims and evidence. I've never talked like this before. That was pressure!
5	Teacher-researcher: I think you are still able to tell your opinions to your students. Aren't you? Nobody can prevent you from telling your opinions.
6	Susan: Right.
7	Teacher-researcher: Isn't it just because it's hard to say?
8	Susan: You know, Jenny and Sylvia are good at science. But I am not. I don't think that my opinion will be accepted easily by them. Maybe they will just refute my opinion. So, this makes it hard for me and it's frustrating.

In assessing Susan's participation, we adapted the concept of productive participation (Engle & Conant, 2002) which considers the student's willingness and expressions of interest to be involved socially and cognitively in any epistemic activity. In scientific modeling like in this study, these two are intertwined with each other because the activities such as speaking, listening, constructing, and argumentation calls for the students' social and cognitive participation. Thus, in our analysis of Susan's level of participation, though she was able to respond, we still classified her responses as non-participation since she only participated when deliberately asked. Most of the time, she was not attentive, isolated herself in the discussion by messing around and playing with her pencils, and her responses did not contribute to the completion of their cognitive tasks (Excerpt 2).

Excerpt 2	
1	Jenny: First we need to explain which body organ has to be included into the human respiratory system. And why these body organs are needed for breathing? Oh, but it's a little awkward. Say that using claims and evidence (laugh).
2	Sylvia: I can't speak any more like this. Anyway...
3	Jenny: I think we need a nose, because we get air through our nose ... we need a nose.
4	Sylvia: Right. We can let air through our nose and nose filters out dirty things from the air.

5	Jenny: Mike, Susan. Why don’t you guys tell us something?
6	Sylvia: I think we need trachea. Because air can move in and out through the trachea.
7	Jenny: Susan, why don’t you do something else and focus on it?
8	Susan: *(Keeps looking at other places, and she is messing with pencils)*
9	Sylvia: Lungs are important, I think.
10	Jenny: I agree with you, too.
11	Sylvia: Me too, it delivers air into the vessels, especially oxygen (reading textbooks). Jenny: What are the other body organs that can be found in the human respiratory system?
12	Sylvia: Let’s write it on paper once. We need to get it organized.
13	Jenny: Hey, Susan (aggressively), why do you think you need lungs?
14	Susan: Um ... that’s what it's like *(No confidence; no social and cognitive contribution).*
15	Jenny: Tell me. Why do you think your lungs are needed?
16	Susan: Um ... to live? *(No confidence; no social ang cognitive contribution).*

In Lesson 2, Susan constructed the epistemic emotion of *anxiety*. This was triggered by her perception that her answers will likely be judged by the other members of the group. She also had low perception of her low academic competence. This was observed from her utterances when she said that she was not sure whether her answers were right or wrong (Excerpt 3).

Excerpt 3	
1	Teacher: You said you felt anxious in Lesson 2. Can you tell me what made you feel anxious?
2	Susan: I felt anxious because I was not sure if what I knew was right or wrong.
3	Teacher: What exactly does that mean?
4	Susan: I felt anxious when I told my opinion to Jenny and Sylvia; I was not sure whether what I was saying was scientifically correct or not.
5	Teacher: *(Shows the video-recordings)* But I noticed that you were able to talk to Jenny and Sylvia in Lesson 2. What has changed compared to Lesson 1?
6	Susan: Yes. I think it was less difficult for Jenny and Sylvia to show me that they would accept everything I would talk about.

Based on our analysis, Susan showed passive participation in their small group activity in Lesson 2. Though she was approached emphatically and was given enough opportunities to engage, she was still not confident in her responses (Excerpt 4). However, compared to the dynamics of their small group in Lesson 1, Susan was able to contribute to the completion of their cognitive tasks when she was emphatically given enough chance to speak. This confirms the work of Jaber, Southerland, and Dake (2018), group empathy enhances participation in small group scientific modeling.

Excerpt 4	
18	Sylvia: But maybe we can breathe out because our brain commands us to breathe for ourselves. If not, will we die? So, I think we need to draw a brain as part of the human respiratory system.
19	Jenny: Um ... Susan. I want you to tell me what you think. Talk comfortably.
20	Susan: *(Without confidence)* I don’t think we need a brain in the drawing because they have no air pockets, lungs, instead. So, it’s better not to draw.
21	Jenny: You may think so *(showing epistemic empathy).* But what if we don’t breathe because we don’t have a brain? So, I think we should draw the brain, also the body (to include lungs). What do you think? Susan?
22	Susan: *(With a little trembling voice)* So the body must be drawn. Because it’s connected to the head, and to the respiratory organs.
23	Jenny: *(Smiling)* But didn’t you say we don’t need it? Anyway...
24	Sylvia: I think we can draw the head because we need the nose.

Based on Susan’s emotion diaries, she constructed *joy* as an epistemic emotion from Lesson 5 to Lesson 6. We observed this with her smiles and playful behaviors when we scanned the video of their small group scientific modeling activity. In the interview, she said that the other members of their group continued to encourage and praise her. She specifically mentioned that her answers were not judged, and she was welcomed to do some playful acts while manipulating their model (Excerpt 5). She was then able to confirm that they do not have negative impressions on her which made her boost her confidence.

Excerpt 5	
1	Teacher-researcher: *(Shows the video-recordings)* Susan, at the beginning of Lesson 5, you seemed so comfortable enough to play with your groupmates. It was surprising to see that compared to the first period. Is there any reason why you acted like that?
2	Susan: I think it's because Jenny and Sylvia encouraged me and accepted whatever I said. It's a lot easier to tell my opinion to them. Actually, Jenny and Sylvia aren't uncomfortable with me, but at least in class, I think I should tell them something correct. You know, Jenny and Sylvia are good students. However, in Lesson 5, even if I joked, Jenny and Sylvia laughed with me without any reproach.

Aside from what was indicated in her emotion diaries, we also interpreted her groupmates' positive reactions such as their smiles and repetition of her actions as a scaffold to enable Susan to actively engage in their group activities (Excerpt 6). The emotion of joy that she epistemically constructed resulted to ease in dealing with others, increased her motivation in participating in the knowledge construction, and boosted her confidence in expressing her ideas. This supports the claims of Pekrun, Elliot, and Maier (2009) that positive emotional experience such as joy may improve learning outcomes; and in our study, the joy that Susan constructed led her to actively participate in the epistemic practice.

Excerpt 6	
29	Sylvia: *(Manipulating the syringe)* This action is air coming in, this action is air coming out, Susan, could you manipulate the syringe *(smiling)*?
30	Susan: *(Manipulates the syringe)* Ladies and gentlemen, listen up, I can make sound like this. Air comes in and out. Shuuuuuu…
31	Jenny and Sylvia: *(Smiling due to Susan's action and words)*
32	Susan: This is air coming in (Shuuuuu). Ladies and gentlemen, that's it! Thank you.
33	Jenny, Sylvia: *(Smiling due to Susan's action and words)*
34	Sylvia: *(Following Susan's action).* This is air coming in. Shuuuuuu…

In summary, two main factors influenced Susan's construction of epistemic emotions: 1) task familiarity, and 2) sense of acceptance. These were further affected my several underlying factors such as prior knowledge, argumentation skill, exposure to argumentation, motivation to do the tasks, curiosity about the lesson, difficulty level on the task, and certainty of ideas with varying influences in each of her engagements in the group activity in each lesson (Fig. 1).

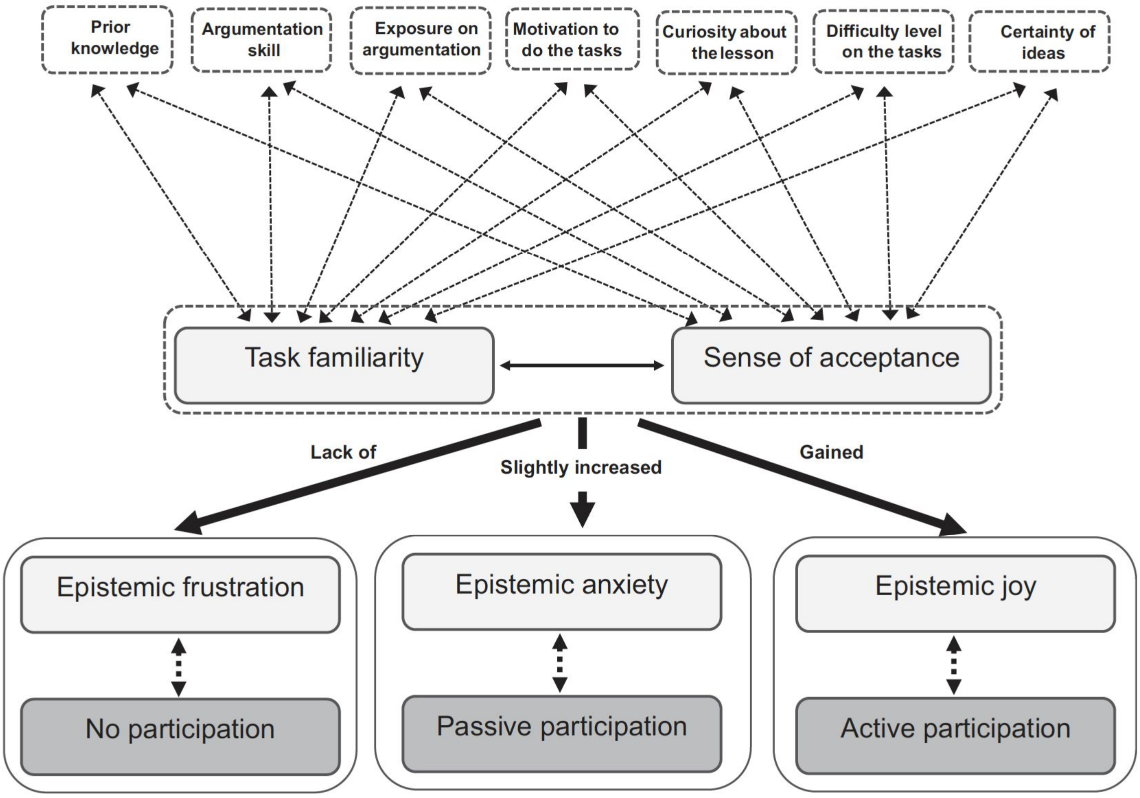

Figure 1. Reciprocal relations of the factors that contributed to Susan's construction of epistemic emotions and patterns of participation in the scientific argumentation and modeling.

In Lesson 1, Susan constructed epistemic *frustration* because of her unfamiliarity with the epistemic practices of science argumentation which was their main task in their group activity. In Lessons 2 and 3, she was able to slightly recover from unfamiliarity which relieved her discomfort in interacting with her groupmates. However, her lack of prior knowledge about the lesson topic and her lack of argumentation skill were not enough to motivate her participation; thus, facilitating her construction of epistemic *anxiety*. In Lessons 5 and 6, Susan's increased exposure boosted her confidence which resulted to her construction of epistemic joy that eventually facilitated her active participation. This is in combination with her improved sense of acceptance from her groupmates.

Previous studies which used the cognitive-motivational model distinguished emotions according to their performance effects: positive-activating, positive-deactivating, negative-activating, and negative-deactivating (Pekrun et al., 2002; Pekrun, Elliot, & Maier, 2006). In this study, we noted that epistemic *joy* was a positive-activating emotion while epistemic *frustration* and epistemic *anxiety* were negative-deactivating emotions. According to Pekrun et al. (2002), positive-activating emotions such as epistemic *joy* reinforce motivation for learning. This was observed when Susan displayed task-related enjoyment. We particularly observed this when she had fun in explaining and summarizing their group arguments and in her relational processing of information when she was actively engaged with Jenny and Sylvia in explaining and manipulating the syringe as a scientific model. We therefore confirm previous studies which hypothesized that positive epistemic emotions drive students' collaboration in group activities (Nicolaou, Evagorou, & Lymouridou, 2015). Her epistemic *joy*, which was triggered by her familiarity on their tasks and her perceived sense of acceptance by Jenny and Sylvia helped her to pay attention to the discussion and eventually engage with unsolicited arguments. On the contrary, her epistemic *frustration* and epistemic *anxiety* limited her participation in scientific argumentation and activated her avoidance due to her fear of committing mistakes. Her desire to engage in the small group argumentative discussions was affected by her perception that her ideas will be rejected resulting from her lack of prior knowledge. This sense of rejection led her to avoid the task even though she was deliberately asked by her groupmates to tell her opinions.

To assess the impact of her negative epistemic emotions in relation to the concept of productive participation (Engle & Conant, 2002), these negative epistemic emotions affected not only herself but also her small group cognitive and social performance. Instead of voluntarily sharing her ideas which may increase their opportunities for scientific argumentation in their small group, her limited participation due to her negative emotions suppressed their learning opportunities in the group. However, more than the group members who were affected, we claim that her emotions had more negative impacts on her because even without her participation, the other members of her group were able to proceed and accomplish their tasks. This confirms previous studies report that an individual's emotions still have great impacts compared to group emotions (Boekaerts, 2007). Thus, socio-cognitive interactions, though may seem to trigger construction of collective or group epistemic emotions, each member's construction of emotions appears to be more influential in facilitating their patterns of participation.

CONCLUSIONS AND IMPLICATIONS

The results of the study addressed the multi-faceted effects of Susan's prior knowledge and skills, level of understanding of the science concepts, how she perceived herself relative to her classmates, and the ongoing and developing into her construction of epistemic emotions. These results indicated that epistemic emotions and the socio-cognitive interactions in a small group have reciprocal relations to a student's pattern of participation in a small group modeling activity. Our analyses contribute to the ideas of the constructionists' views of emotions which emphasized that instead of being prewired from birth, emotions are derived from the changing dynamics of interaction and relational patterns in a social environment where an individual belongs (Boiger & Mesquita, 2012). Thus, we report the possibility that the momentary nature of epistemic emotions may facilitate different patterns of participation in the classroom activities.

In this study, Susan, represented the case of a passive student in science, who showed no participation and passive participation in the early stages of their lessons when she constructed negative epistemic emotions. However, when she constructed the positive epistemic emotion of *joy* as soon as she was able to resolve her difficulties, she was able to show active participation especially when she received support from her groupmates.

The primary implication of this study is provision of evidence on how epistemic emotions are socially constructed. Our analysis emphasized that the construction of epistemic emotions is momentary and unconscious which may shift the nature of students' participation during social interaction. This supports earlier studies that contingent on the different activities that occur in the social system is the emergence and construction of epistemic emotions (Boiger & Mesquita, 2012). It is therefore necessary for teachers to make efforts in identifying these emotions at least through students' emotion diaries.

Thus, we recommend that for teachers to harness the significance of small group modeling, they must be aware of the nature of the tasks and the students' prior knowledge which may influence their intrinsic motivation and excitement. Moreover, they should also be mindful and be ready to intervene especially when they have students who are inherently active with the tendency to dominate the small group activity. In our study, the teacher allotted some time to conduct post-session processing after their group activities to remind the students give students in the group that each one has to be given opportunities to contribute while displaying emotional empathy on each other's opinion. We therefore suggest that teachers should be mindful of these scenarios by assigning student roles to ensure the participatory construction of knowledge.

With the contention that epistemic emotions are implicated during cognition and learning, we also recommend that future research explore the possibility of shared constructed epistemic emotions. Studies can focus on how and what factors contribute to the shared constructed epistemic emotions in a small group of students as they engage in an epistemic inquiry. The differences in the socially constructed epistemic emotions which was also observed in this study can be given attention by exploring other triggering factors for each member of the small group.

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PRELIMINARY RESULTS OF A PARAMETRIC ANALYSIS OF EMOTIONS IN A LEARNING PROCESS IN SCIENCE

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In the last decades, several studies have highlighted the importance of emotions in the teaching and learning process. The classroom is considered an emotional place, where the learning is influenced by cognitive and emotional-motivational mechanisms. Classically, emotions have been classified in discrete categories. Furthermore, in educational settings, it is possible to evaluate dimensional categories as engagement and attention. According to this vision, we designed an activity to analyse emotions and their flow when students are involved in an inquiry-based activity. To avoid limitations of self-reports and observational methods, we evaluated emotions with an automatic facial coding system. This system detects facial human expressions using facial reference points and classifies their emotional value parametrically. The data shows different flows for each affective parameter. Thus, we obtained a constant high level of attention and intense engagement along the whole activity. Moreover, joy and surprise flows showed a global presence higher than negative emotions. Four parameters' flow graphics are related to characteristic educational behaviour. This work opens to the possibility of objective parametric evaluations of the emotional component in the teaching-learning process.

Keywords: Emotion, Science Education, Conceptual change.

INTRODUCTION AND THEORETICAL FRAMEWORK

In Education emotions may be described as appraisals and reactions to the information received from the context, whose intensity depends on subjective evaluations, influenced by personal prior knowledge beliefs and priorities (Dávila et al., 2021; Graesser, 2020; Harley et al., 2017; Rubin & Talarico; 2009). Emotions may occur due to evocation of events that happened in the past or by anticipating possible future situations (Damasio & Carvalho, 2013; Hutchinson & Barrett, 2019; Pekrun et al., 2014; Russell, 2003). Thus, antecedents as academic successes and failures, may shape students' emotions. Conversely, emotions may impact outcomes, determining a reciprocal influence (Murphy, 2019; Pekrun et al., 2017).

Emotions influence in different ways experiences, strategies, and attitude of students toward learning (Borrachero et al., 2014; Murphy et al., 2019). They may be positive (happiness, hope, etc..) or negative (anxiety, frustration, etc..). In general, positive emotions (such as enjoyment, hope, satisfaction, self-confidence) support the teaching-learning process positively (Pekrun et al., 2017). On the contrary, negative emotions (such as boredom, confusion, frustration, and hopelessness) tend to have negative influences on learning and are negatively related to achievement (Murphy et al., 2019; Marcos-Merino, 2019; Pekrun et al., 2014).

Moreover, the emotional state can be described dimensionally. Dimensions describes emotional experiences along a continual variation of parameters as pleasure and arousal, directly related to core affect (Deckert et al., 2019; Plass et al, 2019). Anyway, dimensions may represent a superior level that includes emotion discrete categories (Loderer et al. 2019). Some prominent dimensions in educational context are attention and engagement (Graesser, 2020; Harley et al., 2017; Loderer et al., 2019; Mrkva et al., 2019).

Introduction to parametric study of emotions

Basically, up to the present days, scientific research in Education has been focused on observational and self-reports methods (Azari et al., 2020; Harley et al., 2019; Loderer et al., 2019; Meindl et al., 2018; Pekrun, 2006). These methodologies, for assessing personal qualities, are the most common approaches in research (Duckworth & Yeager, 2015). They have the capacity to get outcomes in a cheap, quick and versatile way of emotion recognition (Engelman & Bannert, 2019).

Anyway, self-reports are difficult to edit and the declarations of the participants may be affected by biases, as consequences of incapacity to self-estimate or express correctly their own emotions (Engelman & Bannert, 2019; Goetz et al., 2016; Izard, 2009; Pekrun, 2006). As far as observer-reports, coder experts need a long and intense practice to achieve reliable data by observation (Barrett et al., 2019).

In the last decades, the continuous development of technology offers different methodologies and analytical instruments to identify the emotional process. These systems collect and analyse data related to the brain and nervous system. Some among the most investigated are EEG, heart rate, skin conductance, fMRI and eye tracking. Furthermore, recent advanced included no-intrusive techniques to automate facial expression recognition systems using cameras or webcams (Darvishi et al., 2021; Monkaresi et al., 2017), now commercially available for scientific research with high level of reliability (Stöckli et al., 2018, Küntzler et al., 2021). This is relevant in education, considering that the movements of the facial muscles almost always accompany an emotional state, which can be related to discrete emotions and affective dimensions. Thus, the analysis of facial expressions is one of the most appropriate automatized techniques to estimate emotions and behaviours in class (Calado et al., 2017).

Facial automatic detection systems can achieve an appropriate and accurate postural, head movement and facial expression coding recognition around 90%, depending on the conditions of clear and correct illumination of the participant's face (Benitez-Quiroz et al. 2017). That gives us the chance to bring to bear a dynamic perspective on emotional changes over a period of time. Thus, it is possible to analyse profiles of emotional response and behaviour occurring in a given situation (Gross, 2015; Kuppens et al., 2009; Kuppens & Verduyn, 2015).

The first step of the automatic facial expression recognition was to detect the face of the subjects (Kulkarni et al., 2021). For that, the software iMotions (2018) utilised the algorithm Viola Jones Cascaded Classifier (Viola & Jones, 2004). Successively, to estimate the facial expression recorded, it used an automatic coding system based on Facial Action Coding System (FACS) (Barrett et al., 2019; Ekman & Friesen, 1978; Keltner et al., 2019). Eventually, the Affectiva AFFDEX algorithm SDK 4 (Affectiva, 2015, Boston, MA) correlated the facial expressions to the affective states. This system can detect head orientation (yaw, pitch, roll); interocular distance; 34 facial landmarks; 14 facial expression metrics.

In detail, to describe facial movement, the software uses algorithms to detect landmarks as brows, mouth corners, etc., as well as groups of landmarks. When these reference points change their relative position, due to a change of respondent's expression, the system evaluates the new facial configuration in terms of affective metrics. Each movement corresponds to an Action Unit (AU). One or more AUs describe an emotional facial expression based on FACS. It allows to assess basic emotions: Anger, Sadness, Joy, Surprise, Disgust, Contempt and Fear; moreover, affective dimensions as Attention, Valence and Engagement. When an emotional event occurs, it generates an emotional episode that is evident in the change of facial configuration, ending when it goes back to its baseline level (Kuppens et al., 2015). Because respondents differ in their natural expression, the Affectiva algorithm applies a rolling baseline on the neutral expression of the respondent. This process keeps into account the frames preceding and following the current frame, and calculates changes. Each frame get an assigned score, depending on facial expression recognition and its intensity, from the absence of expression (0%) to an expression fully present (100%).

In this work, based on an artificial intelligence system for facial expression recognition, we have set out to develop and apply an experimental design which would allow us to collect and study the emotional and behavioural dynamics in a science education activity.

RESEARCH METHOD AND DESIGN

With the aim to investigate emotional and behavioural dynamics in science education, we proposed an inquiry activity to 24 teaching students (15 women and 9 men) attending the Master in Secondary Education, at School of Education, Complutense University of Madrid. The participants had to predict the contents of a box, with dimensions of 9x6x20 cm. It contained some euro coins: two of 1 cent; one of 5 cents; one of 10 cents; one of 20 cents; one of 1 euro. All these coins moved freely inside it. The participants could not open the box or break it. That is, they had to make use only of their scientific-technical knowledge, such as observing, testing hypotheses, drawing conclusions, etc. They could use some magnets. A similar activity was proposed among others by Lederman & Abd-El-Khalick (1998) and Haber-Schaim et al. (1979).

The participants were divided into pairs. Only one student of each pair had to guess the contents, and they were video-recorded. The other students observed their peers' activity. They checked the right operation of the camcorder, and they warned their peers to remain inside the video framing. In this way they learnt the operational best practice. Each HD video camera was placed on a tripod in front of each observed student, at a distance of one metre to obtain the best recording view of the face and upper body. The activity lasted twenty minutes. We divided the session into ten periods of two minutes each. After each period, students filled a form in which they reported their emotions. Nevertheless, here, we only describe the emotional dynamics obtained from the video recordings.

After data collection, we devised the protocol to process and analyse the data. The videos recorded during the activity were saved and named with a specific code. Later, they had been edited to prepare them for the analysis. Specifically, they were synchronized with the start, the frames recorded outside of the activity's duration were cut off, as well the pause intervals (time utilized by the students to take notes), then the remaining parts were merged. The videos were imported and processed by iMotions® program.

The total processed data constituted our initial signal for analysis, it consisted of 60.856.164 entries, determined by 141 entries per frame. The frames analysed were 35.967 for each respondent (12).

RESULTS

Our preliminary results indicated different dynamics for each affective parameter. Throughout the ten time periods (Table 1), we observed Attention with the highest global average presence value (69,4%), then Engagement (20,8%), Joy (4,8%) and Surprise (3,2%). Other emotions were quite lower (< 1%). Basically, four emotional states were prevalent for all participants. The Standard Deviation (SD) was restrained to a range from 0,05% (Sadness) to 3,91% (Attention). It seems to indicate that emotional states, experienced by the students, maintained their average presence percent along the whole activity. Effectively, the analysis of the parameters in particular with high presence, Attention and Engagement, indicated that all the students were engaged with high attention carrying out the activity.

Table 1. Percent of time for each of the 9 selected parameters, they were measured by the system for each of the periods. "Mean" indicates the mean value of each emotion for all periods within the 12 respondents.

	Anger	Sadness	Disgust	Joy	Surprise	Fear	Contempt	Engagement	Attention
Period 1	0,00%	0,10%	0,30%	9,40%	2,90%	0,30%	1,60%	25,10%	60,30%
Period 2	0,90%	0,00%	0,30%	7,50%	1,50%	0,50%	0,90%	22,30%	66,10%
Period 3	0,70%	0,00%	0,10%	3,90%	1,90%	0,10%	0,90%	17,20%	75,10%
Period 4	0,00%	0,00%	0,20%	4,60%	2,20%	0,40%	1,00%	20,60%	71,00%
Period 5	0,10%	0,00%	0,30%	3,60%	3,10%	1,10%	1,30%	19,40%	71,30%
Period 6	0,10%	0,00%	0,10%	5,00%	4,50%	0,60%	0,40%	21,00%	68,30%
Period 7	0,20%	0,10%	0,30%	2,20%	3,90%	0,50%	0,70%	19,40%	72,70%
Period 8	0,00%	0,00%	0,30%	3,90%	4,20%	0,50%	0,70%	21,90%	68,50%
Period 9	0,10%	0,00%	0,20%	3,30%	3,40%	0,80%	0,50%	19,60%	72,00%
Period 10	0,00%	0,10%	0,10%	4,50%	4,30%	0,50%	0,40%	21,70%	68,30%
Mean	0,20%	0,00%	0,20%	4,80%	3,20%	0,50%	0,80%	20,80%	69,40%
SD	0,30%	0,05%	0,09%	2,02%	1,01%	0,26%	0,37%	2,03%	3,91%

We analysed the graphics of the parameters, focusing specifically on the dynamics of the prevalent four. Then, we observed whether there were profiles which were shared by the respondents. The analysis indicated three different profiles in parameters' graphics. In Figures 1 (Surprise and Engagement) and Figure 2 (Attention) we show the graphics of Respondent 10 as an example.

Profile 1 was correlated to the first part of the activity (in this case till about 6 minutes) and presented Surprise (orange line in Figure 1) with very low presence or absence of peaks. Engagement (light blue line in Figure 1) was characterised by high variability, with sharp peaks and low interval average presence (15%). Attention (Figure 2) was very high for the initial first minute, but then (1-6 minutes interval) it showed high variability with repeated rise and fall, for an interval average presence of 76%.

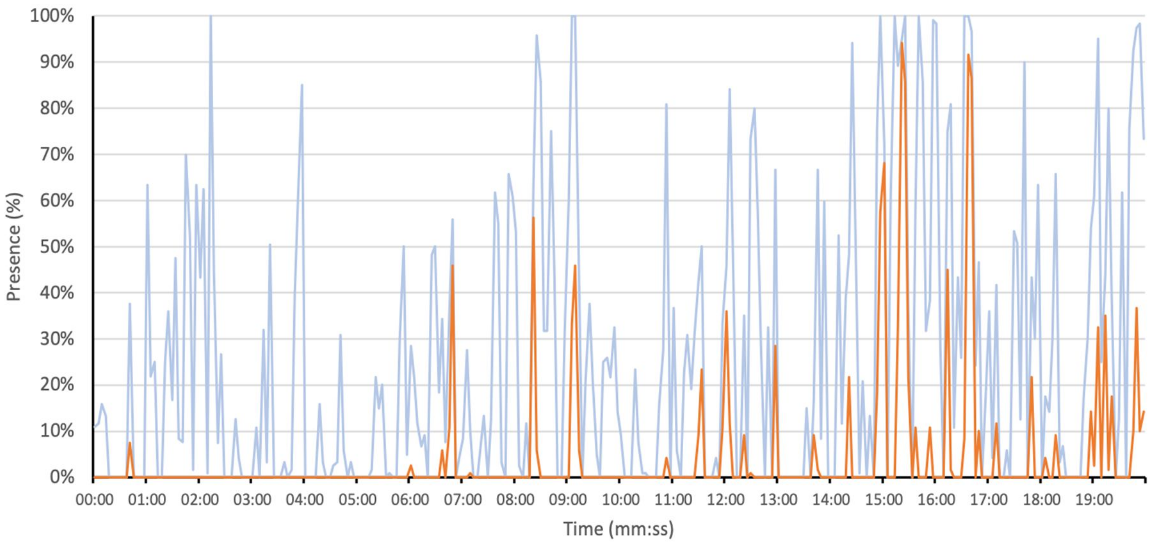

Figure 1. Surprise (orange) and Engagement (light blue) (Respondent 10).

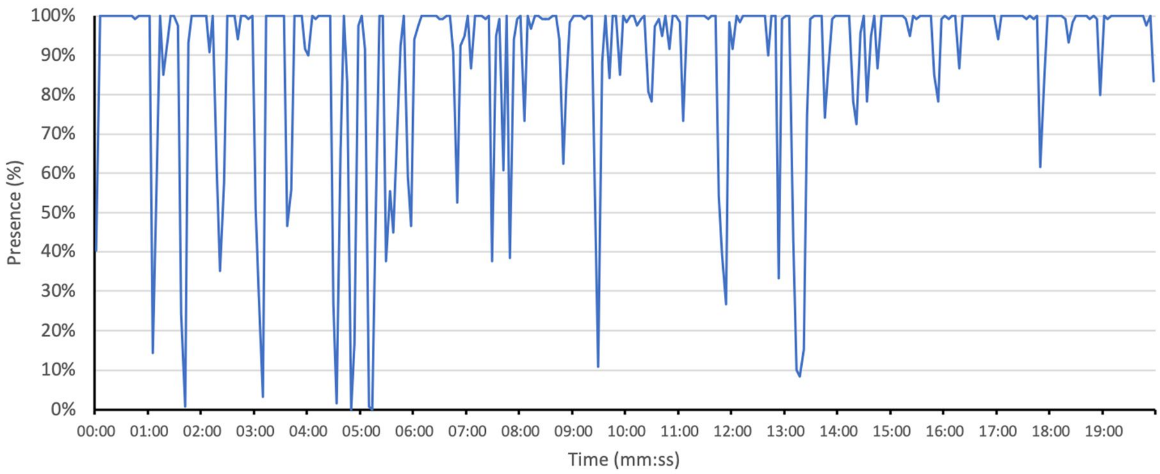

Figure 2. Attention (Blue) (Respondent 10).

Profile 2 was correlated with the central part of the activity (in this case about 6-14 minutes interval). It was characterized by a sequence of isolated sharp peaks of Surprise, of medium and low intensity. It showed covariation with Engagement, that presented variability of peaks succeeding with different intensity and frequency, with an average presence (24%), higher than the previous interval. Attention (Figure 2) presented high presence with variability less evident than the previous profile and showed peaks with either steep or smooth slopes. It showed short tracts with inertia and an interval average presence (89%) higher than the preceding interval.

Profile 3 referred to the last part of the activity (in this case about 14-20 minutes interval). Surprise (Figure 1) showed isolated peaks of different intensity, clustered in the central part of the interval, with some peaks of high intensity of presence (70-90%). It still presented covariation with Engagement, that increased the interval average presence (42%) with higher sharp peaks frequency and roller-coaster trend. Attention (Figure 2) showed an inertia maintained till to describe a plateau, where Attention persisted for several seconds or few minutes at 100% presence, thus achieving the highest interval average presence (97%).

We evaluated the presence and the sequence of the profiles and we could observe different duration depending on the participants. Thus, we could propose common patterns within the respondents, depending on the profiles they showed. This introductory analysis indicated relations of the parameters' patterns (achieved from data analysis) with students' educational actions (inferred from observing the recorded videos).

Pattern 1 showed the sequence of the profiles 1, 2 and 3. Basically, Profile 1 was present at the beginning of the activity, Profile 2 characterized the central part of the time-line, whereas Profile 3 was prevalent on the last part of the activity. This pattern was shared among Respondents 1, 2, 9, 10, 11. This preliminary study of the students' educational actions showed their high capacity of concentration, problem solving and to apply systematically the hypotheses elaborated.

Pattern 2 showed a short tract with the Profile 1 and alternation of Profile 2 and 3, with short (2-3-2-3) or large (2-3-2-3-2-3) sequences, with different intervals for each participant (3, 4, 5, 7, 8). They also showed interest and implication, but more doubts and uncertainty than the previous group.

Pattern 3 didn't present any of the mentioned profiles (Respondents 6, 12), due to reduced engagement and the lack of characteristic trend of Attention and Surprise described for the profiles above. They showed difficulty to elaborate and apply strategy to resolve the task.

This preliminary study seems to point at the existence of emotional dynamics linked with the students' educational behaviours. Nevertheless, more time and data processing are necessary to establish more robust relationships.

DISCUSSION AND CONCLUSIONS

This study indicates the possibility to evaluate parametrically the emotions during an educational activity, overcoming some self-report or observational limitations. We had the possibility to continuously follow the dynamic of students' affective dimensions and emotions by using a facial recognition system.

The data showed the parameters of Attention and Engagement predominant throughout the activity. Positive emotions, Joy and Surprise, displayed global average presence higher than negative emotions. It indicated that the activity was carried out with motivation, implication and positive attitude by the students. Furthermore, the restrained standard deviation implied that the general trend of the different emotional states was consistent throughout the activity.

The analysis of Attention, Engagement and Surprise dynamics permitted to elaborate three graphical profiles. The distinct presence and sequence of these profiles, along the task, drew three patterns shared by different groups of participants. It is remarkable that each pattern's group of students showed a characteristic educational behaviour, related to observation, reflection, systematic exploration and application of strategies. For the students it implied a different ability to carry out the task, such as to develop and test hypotheses, to avoid distraction, capacity of concentration and perseverance.

Basically, the profiles and patterns found are peculiar to this activity. Different tasks would imply rather distinct profiles and patterns classification. Anyway, this study confirms the correlation between emotions and educational behaviours, and encourages us to expand the research to other educational activities.

Concerning the teaching-learning process, this preliminary study underlines the importance of teachers' capacity to correlate educational actions with the affective states that students go through, when they are involved in an educational activity. Evidently, the future teachers cannot still ignore the emotional dynamics in class. Thus, it should be an important part of their training.

It is worth considering some limitations, such as the difficulty for some respondents to avoid covering the face or turn it on a side over a suitable angle, aligned with the camera, to be correctly detected by the system, for the whole time of the activity. Moreover, the large quantity of data implicated the necessity of managing a notable noise reduction. Anyway, this work opens up the possibility for objective parametric evaluations of emotional components during the teaching-learning process.

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STUDENTS' PERCEIVED COMPETENCE AS PREDICTOR OF THEIR FLOW EXPERIENCE DURING EXPERIMENTATION

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Several studies have shown a decrease in student motivation in science education. To design measures to motivate students such as their flow experience variables that have an impact on flow experience must first need to be identified. Previous studies reveal that students' perception of competence (e.g., during experimentation) is crucial for their flow experience in science classes. According to the scientific discovery as dual search model, perceived competence during experimentation refers to the perception of competence during the three phases 'Search Hypotheses Space', 'Test Hypothesis', and 'Evaluate Evidence'. In this study, we investigated whether students' perceived competence during the aforementioned three phases of experimentation predicts their flow experience. To investigate these effects, 212 German students were taught in biology classes (age: M = 16.30 years, SD = 0.96 years; 59% female). The students performed two experiments. Immediately thereafter, students' perceived competence and their flow experience were assessed. Regression analysis revealed that students' perceived competence during the phases 'Test Hypothesis' and 'Evaluate Evidence' but not during the phase 'Search Hypotheses Space' predicted their flow experience. The more competent the students felt, the higher their flow experience. With these results, specific support measures for experimentation processes can be designed.

Keywords: scientific experimentation, perceived competence, flow experience

RATIONALE

Research demonstrates that students in Germany are losing their interest and motivation in science education (e.g., Krapp & Prenzel, 2011; Organisation for Economic Co-operation and Development, 2016), leading to many studies focusing on how to counteract this decrease. Science education employs several hands-on activities such as experimentation that might have positive effects on students' motivation (Hofstein & Lunetta, 2004). However, the process of experimentation can be rather complex. A wide range of skills and knowledge is required (Bruckermann, Arnold, Kremer, & Schlüter, 2017; Klahr & Dunbar, 1988), which students often lack (Baur, 2018; Chinn & Malhorta, 2002; Etkina, Murthy, & Zou, 2006; Hammann, Phan, Ehmer, & Bayrhuber, 2006; Hammann, Phan, Ehmer, & Grimm, 2008; Randler, Elker, Tempel, & Rehm, 2015). Students might therefore be overwhelmed if an experiment is too complex or they lack appropriate skills and knowledge (Arnold, 2015; Bruckermann et al., 2017; Schmidt-Weigand, Franke-Braun, & Hänze, 2008). If requirements exceed students' skills, they might perceive a high cognitive load (Kirschner, Sweller, & Clark, 2006), which can harm their motivation and learning (Ryan & Deci, 2017).

In this context, previous research frequently addressed cognitive aspects, such as the assessment of students' experiment-related skills and knowledge (e.g., Arnold, 2015; Chinn & Malhorta, 2002; Etkina et al., 2006; Hammann, Phan, & Bayrhuber, 2007; Hammann et al., 2006, 2008; Neumann, Schecker, & Theyßen, 2019). In addition to cognitive aspects, successful learning also depends on affective-motivational factors, such as intrinsic motivation (Ryan & Deci, 2017; Taylor et al., 2014) or flow experience (Engeser & Rheinberg, 2008). That is, student motivation must be considered when designing measures that optimally support students during learning. As a first step, variables that affect student motivation should be investigated to design such measures. In science education, this seems to be especially important for experimentation processes. As one of those variables, students' perceived competence was tested in this study in three phases of experimentation as a predictor of a specific situational motivation, namely, students' flow experience.

The need for competence refers to an individual's desire to feel effective in action and express and extend his or her skills (Reeve, 2015; Ryan & Deci, 2017). Individuals perceive competence if they perceive their skills and the challenge of their task as corresponding and are able to master the task (Deci & Ryan, 2000; Jang, Reeve, & Deci, 2010; Reeve, 2015; Ryan & Deci, 2017). The perception of competence can lead to intrinsic motivation (Reeve, 2015; Ryan & Deci, 2017). Intrinsically motivated actions are not driven by external incentives, but rather are an expression of interest and enjoyment (Ryan & Deci, 2017).

A complementary motivational quality to intrinsic motivation is flow (Deci & Ryan, 2000; Sheldon & Filak, 2008; Nakamura & Csikszentmihalyi, 2014; Reeve, 2015). *Flow* is a state in which individuals experience themselves as absorbed by their current action and perceive a smooth progression of their action (Nakamura & Csikszentmihalyi, 2014). During a flow experience, the individual perceives him or herself as optimally challenged (Nakamura & Csikszentmihalyi, 2014; Reeve, 2015; Taylor, Shepers, & Crous, 2006). That is, the challenge of an action is not perceived as too difficult or too easy, it corresponds to the perceived skills (*perceived balance between skills and challenges*; Nakamura & Csikszentmihalyi, 2014; Reeve, 2015).

Due to this common element of perceived competence and flow experience – namely, the perceived balance between skills and challenges (Deci & Ryan, 2000; Reeve, 2015) – a positive relationship between these variables is assumed, which has already been found in previous studies (e.g., Kowal & Fortier, 1999; Schüler, Sheldon, & Fröhlich, 2010; Taylor et al., 2006). Perceived competence is discussed as an antecedent of flow (Kowal & Fortier, 1999). However, the prediction of students' flow experience by their perceived competence during the phases of experimentation has thus far not been investigated in a differentiated manner. For this interrelationship, a closer look at the experimentation process reveals that a differentiated perspective can be useful.

As a problem-solving process, experimentation can be described using the scientific discovery as dual search model (SDDS) developed by Klahr and Dunbar (1988; see also Klahr, 2000). In SDDS, problem-solving occurs within and between two problem spaces, the *hypotheses space* and the *experiment space* (Klahr, 2000; Klahr & Dunbar, 1988). The search in these two spaces is described by three basic components: *Search Hypotheses Space*, *Test Hypothesis*, and *Evaluate Evidence* (Klahr, 2000; Klahr & Dunbar, 1988). The search for a hypothesis involves finding an appropriate research question and hypothesis within the hypotheses space (Search Hypotheses Space; Klahr, 2000; Klahr & Dunbar, 1988). To test this hypothesis, a meaningful and reasonably controlled experiment needs to be discovered in the experiment space and conducted afterwards (Test Hypothesis; Klahr, 2000; Klahr & Dunbar, 1988). The evaluation of evidence refers to the interpretation of the results of the current experiment and the consideration of further findings (Evaluate Evidence; Klahr, 2000; Klahr & Dunbar, 1988). The evaluation leads to a decision on the acceptance or (partial) rejection of the tested hypothesis (Klahr, 2000; Klahr & Dunbar, 1988).

Through the lens of SDDS, experimentation comprises an array of components and subcomponents of problem-solving processes. However, when experimenting in science class, not all of these (sub)components are usually considered (Seidel et al., 2002; Wirth, Thillmann, Künsting, Fischer, & Leutner, 2008). As teachers want to ensure that their students successfully perform the experimental tasks within a time-limited lesson, many teachers implement 'recipe-style' experiments in their science class (Abrahams & Millar, 2008; Abrahams & Reiss, 2012). For instance, the students work on a research question or hypothesis, conduct a pre-structured experiment following explicit instructions and analyse the collected data based on a problem given by the teacher. As this type of experiment is prevalent in school life (Abrahams & Millar, 2008; Abrahams & Reiss, 2012), we focused on three phases of experimentation: The development of a research question or hypothesis (Search Hypotheses Space), the conduct of an experiment (Test Hypothesis), and the analysis of the obtained results (Evaluate Evidence). In these three phases, students' perceived competence was investigated as a predictor of their flow experience.

RESEARCH QUESTION

Experiments offer the opportunity for hands-on activities in science class. However, students often lack skills and knowledge required for experimentation (Baur, 2018; Chinn & Malhorta, 2002; Etkina et al., 2006; Hammann et al., 2006, 2008; Randler et al., 2015). This gap can have a negative effect on students' motivation (Kirschner et al., 2006; Ryan & Deci, 2017). As motivation plays a key role in successful student learning (Engeser & Rheinberg, 2008; Ryan & Deci, 2017; Taylor et al., 2014), measures that optimally support students during experimentation should be developed. In this regard, the effects of motivational factors such as students' perceived competence during experimentation on their situational motivation must be investigated as a first step. In particular, the perception of competence during the three phases of experimentation should be separately considered. Therefore, we investigated the following research question:

Does students' perceived competence during the development of a research question or hypothesis (Search Hypotheses Space), the conduct of an experiment (Test Hypothesis), and the analysis of the obtained results (Evaluate Evidence) predict their flow experience?

METHODS

Sample

In this study, 212 German students (age: M = 16.30 years, SD = 0.96 years; 59% female) were taught about enzymology in biology class. The students attended the first year of upper secondary school (53% '*Gesamtschule*', i.e., comprehensive school; 47% '*Gymnasium*', i.e., high school).

Design and teaching content

A cross-sectional study was conducted in two subsequent lessons of 60 min each. At the beginning of the first lesson, all phases of experimentation described in the SDDS were explained to the students. Afterwards, the first experiment was performed. In the second lesson, the second experiment was performed. Immediately thereafter, students' perceived competence and their flow experience were assessed (Figure 1).

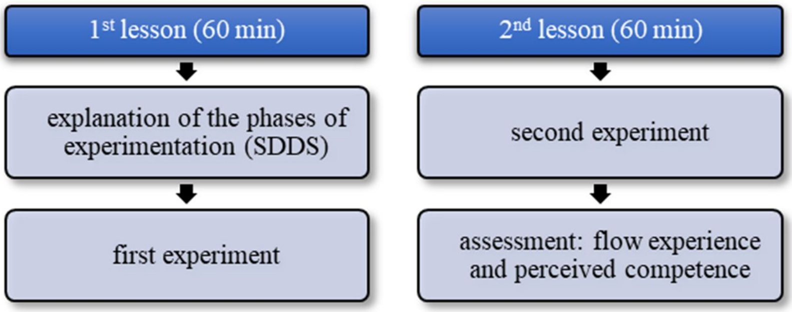

Figure 1. Study design.

The first experiment dealt with the catalysis of starch degradation by the enzyme amylase (α-amylase extracted from filamentous fungi *Aspergillus oryzae*). The students treated three 1% starch solutions stained with Lugol's iodine with amylase, saliva, and water. Students should have observed a decrease in the blue colouration of the mixtures containing amylase or saliva and no colour change in the mixture containing water. In that saliva contains amylase, the decrease in the colouration of these mixtures indicates that amylase catalyses the degradation of starch.

The second experiment regarded the temperature and pH dependence of the enzyme catalase (extracted from yeast *Saccharomyces cerevisiae*). In the first part of the experiment, the catalase was exposed to different temperatures. In the second part, the catalase was treated with different pH using hydrochloric acid (1%), water, and caustic soda (1%). Afterwards, hydrogen peroxide (10%) was added to the enzyme suspensions. Depending on the temperature and the pH, foam columns of different heights should have been formed in the test tubes, which were then correlated with the enzyme activity.

Measures

To assess students' perceived competence during experimentation, we used a self-developed test instrument. According to the three basic components of the SDDS (Klahr, 2000; Klahr & Dunbar, 1988), we adapted items of validated scales for the assessment of perceived competence (Van den Broeck, Vansteenkiste, De Witte, Soenens, & Lens 2010; Wilde, Bätz, Kovaleva, & Urhahne 2009). The test instrument consists of three subscales, each consisting of three items: *Search Hypotheses Space* ('While I was working on the hypotheses, I felt competent.'; Cronbach's Alpha: $\alpha = .74$), *Test Hypothesis* ('While I was conducting the experiments, I was convinced that I am able to do this properly.'; $\alpha = .71$), and *Evaluate Evidence* ('While I was analysing the data from the experiments, I felt that I was pretty good at it.'; $\alpha = .80$). A three-factorial confirmatory factor analysis with a maximum likelihood estimation with robust (Huber-White) standard errors (R-Studio with the lavaan package) yielded a good fit ($\chi^2(24) = 63.01$, $p < .001$, RMSEA = .08, SRMR = .05, CFI = .93; see Bryne, 2001; Hu & Bentler, 1999).

Students' flow experience was assessed using the flow short scale by Rheinberg, Vollmeyer, and Engeser (2003). The validated scale is a frequently applied test instrument (Engeser & Rheinberg, 2008; Stoll & Ufer, 2021). The flow short scale consists of 13 items ('I am completely absorbed in what I am doing.'; α = .70). The internal consistencies for both test instruments were satisfactory (see Field, 2018; Schmitt, 1996).

Statistics

The presumed relationships between the investigated variables were preliminarily investigated using Pearson correlation coefficients. Afterwards, a multiple regression analysis was performed to investigate the three aforementioned dimensions of students' perceived competence during experimentation as predictors of their flow experience.

RESULTS

The preliminary analysis revealed that the assumed predictors (*perceived competence during experimentation*) and the criterion (*flow experience*) were significantly correlated (Table 1).

Table 1. Descriptive statistics and Pearson correlation coefficients.

Variables		*M*	*SD*	1	2	3	4
Perceived competence during experimentation	Search Hypotheses Space	2.38	0.71	–	$.69^{***}$	$.77^{***}$	$.60^{***}$
	Test Hypothesis	2.62	0.68		–	$.67^{***}$	$.65^{***}$
	Evaluate Evidence	2.46	0.74			–	$.64^{***}$
Flow experience		2.54	0.46				–

Note: Variables range from 0 = strongly disagree to 4 = strongly agree; $N = 212$; *** indicates $p < .001$

The following regression analysis yielded a suitable model to investigate predictors of students' flow experience ($R^2 = .50$; $F(3, 208) = 69.39$, $p < .001$). Whereas students' perceived competence during the phase *Search Hypotheses Space* could not be confirmed as a predictor in this model, students' perceived competence during the phases *Test Hypothesis*, and *Evaluate Evidence* were predictors of their flow experience (Figure 2). The more competent the students perceived themselves during the test of the hypothesis and the evaluation of the evidence, the higher their flow experience during experimentation.

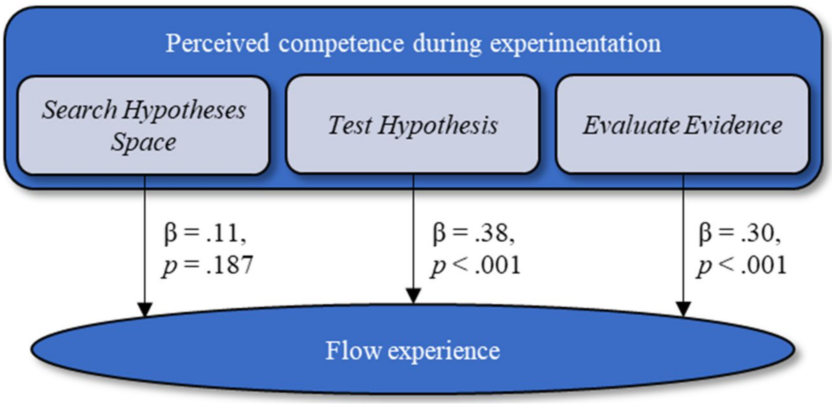

Figure 2. Results of the multiple regression analysis.

DISCUSSION

This study aimed to investigate the effects of students' perceived competence during experimentation on their flow experience. As previous studies found an impact of perceived competence on flow experience (Kowal & Fortier, 1999; Schüler et al., 2010; Taylor et al., 2006), we expected that students' perceived competence during the work on the hypothesis, the conduct of the experiment, and the analysis of the results would predict their flow experience. Our findings partially support this expectation.

Regarding the conduct of the experiments (Test Hypothesis) and the analysis of the results (Evaluate Evidence), students' flow experience was predicted by their perceived competence during these phases. That is, the more competent the students felt during the execution of the experiments and the analysis of the results, the more their flow experience was exhibited. Students' perceived competence during the conduct of the experiments was the strongest predictor. In contrast with the other phases, the test of the hypothesis mainly involves hands-on activities that might have led to a different quality of competence experience. Therefore, the perceived competence during this phase of the experimentation process might have been of special significance for the students' flow experience during experimentation.

However, students' perceived competence during the work on the hypotheses (Search Hypotheses Space) did not predict their flow experience. Students often do not make a connection between an experiment and the underlying hypothesis (Baur, 2018; Hammann et al., 2006, 2008; Hofstein & Lunetta, 2004; Randler et al., 2015). Therefore, the investigated students might not have been aware of the importance of their work on the hypothesis in the experimentation process. This could explain why students' perceived competence during the work on the hypotheses did not predict their flow experience.

Despite our interesting findings, we have to address some limitations. First, we used a self-developed test instrument to investigate students' perceived competence during experimentation. However, the scales consisted of adapted items derived from validated scales that assess perceived competence (Van den Broeck et al., 2010; Wilde et al., 2009); therefore, content validity is assumed to be sufficient. In addition, the internal consistencies were satisfactory (see Field, 2018; Schmitt, 1996). Furthermore, a confirmatory factor analysis revealed a good model fit supporting factorial validity (see Bryne, 2001; Hu & Bentler, 1999). To summarise, these indicators preliminarily suggest sufficient validity.

Second, some experimentation processes may involve additional or different components than those we investigated (see Klahr, 2000; Klahr & Dunbar, 1988). Therefore, it is conceivable to extend the test instrument with additional subscales that refer to further components of the SDDS, if needed. Moreover, students' flow experience might be affected by other student variables such as their perceived autonomy (Kowal & Fortier, 1999; Taylor et al., 2006). As teachers may pre-structure some phases of the experiments in their science class (Abrahams & Millar, 2008; Abrahams & Reiss, 2012), the students might feel controlled during these phases. This perceived lack of control would in turn impair their perception of autonomy and their experience of flow. Future studies should therefore include additional variables in the exploration of motivation during experimentation.

CONCLUSION

The results of this study contribute to a deeper understanding of motivational processes during experimentation. The perceived competence during various phases was found to be of varying significance for student motivation. This variance indicates that a differentiated investigation of the effects of perceived competence during experimentation might be worthwhile. In addition, our results hint that focus should be placed on perceived competence during the conduct of an experiment and analysis of the results to support student motivation. This suggested emphasis is of special importance for designing and evaluating competence-supportive measures during experimentation. Further studies might embrace this issue and design differentiated measures to support student motivation during experimentation.

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SPANISH STUDENTS' PERCEPTIONS OF THEIR SCHOOL SCIENCE: THE RELEVANCE OF SCIENCE EDUCATION (SECOND) PROJECT

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This paper studies the Spanish students' perceptions of their school science classes and some additional comparisons across several variables in order to update affective data on science education from the students' voice. The theoretical and methodological background are drawn from the elaborations and contributions of the Relevance of Science Education Second (ROSES) project, from its predecessor, the Rose-2002 project, and from literature on science-related attitudes. The participants are 15-year-old Spanish students (n = 152), who answered the ROSE-2020 questionnaire. This study refers to the scale "my science class", which asks for students' agreement/disagreement on twelve items that depict several aspects of school science education. The findings report the aspects that conform the students' highest perceptions (interest, importance of science and curiosity) and their lowest perceptions (the intention to become scientists or to get a job in technology) on school science. Further, some comparisons across gender, science choice and along time pinpoint some significant differences across groups. The differences with previous Rose-2002 point out that both waves display the same overall profile for students' perceptions, yet the 2020 perceptions display progress across all items, making the overall picture of current science class more encouraging and optimistic than the previous one. However, the science career gap still remains a challenge for science education. Further, the students planning to choose science next year show significant higher agreements on science classes than the others, yet the gender differences seem widely fading. Beyond the positive achievements, developing students' interest and curiosity through science education and renewing the efforts to close the vocational and gender gap towards scientific and technological careers are discussed and some agencies recommended.

Keywords: perceptions of school science, gender issues, student choices

INTRODUCTION

The Relevance of Science Education (ROSE) project (thereafter Rose-2002) gave voice the students to diagnose their attitudes to science and technology worldwide twenty years ago. an overall pattern of disenchantment with STEM and many gender differences was reported for young people in Western countries, where the science career gap was dramatic, as few Western teens would like to become a scientist or a technologist, and extremely fewer girls (Sjøberg & Schreiner, 2019). Spanish teens fit somewhat the previous pattern, yet the gender differences were the lowest of Western countries (Vázquez & Manassero, 2007).

Recently, a new wave called ROSE Second (ROSES-2020) has been launched to update the evidence about young people's attitudes towards science worldwide. This paper aims to present some results of Spanish students' perceptions about school science classes and their gender, time and choice differences, and to discuss some recommendations for improving education within science, technology, engineering and maths (STEM) on the basis of extant evidence (Jidesjö et al., 2021).

Rationale and framework: 21st century challenges

The current knowledge societies are deeply embedded in STEM and many of the challenges they are facing are STEM-related challenges: environmental issues are perennial and COVID19 is the last but not least. International organizations like UNESCO, OECD and the European Union pay increasing attention to education, and in particular to STEM education, because STEM literacy plays key roles and gains importance in modern societies. STEM education is key both for the STEM-driven economies and for personal, social, cultural and democratic aims, where STEM-literate and participating citizenry is on the focus (OECD, 2016b).

Large-scale international achievement testing like TIMSS and PISA assess student cognitive learning and the related factors that may explain test scores. The affective factors are not the key concerns of TIMSS and PISA, as their main focus is cognitive (the knowledge of science) yet the last waves present some attention towards attitudes; for instance, PISA 2015 appreciated some increase in student enjoyment of science. Further, many top scoring countries on TIMSS and PISA tend to display low interest and attitudes to science, which is a main concern for STEM education (OECD, 2016a). The lack of perceived relevance for school science education is probably the greatest barrier to STEM literacy, to significant STEM learning and to develop interest toward STEM subjects, and these hindrances harm personal and social interests in the long run. Thus, positive attitudes towards STEM are worth and important learning goals for school education.

ROSES-2020 project gives again voice to students for gathering empirically-based insights into the affective contexts of STEM education to unveil the factors that conform their attitudes and motivations to learn STEM, thus complementing TIMSS and PISA cognitive aims. The focus on students' voice reflects the idea that students have something to say about their education and schools, the values, interests, and cultural backgrounds of individual and groups of students, and the corresponding pedagogies that are based on student choices, opinions, and ambitions. The literature on student voice develops the faithful attention to students' voice and their engagement and motivation in learning (Quaglia & Corso, 2014).

Rose-2002 study collected worldwide answers to "School Science Classes" (Sjøberg & Schreiner, 2019) and set up their general profile: school science was less interesting than other school subjects and displayed a strong gender difference pattern, with girls disagreeing more than boys in the wealthier countries. The statement claiming that science has opened my eyes for new and exciting jobs displays the same gender pattern and the lowest agreement scores for the richest countries. Three statements about school science (teaching to take care of my health, increasing my curiosity and showing the importance of STEM for our way of living) display less than half respondents agreeing with in most European countries.

Recently, Aschim et al. (2021) displayed the ROSES-2020 Norway results that represent a reference for this study on school science classes. The proportion of Norwegian students agreeing that school science is interesting is high (68%), yet in regard of school science opening eyes to new and exciting jobs the agreement rates stay around a low agreement rate (ca. 30%), slightly higher in ROSES-2020. The proportion of students that like school science better than most other subjects has increased from 33% (Rose-2002) to 41% (ROSES-2020). Further, the proportion of students agreeing that science will be useful in their everyday life shows a slight decrease (from 57% in Rose-2002 to 54% in ROSES-2020).

The picture of school science between Norwegian boys and girls are nuanced and interesting. In 2002 a significant proportion of boys (larger than girls) agreed that school science is interesting, better than most other subjects, helpful for everyday life, and opened to new and exciting jobs. In 2020 the gender differences have strongly decreased and the differences have even been reversed in some items, such as about school science has been helpful in my everyday life and opened eyes to new and exciting jobs (Aschim et al., 2021).

Impacts, aims and hypothesis

ROSES-2020 specifically aims to develop sound theoretical perspectives that are sensitive to the diversity of student backgrounds (cultural, social, gender, etc.) for evidence-based discussions related to education. As a consequence, ROSES-2020 aims to contribute recommendations for the improvement of STEM teaching, curricula, textbooks and classroom activities on the basis of the empirical findings about student voices and to raise some critical issues related to the relevance and importance of STEM and education for public debates on scientific and educational issues (i.e., reliable information, fake news, health, environment, etc.).

The innovation of ROSES-2020 project lies in the shift from mainstream cognitive knowledge (i.e., TIMSS and PISA) toward alternative criteria for success in education, which are related to innovative attitudinal aspects on STEM: interest, positive attitudes, willingness to engage in STEM issues, understanding the significance of STEM for our well-being and culture, etc.

This attitudinal shift in science education is closely linked with fostering sustainable, lasting and life-long results on STEM learning, through improving STEM literacy, motivation and engagement to STEM (school subjects, careers and occupations) and coping with gender differences. Overall, the results on gender differences are the most striking findings that discouragingly impact STEM learning and the recruitment to STEM. The low proportion of girls willing to choose STEM careers and occupations is a key concern in many countries. For instance, Spanish educational system at grades 11-12 splits up into vocational and pre-college studies, the latter enrolling a majority of girls (53.5%); then, pre-college students split again between science and non-science careers, where science careers enrol 52.7% girls, which is quite close of the global women enrolment. Thus, the Spanish statistics does not show any challenging gender gap between science and non-science studies at this overall level, yet some women underrepresentation appear at some STEM careers (physics, engineering or computers).

The ROSES-2020 data may provide equitable insights into how are configured the students' attitudes and opinions and how to increase girls' interest and motivation for STEM studies and careers. The overall hypothesis deal with the diagnostic of the current Spanish student attitudes and opinions about STEM education and its comparison to those diagnosed 20 years before. Further analysis across gender, type of school, choices, community, family books, etc. allow comparisons and hypothesis testing across groups and variables.

The research question posed here refers to the Spanish students' perception of school science classes: How do students perceive their school science? What features are perceived better and worse? These main questions are developed in regard of comparisons across gender, future choice and Rose-2002 previous results: How do ROSES-2020 results relate to the previous Rose-2002 results? Do the differences represent a progress or a regress? How do boys and girls perceive their school science classes? How does future science choice affect perception of school science classes?

METHODOLOGY

ROSES-2020 uses a mixed-method methodology, which involve qualitative and quantitative procedures to analyse the answers to the questionnaire and the comparisons between groups of students, yet for this preliminary study only quantitative data are used.

Participants

The ROSES-2020 target population are the students at the end of their compulsory education, because this educational stage allows students looking back to their education, reflect on what they have learned on STEM, and on how the educational choices for further studies are going to be made. This target population points out to students in late secondary education (aged 15) that corresponds in Spain to 3rd and 4th courses of the lower secondary education (grades 9-10). The participants in this study are 152 Spanish students (78 boys, 64 women and 10 blank), who validly answered ROSE-2020 questionnaire (average, 15.3 years). The participants are attending 4 publics and 2 public-funded private secondary schools, placed at a small city and at the suburb and the center of two different cities. The participants attend four public and two public-funded private secondary schools that are located at two small cities and at the suburb and the centre of two big cities, where they were surveyed by their teachers through whole group-class, which balances experiences across the independent variables (gender, choice, etc.)

Materials

The ROSES-2020 core methodological tool is a large questionnaire (ROSES-Q) that was developed by an international team of science education experts to gather the different affective data about the attitudes towards school and out-of-school experiences in science education, environment, interests, priorities, images and perceptions that are relevant for their STEM learning and literacy. Students answer ROSES-Q anonymously and they are free to let some items unanswered. ROSES-Q starts with a short presentation and a few background questions (sex, age, nationality and school and books at home); lastly, some country-specific items about city, region, and current engagement and future choice of STEM school subjects are asked.

The attitudinal categories of ROSES-Q involve interest in learning about STEM contents, priorities and motivations for a future occupation, views about environmental challenges, perceptions of school science classes and science education, perceptions on the role of STEM in society, use of ICT at home and school, out of school experiences related to STEM and two short open essays on “Myself as a scientist” and “the future occupation”.

The item wording is direct, simple, short, and avoids negative statements. Most items adopt the format of four-point Likert scale (1 – 4), where students are asked to tick the appropriate box number that best expresses their attitudes on the item. The meaning of box numbers varies across scales through the following categories: Disagree-Agree (the case for science classes scale), Not interested–Very interested, Not important–Very important, etc.

Procedures

The focus of this study is the scale of ROSES-Q categorized as "My science classes", where students are asked to sincerely answer about their perceptions of 12 aspects of the science classes on a four-point Likert scale (table 1). The students' responses on each item are codified as 1 (disagree), 2, 3 and 4 (agree); the agreement percent and weighted averages are computed to display simple and faithful representation of student opinions. Let's take into account that item 1 has a negative wording (science is difficult) so that its score interpretation must be reversed: lower scores (disagreement) mean the students perceive science less difficult and higher scores (agreement) mean the students perceive science more difficult.

The data gathering took place from April until November 2020, when the schools were temporarily closed and the students were taught on line due to the COVID19 pandemic. Students anonymously and digitally answered the ROSES-2020 questionnaire as an on-line class assignment led and collected by their teachers at each participating school. The researchers and the secondary school teachers collaborated in real time to manage the administration process in each group class, the distribution to students the on-line links and the control of the reports on the questions and incidences during the surveying process.

RESULTS

The results are based on the participant students' answers to the 12-item school science classes scale of the ROSES-Q. Table 1 summarises the descriptive statistics of students' responses; the percent of agreement is computed by collapsing the students' answers on the 3 or 4-point of the Likert scale. Further, the negative wording of item 1 that asks for the difficulty of school science subject requires a reversed interpretation of its scoring; for instance, 42.4% of agreement to difficulty means that a complementary majority of students (57.6%) do not perceive school science as difficult. Likewise, the average (2.40) must be reversed to its complementary (2.60), to join the same meaning of the remaining items.

The overall picture of student perceptions on school science is positive as most items (8) reach agreement rates over 50% and mean scores over the middle point of the Likert scale (2.5). However, some differences are appreciated across items; for instance, the top agreement items are item 2 (school science is interesting) and item 7 (school science has increased my curiosity), both showing large majority of students who perceive school science interesting (81.9%) and increasing the curiosity (70.7%).

On the other hand, the bottom agreement items are item 10 (wish to become a scientist) and item 11 (wish to get a job in technology), both reaching the lowest rates (around 30%) and the lowest average scores (around 1.9). These results depict the so-called vocational gap to STEM studies and careers among young people: few teens would like to enrol in STEM.

Table 1. Descriptive statistics for students' responses to the items of the scale "My science classes".

Item sentences	ROSES_2020				ROSES_2002	
	Mean (1-4)	St.D. Error	Standard deviation	Agree* (3-4)	Mean	SD
F1. School science is a difficult subject**	2.40	0.080	0.983	42.4%	2.58	0.77
F2. School science is interesting	3.26	0.070	0.867	81.9%	2.79	0.77

F3. School science has opened my eyes to new and exciting jobs	2.63	0.087	1.058	53.3%	2.28	0.89
F4. I like school science better than most other subjects	2.61	0.095	1.153	56.5%	2.31	1.00
F5. The things that I learn in science at school will be helpful in my everyday life	2.69	0.077	0.948	60.2%	2.46	0.82
F6. School science has made me more critical and sceptical	2.31	0.084	0.997	46.0%	2.07	0.81
F7. School science has increased my curiosity about things we cannot yet explain	3.01	0.085	1.033	70.7%	2.81	0.90
F8. School science has shown me the importance of science for our way of living	2.89	0.079	0.958	66.7%	2.65	0.82
F9. School science has taught me how to take better care of my health	2.55	0.083	1.008	56.5%	2.43	0.81
F10. I would like to become a scientist	2.03	0.091	1.106	31.2%	1.96	1.01
F11. I would like to get a job in technology	2.12	0.092	1.120	29.3%	1.90	0.99
F12. School science has helped me to understand sustainability solutions in my everyday life***	2.43	0.077	0.929	51.1%	-	-

* Percent of students who agree (scoring 3 or 4 on the Likert scale)
** This item displays a reverse writing (difficult); the interpretation of its scores must be inverted.
*** This item was not involved in Rose-2002

Comparison of the current ROSES-2020 results with the previous Rose-2002 results

The current sample data (ROSES-2020) are compared with the previous results (ROSE-2002) that were drawn from a larger sample at the same Spanish region (figure 1) just along the 11 items that share exactly the same content at both waves (item 12 of ROSES-2020 is excluded for not being included in Rose-2002).

The comparison depicts some relevant findings. First, the overall profiles of both waves are quite parallel (the apparent exception to parallelism of item 1 is due to the reversed meaning of item 1 for its negative formulation); thus, the student overall perception of science classes displays the same structure at both waves, which means that the highest, lowest and medium agreement items are roughly the same. For instance, item 2 (interesting) and item 7 (curiosity) have got the top scores, whilst student willingness to be a scientist or to have a job in technology have got the lowest scores at both waves, and the same applies for the intermediate items.

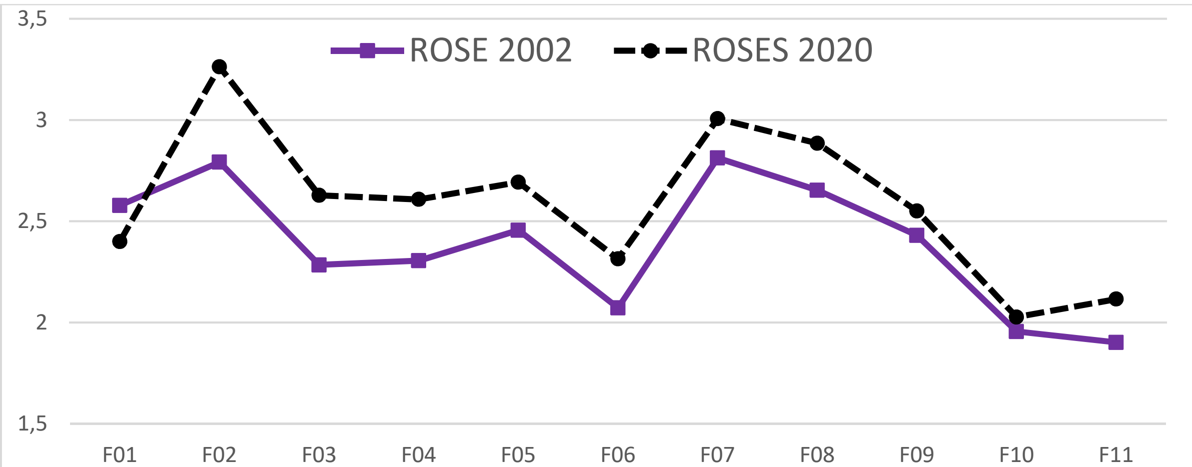

Figure 1. Average scores along the 11 common items of "My science classes" scale for Rose-2002 and ROSES-2020.

The most interesting finding is that ROSES-2020 perceptions display higher mean scores than Rose-2002 scores along all items, yet the effect size of the differences is only important (over half standard deviation; d = .57) for item 2 (school science is interesting). Thus, the overall meaning of this finding suggests that the current Spanish students hold a better perception of science classes than their mates' perceptions twenty years ago. Summing up, the student's appreciation of their science classes have improved along all items, and this global trend makes more relevant the progress of the students' perceptions.

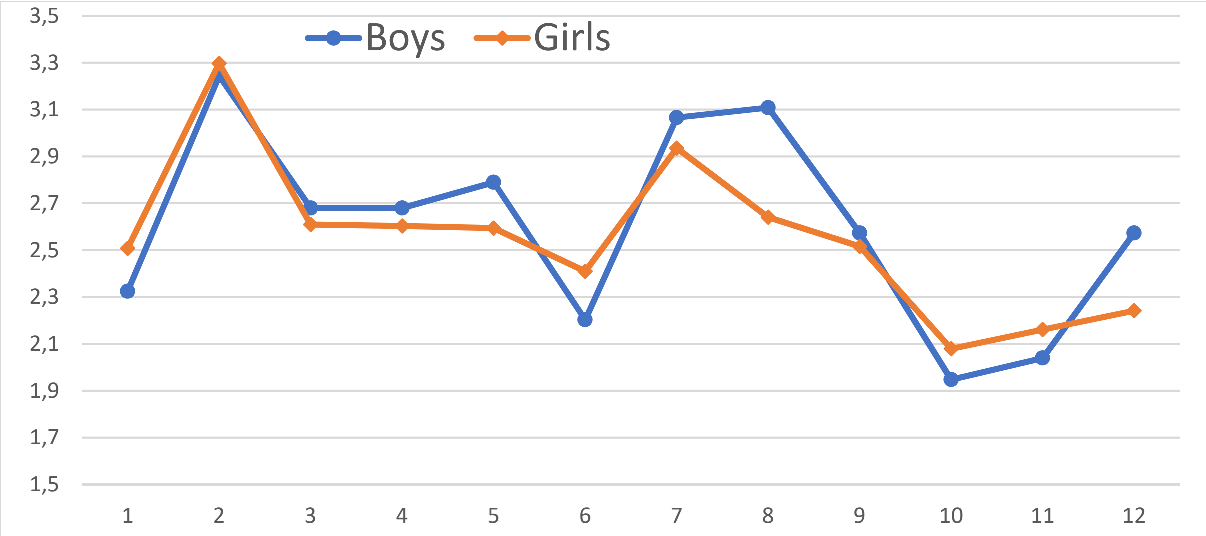

Figure 2. Average scores of "My science classes" scale items for boys and girls.

Comparison between boys and girls

The comparison between boys and girls along the items of the school science classes scale displays some significant findings (figure 2). Overall, boys' mean scores tend to be higher than girls' mean scores across a majority of items (8 out of 12 items); however, most differences are not statistically significant as only two items (8 and 12) display a moderate effect size for gender differences (d = .49 and d = .36 respectively).

Amid this expected outperformance of boys, the main finding to highlight on gender differences point out to girls higher scores than boys on their intention to be scientists (10) or to get a job in technology (11). The novelty of this result stems from the reversion of the usual gender stereotype on career gap (few girls hold a STEM vocation), as Spanish girls display stronger intentions than boys to pursue STEM careers, yet the differences are not significant.

Students expected future choice for science subject and perception of science classes

The organization of education in Spain compels 15-year-old Spanish students to make a choice between science and non-science subjects next year. Thus, ROSES-Q asked students whether they would choose a science subject, other subject or were undecided, and the perceptions of science classes have been analysed among these three response groups.

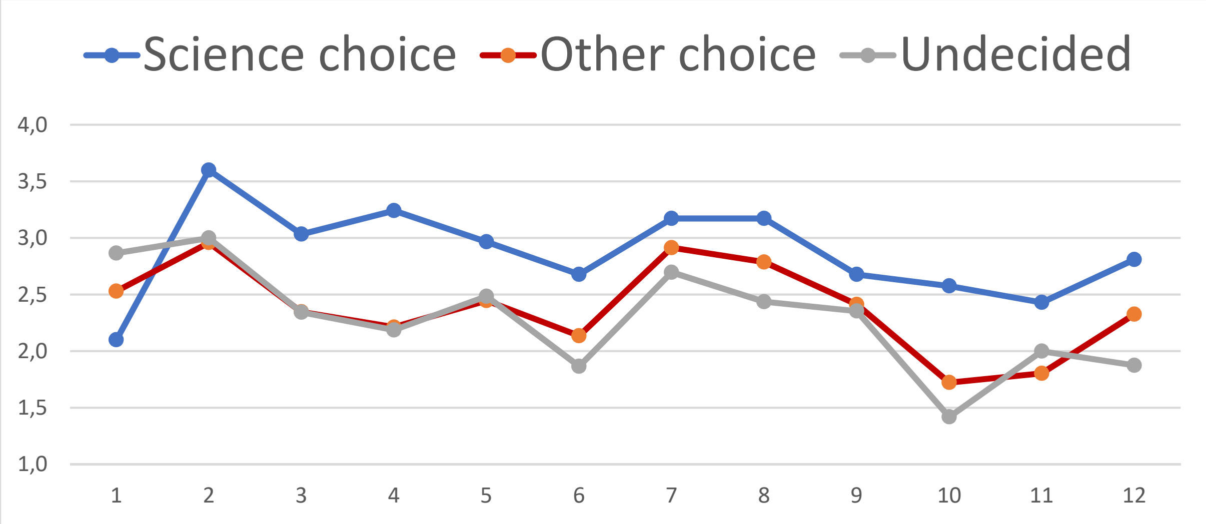

Figure 3. Average scores of "My science classes" scale items for the three student groups that next year will choose science, will make another choice or are undecided.

The results (figure 3) show that the students who will choose a science subject next year display the most positive perceptions of the science classes in regard of the two remaining groups (the undecided and the non-science choice groups), which in turn do not show significant differences between them. Further, half a dozen items of the perceptions on science classes (2, 3, 4, 5, 6 and 10) display relevant differences (effect size greater than half standard deviation) between the choosing science group and the others. This result suggests that improving the quality of classes may help the induction towards scientific careers and vocations.

CONCLUSIONS

The main finding of this study shows the overall student perceptions on school science classes are positive, as the majority of items display over 50% agreement and their weighted means are over the scale midpoint. Thus, the answer to the first research question is positive: Spanish students hold positive views about their school science classes. Further, the results allow pinpointing that the best perceived features of school science are its interest and its development of curiosity; on the other hand, the worst features correspond to the low rate of agreement to become scientists or to get a job in technology (the STEM vocational gap).

The comparisons with the baseline of Rose-2002 previous results confirm an overall similar profile of student perceptions of school science classes at both waves, which involves sharing the highest scored features (interest, importance of science and curiosity), as well as the lowest scored features (the intention to be scientists or to get a job in technology). This stability of profiles suggests some stability of "My science class" scale scores, which may lead to studying their psychometric properties (i.e., validity and reliability). Further, the main finding and positive news highlights that current scores are higher than Rose-2002 across all items, which points out that students' perceptions of school science classes have become more positive. This interpretation justifies the claim that the students' perceptions of school science show clear and positive progress in the last 20 years, which are also good news for Spanish STEM education. Thus, the general pattern of disenchantment suggested by Sjøberg and Schreiner (2019) does not apply to the perception of school science that stems from this Spanish sample.

Further, the gender differences still display the traditional stereotypical gendered pattern in favour of boys, in spite most differences are not statistically significant. Surprisingly, the most striking finding to highlight here is that girls outperform boys on their intention to be scientists or to get a job in technology, because it breaks the girls' traditional profile of lower vocations to STEM. These results are in line to the Norwegian students' overall reduction of gender differences on their perception of school science (Aschim et al. 2021).

The comparison of science classes perceptions across the students' intention to choose a science subject (or other subject) for the next year shows that the students who are willing to choose a science subject have got more significant and relevant perceptions of science classes than the remaining mates (undecided o willing to choose another subject). In spite this result may be expected, the good news is that science classes may induce students into the STEM pipeline.

In spite of the positive findings on science classes there is still room for improvement starting from some weakness reported here. An overall improvement aim must point out to increase all those features of science classes that have got the bottom scores; for instance, make students more critical and sceptical may be improved by developing their critical thinking skills that are also inherent to the scientific way of thinking. However, the main challenge would focus on the career gap to STEM studies, as it still remains a world concern of 21st century educational challenges for the current STEM-embedded societies (OECD, 2016a).

Finally, this study relates to the ESERA conference theme "Fostering scientific citizenship in an uncertain world" having in mind the severe social and educational changes resulting from the COVID19 public health problem, as it gives voice to students about their perception of school science in order to promote a student-centred and evidence-based framework specifically aimed to enhance STEM education (Quaglia & Corso, 2014). Taking the students' voices as the evidence to develop approaches to education that are aligned to the findings suggest the implementation of evidence-based pedagogy to teach science. Besides, the study also highlights the students as participating citizens, as their collaboration for assessing their school science classes is an exercise of students' responsible participation and engagement in their education (OECD, 2016b).

The main limitation of the present study arises from the tiny size of the sample, which makes the results tentative. As the project is currently in progress, it is expected that future larger samples will allow us to follow-up and, eventually, to confirm the trends presented here.

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CONTEXT-BASED LEARNING AS A METHOD FOR DIFFERENTIATED INSTRUCTION IN CHEMISTRY EDUCATION

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A well-known strategy to deal with heterogeneity in the classroom is called differentiated instruction. While the results of performance-based differentiation in chemistry education mostly do not show significant effects, research results on context-based learning indicate the potential of interest-based differentiation through contextual tasks with systematically varied characteristics. However, it is unclear which groups of students benefit from which contexts. The goal of this study is to identify groups of students that differ in terms of their context choice and to investigate how these students evaluate their choice after working on a context-based task in chemistry. For this purpose, a questionnaire study has been conducted with 349 third-year learners in chemistry in secondary schools. Through a cluster analysis based on individual student characteristics, four groups of students could be identified that show varying preferences at contexts with different characteristics. The results will be used for an interest-based differentiation with the help of systematically varied contextual tasks.

Keywords: Context-based Learning, differentiated instruction, Student Choices

THEORETICAL BACKGROUND

One of the expected impacts of the pandemic-related school closures is the increasing heterogeneity of students in class (Hammerstein et al., 2021). A central strategy to respond to this heterogeneity is called differentiated instruction. Differentiated instruction is an approach for teaching, in which the teacher takes the learning needs of small groups of students into account and varies his or her teaching accordingly (Tomlinson, 2016).

However, there is insufficient evidence for the effectiveness of differentiated instruction in secondary education (Smale-Jacobse et al., 2019). In chemistry education, first studies have been conducted that have investigated the effectiveness of differentiated instruction according to students' performance. Studies to date have mostly not found any effects of performance-based differentiation in chemistry education (e.g., Kallweit & Melle, 2014). As an additional approach, affective student characteristics (e.g., interest) could also be used to differentiate students' learning.

One way to address students' interests in chemistry is using out-of-school situations (so called contexts) with different overarching characteristics (Habig et al., 2018) . Bennett (2016) defines contexts as external situations that are used as a starting point for the development of subject matter. Furthermore, van Vorst et al. (2015) describe context characteristics, deduced from an in-depth literature review, to differentiate between contexts in science education systematically. One frequently observed context characteristic is *familiarity*. This characteristic is strongly dependent on the individual experiences of the students and is more closely described by the context characteristics *everyday* and *uncommon*. An *everyday* context has a strong relation to the living environment of the students (George & Lubben, 2002), while *uncommon* contexts deal with objects and situations that occur only rarely or not at all in the immediate students' daily life (Kasanda et al., 2005).

Habig et al. (2018) conducted a study to examine the effects of everyday contexts compared to uncommon contexts on student outcomes in chemistry education. The results indicate that students with a high level of interest and prior knowledge in chemistry benefit from uncommon contexts. In contrast, learners with a low interest and prior knowledge in chemistry benefit from everyday contexts. This leads to the assumption that individual student characteristics must be considered for an appropriate selection of contextual tasks.

For this reason, a further study investigated which contextual tasks are suitable for which students (van Vorst & Aydogmus, 2021). Students' context choice, their choice motives, and their satisfaction after completing the task in chemistry class were surveyed in this study. Three different clusters of students could be identified, which differed in terms of their context choice and choice motives. The first cluster consisted mainly of students with a low interest in chemistry. These students chose everyday contexts and indicated personal relevance as the most important motive for their choice. The second group summarized students with a high level of interest in chemistry. They chose uncommon contexts due to curiosity and interest. The third group was heterogeneous in terms of interest in chemistry and showed no clear contextual preference or choice motive. Additionally, these students were less satisfied with their chosen tasks compared to students from the first and the second cluster.

Based on these results, van Vorst & Aydogmus (2021) assumed that the third cluster may include students who are more interested in chemistry itself and do not need a context for their learning. A task without context uses a chemical situation (e.g., a situation from the laboratory) instead of an external situation as a starting point for learning. Based on the state of research to date, it is still unclear how to characterize students who choose everyday contexts, uncommon contexts, or tasks without a context. However, this information is necessary to offer appropriate contexts to different students in interest-based differentiated instruction.

RESEARCH QUESTIONS

The main goal of the study presented in this paper is to investigate which students choose which contextual tasks (everyday context, uncommon context, or non-contextualized task). Moreover, the aim is to examine how students evaluate their choice decision after working on their chosen task to find out whether the task suited the students. The following research questions will be answered.

(1) Which groups of students can be distinguished in their context choice with regard to their personal characteristics and which contextual preference do they show?

(2) How do students evaluate their context choice in terms of satisfaction, situational interest, and cognitive load after working on a chosen context-based task?

METHOD

To answer the research questions, a quantitative study with the help of questionnaires has been conducted. The context choice of 349 students (male: 49.9%; female: 50.1%) of the third year in learning chemistry from seven different secondary schools in Germany has been analyzed.

The study has been conducted using tablet computers in regular chemistry classes within 90 minutes. Figure 1 gives an overview of the proceeding of the study.

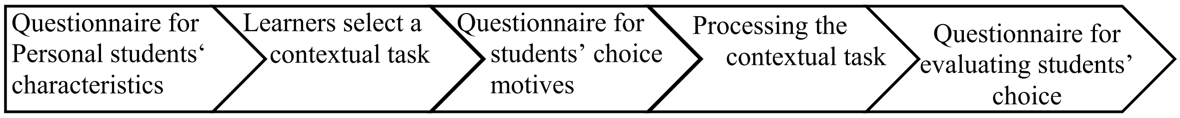

Figure 3. Design of the study.

In a first step, students’ individual variables like their demographic data, reading comprehension (Schneider et al., 2017), content knowledge in chemistry (Celik & Walpuski, 2018), individual interest and motivation in chemistry (Wild & Krapp, 1995), their chemical self-concept (Hoffmann et al., 1998), the leisure interest (Albert et al., 2019) as well as their career choice perspective (Kunter et al., 2002) have been surveyed. Afterwards, five different tasks have been presented to the students: two tasks were dealing with an everyday context, two tasks were dealing with an uncommon context and the last task was dealing with the chemical content without a context (Tab. 1).

Table 5. Developed contextual tasks and their characteristic affiliation.

Context characteristic	Context
Relation to everyday Life	Why brushing teeth is so important
	Our digestion
Uncommon Phenomena	The consequences of chronic gastritis type a
	Bone damage due to chronic renal insufficiency
Non-contextualized	Acids in the laboratory

To ensure that the context choice can be clearly attributed to the corresponding context characteristic, all tasks were completely identical except for the underlying context characteristic. All tasks addressed the chemical content acidic and alkaline solutions, which is rather interesting for most students (Habig, 2017). This was to ensure that enough students chose the non-contextualized task to characterize this group in more detail. Furthermore, all contextualized tasks focused on a context from the field of the human body and human diseases to address the interests of both genders as far as possible (Sjøberg & Schreiner, 2010). Lastly, all tasks were identical with regard to task formulation and external characteristics (e.g., layout, text structure, text length). In the next step, students’ choice motives (van Vorst & Aydogmus, 2021) have been investigated by using another questionnaire. Afterwards, students worked on their selected task. Finally, a questionnaire on satisfaction (own development), situational interest (Engeln, 2004), and cognitive load (Schwamborn et al., 2011) have been used to evaluate the choice decision.

RESULTS

Statistical data were analyzed using the statistical software *R*. Different packages were used, which significantly extend the functionality of R. We examined the quality of the knowledge test using Item Response Theory (Bond et al., 2021). Exploratory factor analyses and reliability analyses were used to examine the quality of the affective test instruments. Significant differences in person characteristics were analyzed using a multivariate analysis of variance

(MANOVA) followed by multiple analyses of variance (ANOVAs) to avoid the inflation of the familywise error rate (Field et al., 2013). Subsequently, we conducted a K-means cluster analysis to identify homogeneous groups of students. The number of clusters was determined using different measures such as the elbow criterion or the silhouette coefficient (Everitt et al., 2011). Linear regression analyses were performed to examine relations (Field et al., 2013).

Quality of the survey instruments

The quality of the knowledge test has been analyzed using *Item Response Theory*. We analyzed an one-dimensional Rasch model (e.g., Bond et al., 2021). The analysis of the model fit showes that all test items fit the calculated Rasch model ($0.87 \leq$ wMNSQ ≤ 1.10; $-1.99 \leq$ ZSTD ≤ 1.55). Despite this, the test indicates a questionable reliability (WLE-Reliability = .63).

For the analysis of the other test instruments, we conducted an exploratory factor analyses with subsequent reliability analyses (Field et al., 2013). The scales formed by factor analyses show sufficient reliabilities ($.68 \leq$ Cronbach's $\alpha \leq .94$).

Students' context choice

A majority of the students (63.6%) in this sample have chosen an everyday context. Furthermore, 20.1% have chosen an uncommon context and 16.3% have chosen the non-contextualized task.

To respond to the first research question, students have been grouped based on their personal characteristics. For this, variables that contribute to the separation of the groups have to be selected first. We have examined the personal characteristics that distinguish the students who have chosen a particular contextual task. The personal characteristics of the students who selected a certain contextual characteristic were compared for differences descriptively and inferentially (using a MANOVA and multiple ANOVAs). There are statistically significant differences with regard to performance ($F(2, 346) = 15.99$, $p < .001$, $\eta^2 = .08$), individual interest ($F(2, 346) = 5.80$, $p < .01$, $\eta^2 = .03$), chemistry-related self-concept ($F(2, 346) = 16.55$, $p < .001$, $\eta^2 = .09$), the choice motive of personal relevance ($F(2, 344) = 100.88$, $p < .001$, $\eta^2 = .37$), and the choice motive of surprising information ($F(2, 344) = 15.99$, $p < .001$, $\eta^2 = .08$). A one-way MANOVA shows a statistically significant difference between the students who have chosen a particular contextual task on the combined dependent variables ($F(2, 682) = 27.1$, $p < .001$, partial $\eta^2 = .27$, Wilk's $\Lambda = .51$).

A K-means cluster analysis has been conducted to identify groups of students who are as similar as possible regarding these personal characteristics. Analysis point to a four-cluster solution. Figure 2 shows the mean scores for the four clusters of students' personal characteristics.

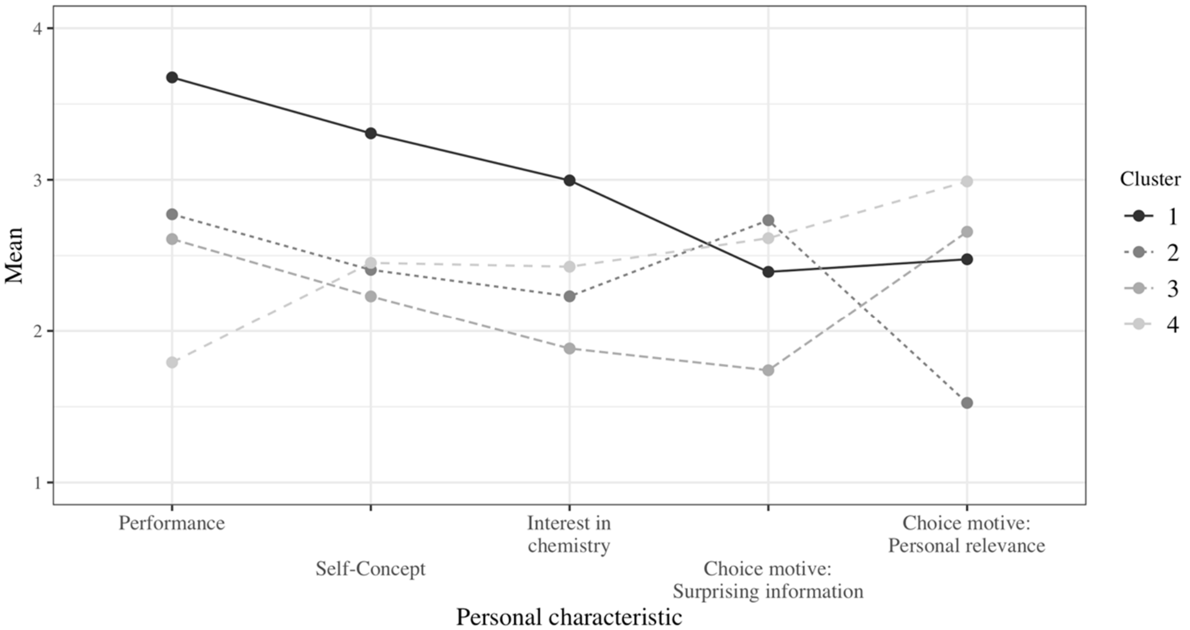

Figure 4. Mean Scores for the four clusters of students' personal characteristics. The person abilities from the Rasch model were transformed to a range of values from 1 to 4 for clarity.

Students from the first cluster show the highest performance, the highest self-concept, and the highest interest in chemistry in this sample. The choice motives surprising information and personal relevance are almost equally important in this cluster. 37.8% of these students have chosen the non-contextualized task, which is about twice as often as in the whole sample. Nevertheless, more students (48.8%) have chosen the everyday context.

The second cluster includes students with a lower performance, self-concept, and interest in chemistry. The primary choice motive is surprising information. Students from this cluster have chosen uncommon contexts to 60.0%. This is almost three times higher compared to the total sample.

Students with a lower performance, interest and self-concept compared to the students from the second cluster make up the third cluster. The primary choice motive is personal relevance. 84.5% of the students have chosen an everyday context. This is almost 20% higher than in the whole sample.

The last cluster contains students with a similar self-concept and a slightly higher interest compared to students from the second cluster. However, students in the fourth cluster show a much lower performance. The choice motive surprising information is almost as important as in the second cluster, but the personal relevance of a context is an even more important motive for choosing a context. This leads to the fact that 81.1 % of the students in the fourth cluster have chosen an everyday context.

Furthermore, we examined to what extent the clusters differ with regard to reading comprehension. Our results show that students from the last cluster (M = 17.51, SD = 12.94) have a much lower reading comprehension compared to students from the first (M = 26.30, SD = 12.94), second (M = 25.40, SD = 12.78), or third (M = 22.62, SD = 12.78) cluster. An ANOVA points to a statistically significant difference (F (3,330) = 7.65, p < .001, η^2 = .07). The Tukey post-hoc test indicates significant differences at $p < .05$ between the last and the other clusters, with no significant difference between the first three clusters.

Evaluation of context choice

The descriptive and inferential statistical analysis show that students in a certain cluster do not differ in satisfaction, situational interest or cognitive load depending on the chosen contextual task.

Satisfaction and situational interest after working on the selected task mainly depend on personal characteristics such as interest in chemistry. Results of a linear regression analysis show that interest in chemistry significantly predicts situational interest ($F(1,333) = 82.43$, $p < .001$, $R^2 = .20$) after working on the chosen task.

DISCUSSION

The results show that most learners choose an everyday context for learning chemistry. Other studies also found a preference for contexts with a personal relevance (Broman et al., 2020).

The context choice from the first cluster indicates that learners with high performance and high interest in chemistry are more likely to choose non-contextualized tasks. This cluster could be a group of learners that has also been identified in the study by van Vorst & Aydogmus (2021). This group of students might not be interested in contexts and thus, is not influenced by any context. The authors hypothesized that this type of student may be high-performing and/or highly interested, and not in need of an additional context. Based on our data, it can be shown that this type of students choose non-contextualized contexts more often. It is possible that a context is perceived as disruptive by this group because they want to learn more about chemistry itself. Only hypotheses can be made about the exact reasons since no clear choice motive could be identified in this cluster. However, this is also because the test instrument for assessing the choice motives did not include a scale for measuring the motives for choosing a non-contextualized task.

The second cluster indicates a type of students who is interested in chemistry and shows an intermediate level of performance. In addition, these learners choose a context based on surprising information. This is also reflected in their choice of a context, as a large proportion of these students choose the uncommon context. A higher situational interest of highly interested students in uncommon contexts has also been found by Habig et al. (2018). The authors conclude that the uncommon context is a special incentive for highly interested people to expand their knowledge.

Learners with the lowest performance, interest and self-concept belong to the third cluster. The primary motive for choice in this group of learners is personal relevance. Accordingly, more than 80% of the learners also choose an everyday context. Other studies also show a preference of low-interest students for contexts with a personal relevance (Habig et al., 2018; van Vorst & Aydogmus, 2021). We conclude that a connection to everyday life is probably needed for uninterested and low-performing students to engage in chemistry at all.

The profile of the fourth cluster is rather unusual, with learners showing the lowest performance but medium interest and self-concept. In comparison with the other clusters, it is noticeable that the reading comprehension of this group of learners is significantly lower than that of the other groups. For this reason, it is doubtful to what extent the context choice can be interpreted, as the learners may not have understood the description of the context.

After the learners' context selection and task processing, no differences in the clusters could be identified in terms of satisfaction, situational interest, and cognitive load. Therefore, we assume that all learners have chosen an appropriate context for themselves and hence, were satisfied with their choice after task processing.

OUTLOOK

The results could be used for data-supported differentiation in chemistry education (c.f., learning analytics; Clow, 2013) . A further study will be conducted to investigate the effects of an interest-based differentiated instruction, using contexts with different characteristics in chemistry. For this purpose, a recommendation system (Khanal et al., 2020) will be developed that suggests a context to students based on their individual characteristics.

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TEACHING STRATEGIES TO PROMOTE METACOGNITIVE REGULATION IN SECOND LEVEL CHEMISTRY EDUCATION

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This study aimed to address a gap between theory and practice in relation to students' metacognitive regulation in the upper second-level chemistry classroom. The gap pertains to the theoretical evidence that metacognitive regulation is an important skill in learning chemistry whereas attempts to incorporate specific teaching strategies in authentic classrooms are rare in comparison to traditional teaching approaches. To do so, metacognitive teaching and learning strategies were implemented with an upper second level class group studying chemistry over the course of an academic year, which included explicit metacognitive teaching, metacognitive modelling by teacher and student, think aloud protocol, regulatory checklists and pre and post lesson reflections. All lessons were audio and video recorded. A rubric was developed to analyse the teacher actions and dialogue in relation to metacognitive regulation. Students completed the Metacognitive Awareness Inventory at the beginning and end of the academic year. A significant increase was identified in students' overall metacognitive regulation, as well as in specific subcategories thereof.

Keywords: Metacognition, Teaching Practices, Conceptual Change

INTRODUCTION

Georghiades (2004) identified a theory-practice gap – which still exists today – where academic studies highlight the value of metacognition for science learning but reported attempts to highlight metacognition in classrooms are rare (e.g., Davidson et al, 1998). In agreement with Georghiades (2004), Thomas (2012) argues that while there are few researchers who question the importance of metacognition, the recognition of this importance is not reflected in teachers' or teacher educators' practices. Thomas (2012) also stresses that the extent to which teachers themselves are metacognitive is not clear and calls for more research on teacher metacognition because it might enable increased effectiveness of professional development in this area. Metacognitive regulation involves controlling one's cognitive processes and refers to the management of cognitive activities during learning, e.g., making changes in processes or strategies as a result of monitoring (Flavell et al., 2002; Whitebread et al., 2009). Though no universally accepted definition of metacognition can be found in the literature (Dinsmore, Alexander, & Loughlin, 2008; Harrison & Vallin, 2018), a longstanding view is that it comprises two components: knowledge of cognition and regulation of cognition. How metacognitive regulation can be improved through the implementation of teaching and learning strategies which address it are at the centre of the current study. Previous research has taken place into a range of teaching and learning strategies which highlight student metacognitive regulation (e.g. Schön, 1987; King, 1998; Tien, Rickey, & Stacy, 1999; Thomas & McRobbie, 2001; Chiu, & Linn, 2012; Ellis & Denton, 2013; Trimble, Lovatt & Finlayson, 2019).

Metacognitive regulation in this research refers to the regulation or control of one's cognition and one's knowledge about planning, implementing, evaluating, and correcting behaviours. The definition of the subcategories of the metacognitive regulation adopted in this research are outlined in Table 1.

Table 1. Subcategories of the metacognitive regulation

Metacognitive regulation		
Sub category	**Description**	**Example(s)**
Planning	Setting goals, selecting appropriate strategies, making predictions, strategy sequencing and allocating resources.	When one formulates the goal of an assignment or problem, and also decides which steps are needed to get the answer.
Monitoring	Monitoring of one's own cognitive processes which involves awareness and assessment of comprehension and task performance and progress towards the desired goal	In relation to a calculation, one checks whether every step has been calculated well and whether one has made any careless mistakes.
Evaluation	Entails an assessment of the products and efficiency of one's learning and thinking, for example through self-checking, reflection and re-evaluation, reviewing task performance, learning processes.	In relation to a calculation, one compares the outcome of the calculation to one's initial estimate, or do a recalculation.

When engaging in higher order thinking, students need to undergo specific metacognitive skills like monitoring their thinking process, checking whether progress is being made toward an appropriate goal, ensuring accuracy, and making decisions about the use of time and mental effort (Halpern, 1998). In light of this, the current research investigates the incorporation and implementation of teaching and learning strategies which specifically address student metacognitive regulation with a second level chemistry class group. The specific research questions addressed were:

1. *Are teaching and learning strategies which focus on developing student's metacognitive regulation identified in the literature suitable for integration into upper second level chemistry lessons?*
2. *How are metacognitive teaching and learning strategies which address metacognitive regulation evaluated in upper second level chemistry lessons?*
3. *Is there a significant difference between students' pre-test and post test scores on measures of student metacognitive regulation?*

In the initial stages of this research, teaching and learning strategies were identified in the literature which encourage metacognitive regulation in students (Schon, 1987; Schunk, 1989; King, 1991; Stensvold and Wilson, 1992; Butler & Winne, 1995; Elder and Paul 1998; Schraw, 1998; Rickey and Stacey 2000; Thomas and McRobbie, 2001; Gilbert, 2005; Kipins and Hofstein 2007). Following this, two pilot studies were carried out with students who were completing a module in chemistry before entering upper second level education. An analysis of the strategies implemented in these pilot studies identified a number of teaching and learning strategies which are suited for upper second level chemistry lessons (as summarised in table 2). A metacognitive teaching plan was developed by the researcher-practitioner to this end. It was piloted in the academic year 2018-19 and was implemented throughout the academic year 2019 –2020. Implementation of the teaching plan was evaluated through analysis of teacher actions and dialogue, class discussions, classroom activities, student generated work as well as a metacognitive student journal which was developed as part of this research. A rubric for analysing teacher actions and dialogue which promote metacognitive regulation was also developed.

Assessment and evaluation of students' metacognition regulation presents a problem, due to the nature of observing and/or quantifying a phenomenon which relates to one's own thoughts about how aware of, or in control of, one is of one's thoughts. Previous researchers (Winne & Perry, 2000; Muis et al. 2007; Pieschl et al. 2012) have argued metacognition can be assessed as either an aptitude or an event. When metacognition is viewed as an aptitude, students are assumed to possess tactics of metacognition as a relatively enduring trait or to employ relatively stable approaches when solving different tasks When metacognition is viewed as an event, the utilisation of metacognitive tactics is assumed to vary dramatically across different tasks/events, and students are assumed to adjust their learning behaviour dynamically to adapt to different context or task/event demands. Pintrich et al. (2000) argue that including metacognitive regulation, is similar to other kinds of knowledge stored in the long-term memory and that it can be accessed when properly cued. In this line of reasoning, they argue that self-reports are appropriate, as an easy and efficient measurement. The Metacognitive Awareness Inventory (MAI) is a self-report instrument designed to assess general self-regulated learning skills across the disciplines. Developed by Schraw and Dennison (1994), The MAI was developed specifically to address the two theoretical components (or dimensions) of metacognition: knowledge of cognition (17 items) and regulation of cognition (35 items).

Measuring metacognition as an event requires examining the metacognitive skills in real time to capture the dynamic processes within a particular task. Methods are required that allow researchers to document, identify and examine the target behaviours and verbalisations as they occur in real time during an authentic event or situation (Cleary, 2011).

METHOD

Participants

The study was concerned with the teaching and learning of upper second level chemistry in authentic upper second level chemistry lessons. The class group of students in this research were from a non-fee-paying school, drawing from across academic and socioeconomic backgrounds. Data was collected before (MAI), during (video and audio recording, student generated work) and after (MAI) the implementation of the teaching plan. The student participants numbered 24 male students aged between 17-18 years old. A convenient sample was used in this research as the participants are part of the researcher/practitioner's normal class group who have chosen to study chemistry and were in year one of their final two years of upper second level education.

Teaching and Learning Strategies

The teaching and learning strategies implemented and evaluated in lessons which addressed promoting student metacognitive regulation are outlined in Table 2. Each of the activities were developed in the pilot studies of this research and were included in the lessons throughout the academic year in the current study. The sequencing of topics was such that initial topics (e.g., states of matter, gases laws, ionic and covalent bonding, acids and bases etc) where addressed through the lens of concepts such as electronegativity, electrostatic attraction, collision theory, bond energy and consequently building on these threshold concepts. The aim of order of topics was to provide a conceptual structure in which students could improve metacognitive regulation. A student metacognitive chemistry journal contained student templates for activities which promoted metacognitive regulation e.g., pre and post lesson reflections; visualisation of concepts sheets; regulatory checklists; homework and test wrappers.

Table 2. Teaching and learning strategies to promote and incorporate metacognitive regulation in lessons.

Strategy	Details
Metacognitive prompts and questioning;	Metacognitive cues, questions or regulatory checklists that were used by the students during activities such as problem-solving, experimentation, inquiry learning, reading chemistry texts, writing reports and reflections, or discussing science topics
Reflective writing;	Students were asked to write a metacognitive journal about their thinking, visualisation and learning, pre and post lesson surveys, or written responses to reflective prompts.
Visualisation of concepts	Students were asked to link visualisation of concepts in chemistry with the development of their understanding of concepts.
Practice and training	Repeated training and practice which provided opportunities for activating and applying metacognitive knowledge and metacognitive skills in multiple tasks, problems and contexts.
Teacher led metacognitive discussions	Whole class and group discussions of thinking and learning processes, discussions in which the teacher talks with their students about their thinking and learning in order to encourage and develop metacognitive thinking.
Student led metacognitive discussions	Student-led discussions were scaffolded using various instructional aids such as cues and prompts that evoke cognitive or metacognitive processes, scenarios and case studies, stimulated recall using think aloud protocol, student teacher metacognitive modelling.
Explicit metacognitive instruction	Explanations and demonstrations by the teacher regarding specific cognitive or metacognitive strategies and knowledge construction activities which require learners to construct their metacognitive knowledge. Explicit instruction was also embedded in the student metacognitive journal and homework activities.

In this study quantitative and qualitative methods were combined to explore the classroom's learning environment, and the participants' metacognitive regulation. Previous studies have argued for the value of employing a mixed methods methodology in metacognitive research and many studies in the field of learning environments and across education employ such approaches (Johnson & Onwuegbuzie, 2004; Tashakkori & Teddlie, 2010).

Qualitative methods

The visual and audio recordings and student generated work were analysed to identify the strategies used, the frequency of such strategies and to relate these with the quantitative results obtained. The audio and video recordings were analysed to identify specific instances where events occurred during the class that specifically highlighted metacognitive regulation strategies. A rubric was developed for analysing visual and audio recordings for the occurrence of teacher actions (e.g., teacher dialogue, specific teaching and learning strategies) which aimed to promote metacognitive regulation in students (Table 3). Each of the teacher actions were further categorised as specifically aimed at development of student sub-categories of metacognition i.e., Planning, Monitoring, and Evaluation. Development of the rubric for analysis of visual and audio recordings included cross coder agreement involving the researcher/practitioner and the supervisors of this research project, who are professors in STEM education. The qualitative data collected was analysed using QSR International's NVivo 12 qualitative data analytical software.

Table 3. Summary of the rubric developed for video analysis teacher actions incorporate metacognitive regulation

Subcategory	Description of Behaviour
Planning	Teacher decides (or asks students to decide) on procedures necessary for performing the task, individually or with others Teacher sets or clarifies (or asks students to set or clarify) task demands and expectations Teacher (allocates or asks students to allocate) individual roles and negotiates responsibilities Teacher sets (or asks students to set) goals and targets Teacher decides (or asks students to decide) on ways of proceeding with the task Teacher seeks (or asks students to seek) and collect necessary resources
Monitoring	Teacher assesses (or encourages students to assess) the quality of task performance (of self or others) and the degree to which performance is progressing towards a desired goal Teacher (or teacher asks students) to review progress on task (keeping track of procedures currently being undertaken and those that have been done so far) Teacher rates (or teacher asks students to rate) effort on-task or rates actual performance Teacher rates (or teacher asks students to rate) makes comments on currently memory retrieval Teacher checks (or encourages students to check) their behaviours or performance, including detection of errors, self-corrects.
Evaluation	Teacher verbalises or behaves, (or asks a student to verbalise or behave) to reviewing task performance and evaluating the quality of performance (by self or others) Teacher explains (or asks students to explain) their own learning or explain the task. Teacher evaluates (or asks students to evaluate) the strategies they used Teacher rates (or asks students to rate) the quality of their performance Teacher observes or comments (asks students to observe or comment) on task progress, or to test the outcome or effectiveness of a strategy in achieving a goal

Quantitative methods

The Metacognitive Awareness Inventory (MAI) is a self-report instrument designed to assess general self-regulated learning skills across the disciplines. Developed by Schraw and Dennison (1994), the MAI was developed specifically to address the two theoretical components (or dimensions) of metacognition: knowledge of cognition (17 items) and regulation of cognition (35 items). The analysis quantitative data collected in this included the use of the statistical software Statistical Product and Service Solutions (SPSS) (IBM Corp., 2017).

RESULTS

Visual and audio recording Analysis

Using the rubric developed the number of occurrences of teaching and learning strategies which address metacognitive regulation are displayed in Figure 1.

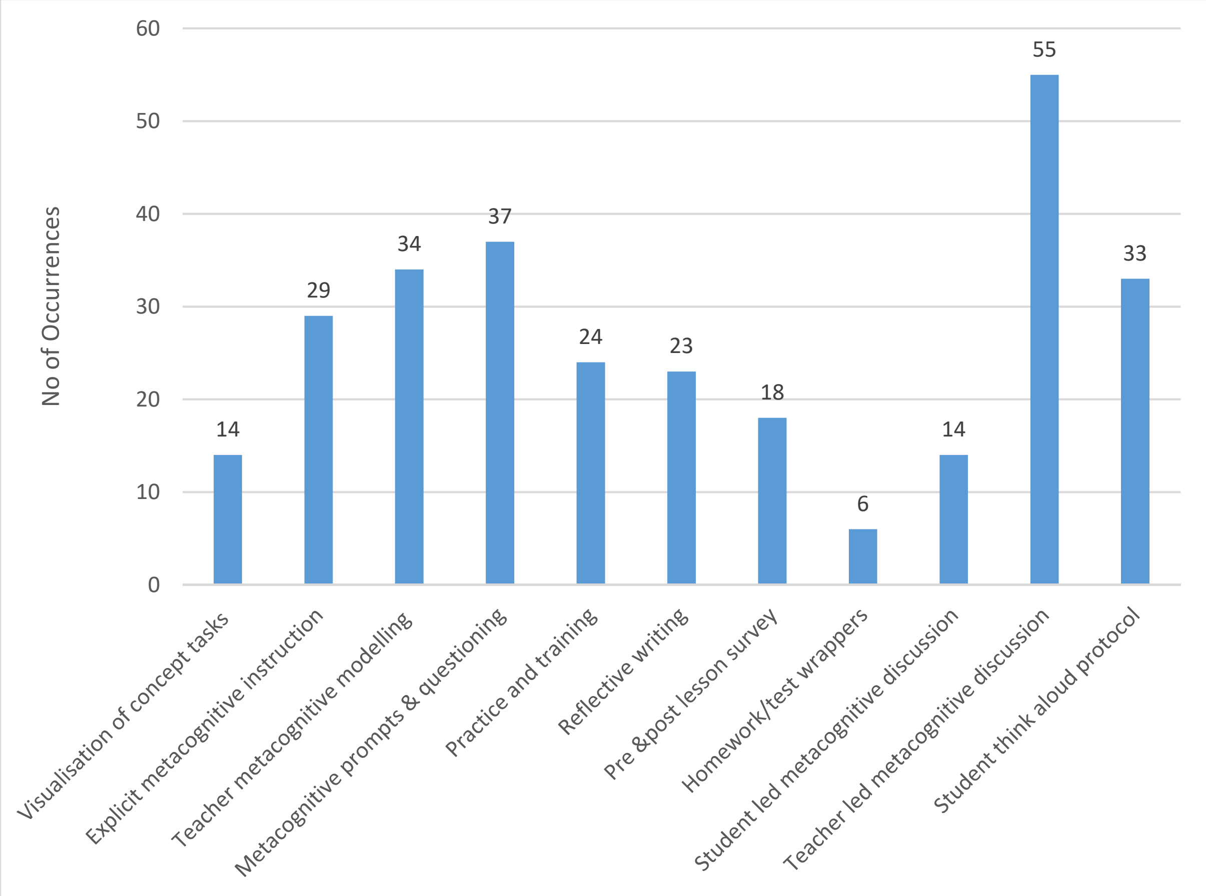

Figure 1. Occurrences of teacher actions addressing metacognitive regulation

Using the rubric developed in this research, the number of occurrences (during the 40 lessons analysed) of indicators of actions or dialogue by the teacher which addressed the subcategories of metacognitive regulation are outlined in Figure 2.

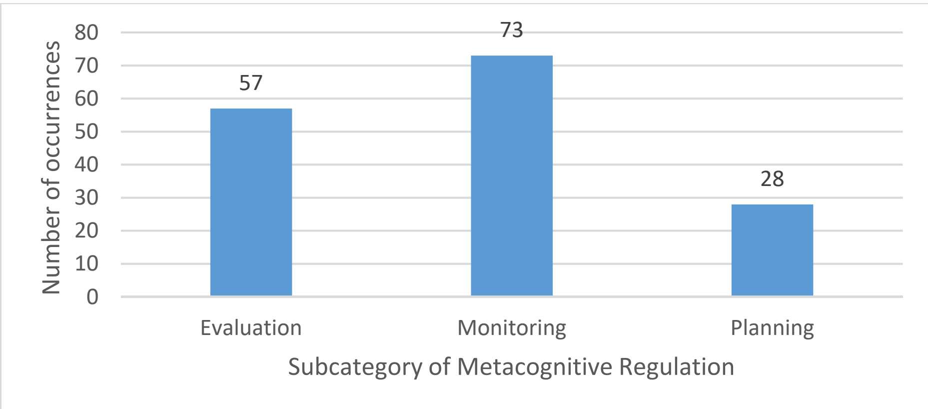

Figure 2. Occurrences of teacher actions addressing metacognitive regulation

A paired sample t test was conducted to evaluate whether a statistically significant difference existed between the mean scores in the subcategories of metacognitive regulation in the Metacognitive Awareness Inventory (MAI) before and after of the year. For the purpose of this study, only the 35 items which pertain to metacognitive regulation are included. A summary of the statistically significant increases in the subcategories of metacognitive regulation (MAI) scores are shown in Figure 3. The subcategory of metacognitive regulation (using the MAI) which did not show a statistically significant change in score pre and post the data collection period was evaluation.

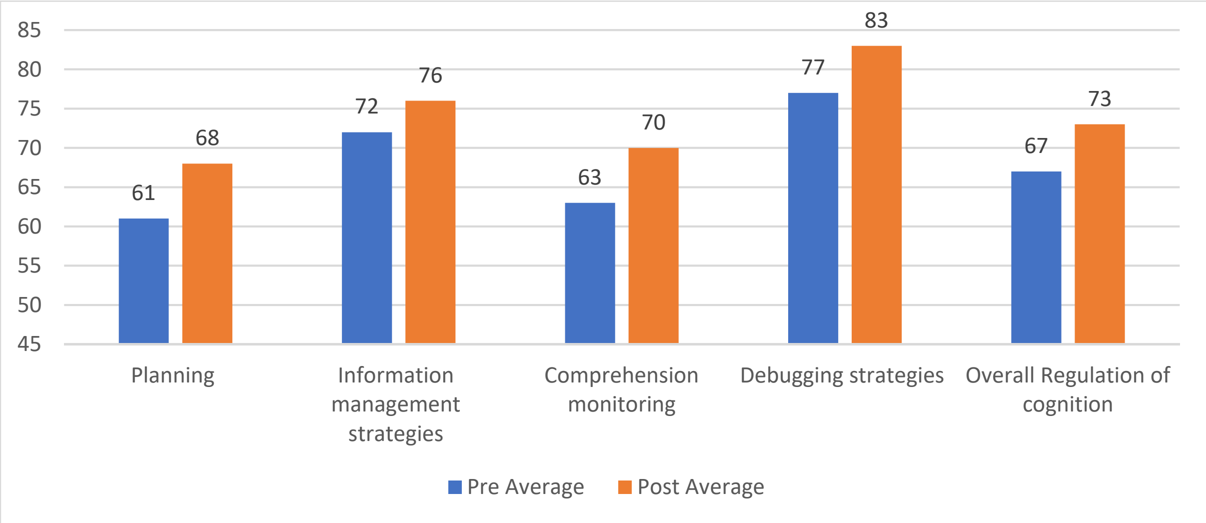

Figure 3. Metacognitive regulation subcategories within Metacognitive Awareness Inventory (MAI) which showed statistically significant changes pre and post the research period.

The paired sample t test which was conducted to evaluate whether a statistically significant difference existed between the mean metacognitive regulation (MAI) scores before and after the research period showed there was a statistically significant difference. Assumption testing indicated no gross violation of the assumptions. The results of the sample t test where significant $t(23) = -4.15$, $p < 0.05$, $\eta 2 = 0.43$ indicating that there is significant increase in metacognitive regulation (MAI) from pre survey (Mean = 0.7, S.D.=0.1, N = 24) to the post survey (mean = 0.7, S.D. = 0.07, N = 24). The effect size (= 0.85) was large based on Cohens conventions (1988). The mean increase was 0.065888 with the 95% confidence interval for the difference between the means of 0.1 and 0.03. The researcher rejected the null hypothesis.

DISCUSSION AND CONCLUSIONS

The metacognitive teaching plan implementation was analysed using the visual and audio records of 40 lessons throughout the academic year 2019-2020. The developed metacognitive journal was used in lessons throughout the research period. Development of the rubric for the analysis of the visual and audio recordings required extensive time-consuming work to ensure validity and reliability using cross coder agreement.

Analysis of the pre and post research period surveys showed a significant statistically important increase in student metacognitive regulation at the beginning and at the end of the research period, as measured by the MAI. The metacognitive teaching plan which included teaching and learning strategies to promote metacognitive regulation identified in the literature were embedded in lessons in upper second level chemistry lessons, this was evaluated and confirmed using visual and audio analysis.

The metacognitive teaching and learning strategies which address metacognitive regulation used in this study were evaluated using visual and audio recordings, practitioner reflections and pre and post research period surveys. A rubric was developed for analysis of visual and audio recordings of teacher actions which incorporate metacognitive regulation

There was a statistically significantly important increase in student's scores in the overall knowledge of cognition, regulation of cognition as reported using the Metacognitive Awareness inventory (MAI).

Limitations of this research include there are that additional factors which could have had an influence of the average metacognitive regulation score (as assessed by the MAI) of the students in the research include the metacognitive teaching plan, increases in conceptual understanding and confidence in chemistry and increase in the age and experience of the students. Isolating any of these variables in a quasi-experimental investigation would be difficult to achieve, and have ethical implications if such a study was carried out.

Future work

This study is part of a larger research project. The research period for the second phase in this research took place during the academic year 2020-21 which involved a pre-service chemistry teacher training module. Phase two of the project was informed by the research carried out in current study. Phase two of the research focused on two aspects of preservice education, namely (i) developing the preservice teachers own metacognitive knowledge and regulation, and (ii) developing the preservice teachers' metacognitive teaching and learning strategies which they can use to develop greater conceptual understanding of chemistry in their future students. A full analysis of the data collected in phase two of the research is currently being carried out.

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THE IMPACT OF PHYSICS ANXIETY ON PERSONAL AND COLLECTIVE AGENCY IN THE PHYSICS CLASSROOM

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School students' attitudes towards physics have been well documented and it is commonly perceived that female students' attitudes towards physics are less positive than those of male students. This has been found in studies researching a range of factors including interest, identity, subject choice, self-beliefs and participation. Physics anxiety is a phenomenon that can be described as students having negative emotional dispositions towards activities in physics lessons, and physics lessons themselves beyond test anxiety. Using Bandura's social cognitive theory, one of the antecedents of self-efficacy, emotional arousal, which relates to levels of anxiety, significant statistical differences were found between the anxiety levels of female students and their male peers in physics lessons. Observations of physics lessons and subsequent qualitative interviews with students confirmed that female students tended to minimise their participation in physics lessons due to concerns about obstructing the learning of others if they proffered incorrect answers in lessons or did not understand a concept. High attaining female students highlighted that physics was not a subject for them confirming widely held stereotype that physics is viewed as more of a male pursuit.

Keywords: Physics, Self-Efficacy, Gender Issues

BACKGROUND

With fewer students choosing physics compared to the other sciences for post compulsory education and the generally perceived unpopularity of physics as a subject or topic of interest in wider society, there is a need to discover the essence of students' relationship with physics in school. Female students' attitudes towards science in school are typically less favourable than male students' attitudes (Barmby, Kind and Jones, 2008). Mathematics anxiety is a term that describes how students hold negative affective states/expressions in anticipation of and during lesson activities in mathematics (Roth and Walshaw, 2015). Roth and Walshaw (ibid) used Vygotsky's socio-cultural framework to investigate maths anxiety in the classroom and highlighted how students' anxiety stems from a loss of agency within the context of the classroom due to the influences of the classroom environment and the relationships students have with their teacher and peers. Though less researched as a phenomenon, physics anxiety has been found to similarly impact on students' affective states in physics lessons and has been considered as significant as other factors such as students' self-efficacy (Sahin *et al*., 2015). Student anxiety in physics has been labelled as a 'stereotype threat' (Steele and Aronson, 1995), highlighting students' perceptions of physics being a difficult subject as well as a male dominated pursuit. Trujillo and Tanner (2014) suggest moving from a student deficit model that solely focuses on conceptual development to a dynamic model that takes into account affirmative affective influences in order to improve students' experiences of their learning environment that will also help to develop their conceptual understanding. The importance of emotions in learning and development was acknowledged by Vygotsky when considering the collaboration involved in the interpsychological relationships as part of the Zone of Proximal Development (Mahn and John-Steiner, 2002). Positive emotions help to develop confidence that can affirm one's beliefs about their capabilities that enhances one's agency that can influence goal driven actions.

Bandura's (1986) Social Cognitive Theory (SCT) attempts to explain the influencing factors that underpin human agency and its role in people's ability to exercise control in their lives. He argued that human agency derives from a dynamic relationship between personal, behavioural and environmental determinants. In the classroom, students' experiences of their surroundings and their relationship with their teacher and peers interact with personal factors that influences their actions in the classroom. Self-efficacy, a key personal determinant, is described as a person's situated belief that they can be successful in a specific pursuit. Bandura (1977, p. 3) defined self-efficacy as ". . . *beliefs in one's capabilities to organize and execute the courses of action required to produce given attainments"*, which, in academic settings, relates to students' beliefs in their capabilities to succeed in subject related tasks and activities. A comparative study of male and female participants with similar performative levels in an introductory physics course (Marshman *et al*., 2018) reported that female students had lower self-efficacy than their male counterparts due to their experiences, and perceptions, of their course. The authors highlight structural and sociocultural biases as well as the impact of the physics class environment with raised anxiety levels leading to female students doubting their capabilities to be successful in physics.

Students' low self-efficacy beliefs can raise their anxiety levels whilst attempting challenging activities which can generate avoidance strategies (Britner and Pajares, 2006). Studies at high school level have shown gender differences in self-perceptions of capabilities in physics (Hazari *et al*., 2010). Hazari *et al.* (ibid) also identified student participation in physics lessons as a factor in enhancing students' self-perceptions, in part due to the sense of becoming an authoritative participant in class with greater confidence and empowerment, i.e. having a greater sense of personal agency.

Collective agency is another factor of human agency in Bandura's SCT and, in a school context, is associated with the interrelated dynamics of the classroom and the wider structures of school and society. In a physics lesson, the collective agency of the class, i.e. the teacher, students and support staff, is not simply the additive sum of personal agencies but an emergent group-level collective property (Bandura, 2001). Students' motivations and actions will be facilitated by the collective belief of the class that it is possible to understand physics concepts, be focussed in, and enjoy physics lessons. Bandura warns against a dualistic dichotomy between personal and collective agency. Humans are not abstract entities divorced from social systems. Individuals' interpretation of socio-structural authorised rules, practices and sanctions allows for a dynamic interplay between an individual and their environment. However, individuals do not just react to their environment, they operate proactively and generatively to influence and shape social structures highlighting the reciprocal nature of intrapersonal and interpersonal domains. Thus, if students, in particular female students, perceive their self-efficacy and personal agency as low in a physics lesson, the overall collective agency of the class will be impacted upon and may result in an overall reduced sense of capability to succeed in physics in school. This study's aims were to investigate female students' anxiety levels and their behaviours in physics lessons demonstrating their personal agencies in the wider social context of the class as part of a wider study focussed on interventions to enhance students' self-efficacy beliefs in physics lessons.

METHODS

A mixed methods approach was used in this study involving three methods: a survey, lesson observations and individual semi-structured interviews. 117 students (female 54, male 63) across five classes (aged 14-16 years old) of the same secondary school in London completed a self-efficacy survey during one of their physics lessons and one class of Year 10 students (15 years old) was chosen to observe physics lessons after the students had completed the survey. Semi-structured interviews were conducted with a sample of students from the Year 10 class after the lesson observations.

Self-Efficacy Survey

The survey instrument used was derived from the Sources of Self-Efficacy in Science - Physics (SOSESC-P) survey (Fencl & Scheel, 2005). The survey contains 33 items in total. The items are specifically designed to be grouped into four subscales for the theoretically derived four sources of self-efficacy (Bandura, 1997) (10 items for Mastery Experiences, 7 items for Vicarious Learning, 7 Items for Social Persuasion and 9 items for Emotional Arousal). This study concentrates on the nine items explicitly focussed on the emotional arousal antecedent of self-efficacy. The surveys were conducted in physics lessons and participants responded to each item using a 10-point Likert scale with responses from 1 (not at all like me) to 10 (very much like me). Some item's scores were reversed. For example, for item 18 'Physics makes me feel uneasy and confused', a score of '2' indicating that the student did not think this was like their behaviour was reversed to a score of '9'. The average score of all the 33 items was calculated to provide a proxy self-efficacy score in physics in school out of 10, the higher the score the higher the level of self-efficacy. Average scores for each antecedent were also calculated, this research utilised the data for the emotional arousal antecedent. Descriptive and statistical analyses of the survey data were conducted on the whole scale and each of the antecedent subscales to explore if there were any significant differences between male and female students' responses. The internal consistency of the entire survey and each of the four antecedents was found using Cronbach's alpha and was found to be 0.912 for the entire survey and 0.820 for the emotional arousal subscale.

Lesson Observations

A high achieving Year 10 class (24 students, 9 female and 15 male) was selected for lesson observations. The class was taught by a male teacher with two years' experience working as a physics specialist at the school. After analysis of the survey data and a discussion with the teacher about seating arrangements in the class, a group of students (3 female and 3 male) were selected to be the focus of the observations. The author observed four physics lessons each of one hour duration. The Year 10 class were learning about different aspects of Forces for each lesson following the AQA awarding body specification.

The focus of the observations was to monitor the students' interactions with peers and with the teacher as well as to record the students' behaviours during the lesson activities. Fieldnotes were taken during each lesson with details of the episodes of the lesson recorded as well as details of the student interactions and behaviours. Immediately after each lesson, the author annotated the fieldnotes with reflections about the student interactions and engagement during the lessons. Codes were identified according to the self-efficacy antecedents of Bandura's (1997) SCT for the group as a whole and for the male and the female students respectively.

Interviews

Individual semi-structured interviews were conducted with the six students who had been the focus of the lesson observations. The interviews provided an opportunity for the students to elaborate on their responses to the survey as well as to discuss their experiences (including affective states) during the lessons that were observed. All interviews were audio recorded and subsequently transcribed by the author.

The author adhered to a constant comparative analysis (Miles, Huberman and Saldaña, 2020) between the data sets. The interview transcripts were carefully read and coded based on Bandura's (1997) construct of agency involving personal, behavioural and environmental factors. The codes for the interviews and lesson observations were compared to discover emerging themes about the students' affective experiences and the exercise of their agency in the lessons.

FINDINGS

Independent t-tests were conducted for the data for all 117 participants who completed the SOSESC-P survey comparing the scores for male and female students. There were significant statistical differences for 18 of the 33 items from the survey including 7 of the 9 items associated with the emotional arousal antecedent of self-efficacy (see Table 1). The majority of male and female students disagreed with the statement that it was fun to go into physics lessons but there was an overall positive response to conducting practical work in lessons. This is consistent with research on students' attitudes of science education (Barmby, Kind and Jones, 2008) and the affective value of practical work (Sharpe and Abrahams, 2020). Data from the lesson observations echoed the more positive attitude towards conducting practical work and watching demonstrations compared to working on questions in worksheets and exam style questions.

The data from the emotional arousal subscale of the survey highlight the overall more negative affective dispositions of the female students in physics lessons compared to the male students. Table 1 shows that female students have lower scores on average for each of the items for the emotional arousal antecedent of self-efficacy. The average scores for the emotional arousal antecedent of self-efficacy for the class was 6.24 with male students' scores higher than that of the female students (male - 6.50, female - 5.80). Negative responses for the majority of students were particularly noted in relation to taking tests and when solving problems in class. The female students' response to worrying about solving physics problems was statistically significantly different to the male students' response for the same item.

Table 1. Average scores of emotional arousal survey items.

Emotional Arousal Survey Items Sample	Male	Female
My mind goes blank and I am unable to think clearly during physics tests*	6.93	5.76
I usually feel at ease in physics lessons*	5.94	4.35
I enjoy physics experiments*	7.89	6.59
I usually don't worry or stress about solving physics problems**	5.19	4.22
Physics makes me feel uneasy and confused (R)*	6.75	5.27
I get a sinking feeling when I think of trying to answer difficult physics questions and problems (R)*	6.38	5.04
I can relax and enjoy physics lessons*	5.63	4.41
I think it is fun to go into physics lessons	4.71	3.69
I get uptight when I take physics tests	5.93	5.19

*t<0.01 **t<0.05, R – *Reversed item – scores for items marked (R) have been reversed*

Data from the lesson observations highlighted that generally female students, though on-task in all activities involving individual and small group tasks and discussions, did not engage to the same level as the male students. This was also witnessed in whole class discussions where the female students remained quiet and rarely voluntarily participated called upon to do so by the teacher. Female students, tended not to volunteer to answer the teacher's questions in front of the whole class by raising their hand but would answer questions from the teacher if directly called upon to do so. Conversely, the male students, engaged very willingly, particularly to answer the teachers' questions. The male students did not appear to be deterred by providing an incorrect response and remained keen to respond to subsequent questions.

There was a difference in how male and female students overcame challenges during activities. If a male student could not answer a question on a worksheet, they would actively seek to find a correct method or solution by asking a peer. On the other hand, female students tended to either move on to another question or disengage from working on the worksheet rather than ask a peer for support. If the teacher noticed that the female student had stopped working, he would ask if they needed support and the student would ask for help.

During practical activities, if working in a mixed groups the male students would take charge of organising the equipment. One activity involved measuring the acceleration due to gravity. The female students stood back when the male students assembled the equipment but did get involved in discussions about recording appropriate measurements and finding patterns in the data as the practical was being conducted. When the group was asked to report their data to the whole class, one of the male students opted to state the group's results with the female students not willing to volunteer.

As well as answering the majority of questions during episodes of whole class discussion, male students asked more questions directed towards the teacher. This resulted in explanations from the teacher and other male students in response to the questions but the female students did not partake in these discussions. These episodes were quite lively and the male students appeared to enjoy the back and forth discussion with the teacher. The female students did appear to be attentive to these discussions, as confirmed in the interviews, but were not willing to interject or ask for further explanation if they did not understand an aspect of the discussion relating to content on forces.

The lesson observations highlighted that the students were having very different experiences during physics lessons and their agency was apparent whether they were visibly fully engaged or appearing to be passive during the lessons. Although the teacher had planned for many collaborative activities during the lessons with space for input from the students, female students worked with their peers less compared to the male students. The male students appeared to be happy to work collectively whilst the female students, working together during practical activities, mostly worked independently for other activities.

During the interviews, when asked about their lack of participation during whole class lesson episodes, the female students' responses included that they did not want to obstruct their peers' learning and did not want to answer incorrectly as they were worried about how this would be viewed by their peers.

I think I am more keen to do practicals rather than joining in in class discussions because I feel a lot of pressure, like getting answers wrong and not understanding it as well as other people in the classroom (not understanding).

They made comparisons with their peers which led to judgements about their own capabilities to engage in the physics activities and their ability to be successful in the subject at school.

I just feel like, I don't know what the word is but my self-esteem would go low. It's like everyone else understands it (Physics) *and I don't understand it and I am holding up the class because I don't know the answer.*

The female students expressed that they had high anxiety levels in school on the days that they had physics lessons and had thus developed a 'coping mechanism' of low participation levels in class in an attempt to minimise their feelings of anxiety. Two female students stated that they were self-motivated to learn physics at home by researching for appropriate YouTube videos on the physics topics that were taught in lessons. One female student, although able to achieve well in physics tests due to time spent revising at home, did not expect to be successful in physics overall, and declared that if she had an option of no taking the subject, she would chose an alternative such as chemistry.

In contrast, the male students expressed satisfaction with their engagement and understanding of concepts in the forces topic during the physics lessons and their ability to support others.

I do well in physics when I fully understand the concept and I have realised that I can explain that concept to anyone in my whole class and I understand it well. That's when I think okay, I have learnt that well, I'm good at it.

They also discussed that they were confident in their capabilities to be successful in the subject and were not put off if they made a mistake and recalled what they had done to ensure they remembered the correct answer in the future by collectively working with one another student,

I can explain to Ajay (pseudonym) *and let's say I got something wrong that Ajay knows, he will correct me. The concept that I know thoroughly, that I think I know thoroughly, but let's say I missed out a very important part of it, he'll explain it back to me as well, so we both are like, our minds are coming together.*

The same student had provided a wrong answer for a question from the teacher during a summing up of a worksheet activity. He appeared disappointed that he had gotten the question wrong but, when appropriate, he sought an explanation from a peer and appeared to be satisfied that he now understood his mistake.

The male students explained that they put more effort to learning physics in school with only a simple going over of content at home to ensure that they understood the concepts taught that day. As one student stated,

To rate out of ten, I probably give a seven in class and then out of school probably four… I focus on it in class and go over it once at home.

The male students demonstrated that they had good working relationships with one another with an apparent collective agency that aided their support for one another to learn physics in lessons. The support did extend to the female students to but requests for this support were not forthcoming from the female students. Their beliefs about their capabilities and their agency meant that they had frequent input into the lesson and spent more time interacting with peers and with the teacher than the female students did.

CONCLUSION

This research describes how students exercise their agency in lessons based on their beliefs about their capabilities in relation to the context of the class and the activities they are asked to do in order to learn physics. The findings of the analysis of the survey data echo the findings of Sahin *et al*. (2015) in their evaluation of the Physics Anxiety Rating Scale where female students were found to have higher physics related anxiety than their male counterparts. Interviews with the female students demonstrated that although their anxiety about physics before and during lessons resulted in the female students working more independently, or perhaps to put it more aptly, in isolation, the students' lack of control of the conditions within the lessons (their agency) limited their actions during the lessons (Roth and Wilshaw, 2015). However, for some female students, this meant that they were resolved to supplement their learning by independently using resources from the internet at home.

Though their self-regulated skills appear to be nurtured by this working at home, female students are missing out on opportunities to develop a relationship with their physics teacher by not receiving as much direct feedback about their progress compared to their male peers who are keen to interact with the teacher as shown by the lesson observations. It could be argued that this lack of participation by capable students renders interactive teaching methods into a more transmission-based style of teaching for the student. With the students feeling anxious about participating and thus developing feelings of isolation during the lessons they have reduced opportunities to develop their sense of agency and take greater control of their learning during lessons. The lack of occasions to utilise their interpersonal skills in physics lessons with their peers and teachers leads to doubts about their capabilities to succeed in physics. This attitude, that physics is not for them, reinforces the stereotype threat where they view the subject as difficult and a pursuit for others. This reduces the sense of collective agency in the class as well as the belief that everyone can contribute to the success of the class in learning physics.

There appeared to be two simultaneous lessons happening within the class. One, shaped by the actions of the male students which had attributes of an interactive lesson with engagement from the male students and the teacher with a strong sense of individual and collective agency. Whilst the other lesson was of more isolated working with little interdependence and low levels of individual agency and collective agency between the female students and the teacher. The female students' 'lesson' appeared to be derived from the male students' 'lesson', that is, their perceived lack of participation was determined by their experiences within the context of a more dominant 'lesson' of confident male students engaging and interacting with one another.

To support all students so that they have more positive perceptions of their capabilities and to develop more inclusive environments to enhance students' sense of personal and collective agency in physics lesson, their affective states in lessons need to be taken into consideration. The class cultural climate in physics lessons needs to provide space for students with low agential and capability beliefs to be able to engage in an environment where they feel that they can actively participate in lessons and reduce their isolation to develop a more supportive and collective approach to learning physics. A heightened sense of agency and feeling of belonging may engender an environment where more students consider that they have control when learning physics and that physics might be a pursuit that they are able to successfully participate in.

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KNOWLEDGE OF PHYSICS AND SUCCESS IN COMMENTING ON SILENT VIDEO TASK

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According to the European Union, communication is one of the key competencies. (Arjomand et al., 2013) Therefore, it is important to develop communication skills during the education. The space for this development could be provided by silent video task. The paper contains a definition of the silent video task and a survey aimed at correlation between knowledge of physics and success in commenting on silent video, which was conducted among high school students.

Keywords: Silent Video, Verbalization, SOLO taxonomy

INTRODUCTION

One of the aims of science education in Slovakia is to develop students' communication skills, i.e., to develop the formulation and expression of their thoughts and opinions. (ŠPÚ, 2015, p. 7). Verbalization of thoughts is an everyday part of a life, not just school life. To verbalize means to express thoughts, opinions, or emotions through words. (Cambridge Dictionary, 2020) For a teacher who wants to develop students' cognitive processes, it is important to know their thoughts. Therefore, the student's ability to verbalize their thoughts is crucial.

The development of the ability to verbalize one's own ideas begins in kindergarten and continues. "By constantly guiding the child to formulate his or her own ideas, his or her ability to generalize is developed. Even though the child implicitly perceives that he understands the observed, it is not easy for him to translate his cognitive idea into a verbalized expression. Much information is brought into the mind without verbalization and completes the understanding of a certain phenomenon without speech coding. That is why expressing one's own ideas is quite demanding." (Žoldošová, 2013) Verbalization of thoughts is closely related to communication skills.

There are current trends in education which are aimed at prioritizing the development of competencies over the acquisition of knowledge. In 2006, the European Union adopted a document entitled Key Competences for Lifelong Learning - A European Framework of Reference (EU, 2006), which sets out eight key competences needed for personal satisfaction, active citizenship, social cohesion, and employability in the knowledge society:

1. communication in the mother tongue,
2. communication in foreign languages,
3. mathematical competence and basic competences in the field of science and technology,
4. digital competence,
5. learn to learn,
6. social and civic competences,

7. initiative and entrepreneurship,

8. cultural awareness and expression.

Communication skill is therefore an important competence that needs to be developed. "The information and communication aspect of scientific thinking is revealed in skills such as communicating and sharing knowledge, publishing discoveries, working cooperatively as a team, participating in congresses, discussing theories and solutions with colleagues, evaluating one's own and others' communications and assuming personal and social responsibilities." (Manassero-Mas, Vázquez–Alonso, 2020).

The opportunity of verbalizing the thoughts and developing the communication skills could be given by silent video task. Silent video is a short video, less than 2 minutes long, which shows a physics phenomenon or experiment. The task for student is to prepare and record the voice-over to the video. It turns out that silent video can contribute to the development of communication skills, argumentation, critical thinking, or evaluation skills. Silent video can be also used as an instrument of determining the communication skills level.

Since the aim of science education is also the development of communication skills and in order to develop communication skills, it is necessary to know their current level, we were interested in the level of communication skills of our students in relation to their knowledge, so we conducted a survey in which the silent video task was used.

The survey was conducted to find a correlation between communication skills and knowledge of physics and success in commenting on silent video. Therefore, it was necessary to evaluate the voice-overs on the silent video. A tool called SOLO taxonomy (Biggs and Collis, 1982) was used to evaluate them. The division of knowledge into five hierarchical levels is contained in SOLO taxonomy:

- *Prestructural level* – contains incorrect findings that are not related to the topic or that are irrelevant.
- *Unistructural level* – contains findings focused only on one phenomenon, one specific aspect described by the student.
- *Multistructural level* – although it consists of several findings, students only name them.
- *Relational level* – contains multistructural findings, which students relate to, combine, analyse, apply and create a broader view of the phenomenon.
- *Extended Abstract level* of findings contains a description of different new views on studied phenomenon, evaluation, generalisation and creation of new concepts.

Silent video task and SOLO taxonomy are important elements of conducted survey.

METHOD

The survey was focused on students' communication skills. The objective was to find out whether there is a correlation between knowledge of physics and success in commenting on silent video. Hypothesis was set as follows:

H: *The higher the level of student's knowledge of physics, the higher the score will be obtained in silent video task by the student.*

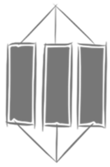
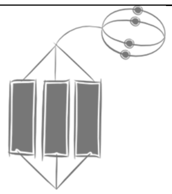
The survey was conducted with the students of 3rd year of French Bilingual High School in Bratislava. The number of participating students was 60. The task was to record the voice-over to silent video named *Ball*. The video shows a real situation approaching the behaviour of objects in the car. It is a video of a man throwing a ball in a car in three different situations. First, when the car does not move, then when the movement of a car is a uniform linear motion, and finally when the movement is non uniform linear motion with acceleration.

Figure 1. Video shot with QR code of the website containing the video – Ball.

The students' voice-overs were evaluated with the help of evaluation sheet (Fig. 2) using the SOLO taxonomy created by Biggs and Collis (1982). Since the SOLO taxonomy is a hierarchical division, we did not sum up points for individual levels in the sheet, but we chose one of the numerical options. For instance, if it was pronounced according to what they examined the movement, but the trajectory of ball was not described, total score was 2 points.

Table 1. Evaluation sheet with criteria created according to SOLO taxonomy.

	It is stated that this phenomenon is related to the speed of the car, which is first immobile, then is in a uniform motion and finally in an accelerated motion.	1	
	It is pronounced, according to what we examine the movement, trajectory of the ball is described.	2 3	

	The trajectory of the ball is related to the speed of the car.	4 5	
	The speed of the ball is considered relative to the car, as well as relative to the road, it is also explained why in the third case the ball moves differently.	6	

Before carrying out the silent video task, the test with physics tasks was used to find out the level of physics knowledge. The main topic of the test was Motion because it is the key knowledge for creating voice-over to this video. Test was composed of several types of exercises i.e. open-ended questions, multiple choice questions, quantitative and qualitative task. Then the score of the test was compared with the score obtained for the voice-over.

RESULTS

All results were transformed in the graph (Fig. 2) with *x*-axis showing score expressed as a percentage of the test and *y*-axis showing the score expressed also as a percentage the student with the given score from the test obtained for his voice-over.

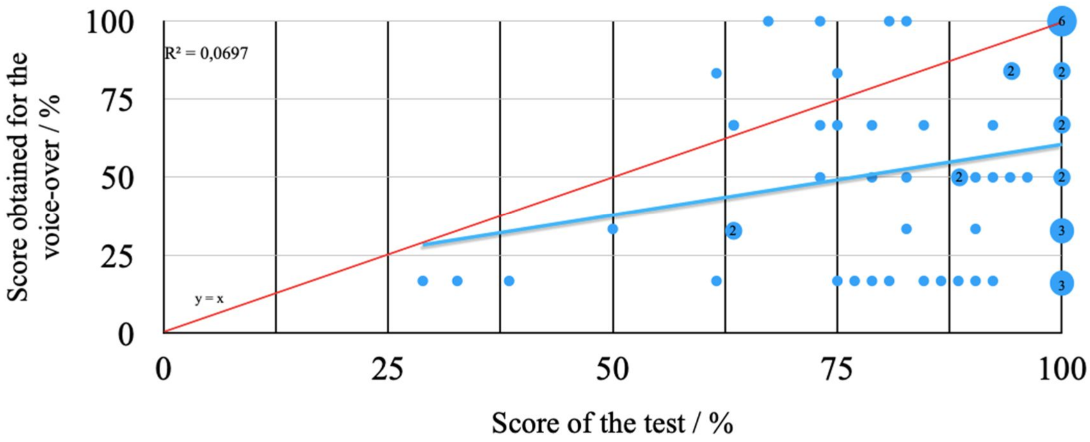


Figure 2. Graph of the correlation between physics knowledge and success in commenting on silent video. Larger points represent multiple students with the same score.

After counting the correlation coefficient (R = 0.26), it can be stated that with the selected students there is weak correlation between physics knowledge and success in commenting on silent video. The hypothesis H need to be rejected. The rejection of hypothesis led to setting hypothesis H': *The score of the test has no influence on the quality of the voice-over.* The test of contingency (Pearson's Chi-squared test with Yates' continuity correction) was used to verify the hypothesis H' and p-value = 0.25. Hypothesis H' cannot be rejected.

DISCUSSION AND CONCLUSIONS

It turned out that students whose score of the test were low, they did not obtain the high score for the voice-over. When creating a comment, students had to apply knowledge of the topic and since they do not have them (as demonstrated by the test), they could not be successful in creating a comment. As many as 46 students obtained less score for the voice-over than for the test. They are represented in graph (Fig. 2) by points, which are situated below the line $y=x$. It can be related to a non-standard type of task. However, up to 31 students whose score of the test was more than 63%, obtained for the voice-over the score with the decrease of 30% or more compared to their score of the test. We interpret this as showing that the students had sufficient knowledge of Movement but have not been successful in creating the voice-over. The results showed that there is a weak correlation between physics knowledge and success in commenting on the silent video. We think that it could be caused by insufficient ability of students to verbalize their thoughts. In order to develop students' ability to express their thoughts and communicate using the correct terminology, we must create the space in our physics lessons. It turns out that one of the suitable ways to provide such space is a silent video task.

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DOMAIN-SPECIFIC THEORIES OF INTELLIGENCE: HOW STUDENTS' MINDSETS IN PHYSICS CHANGE WITHOUT INTERVENTIONS

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Implicit theories about intelligence influence students' goal setting, their engagement in learning and their academic performance. Whether students believe in the fixedness versus malleability of intelligence, they are referred to as holding a fixed versus a growth mindset. Research shows the benefit of a growth mindset especially in an academic context, and how interventions can foster a growth mindset. But a surprisingly small number of studies examined the changeability of mindset over time without an intended intervention. This study aims to survey physics specific mindsets which students hold from the first year of physics lessons to graduation class. N=900 students from academic high schools in Germany participated in this survey and four different mindset types could be identified: a growth mindset, two types of fixed mindset (one holding the fixedness of general intelligence accountable for physics success and one believing in a special giftedness in physics) and a mixed mindset including those beliefs that do not fit the mindset theory. The change in the mindset distribution over the different grades indicate an influence of learning physics on the beliefs students hold about this subject. Also, as indicated in other mindset studies and research concerning different non-cognitive factors in physics, there is a gender-specific differentiation measurable in physics specific mindsets.

INTRODUCTION

Students vary in their beliefs about the nature of intelligence. Since these beliefs are often unconsciously held, they are also referred to as implicit theories of intelligence. Entity theorists believe that intelligence is a fixed trait, and one cannot change it (fixed mindset). Incremental theorists on the other hand, believe that intelligence is malleable and can always be developed through effort (growth mindset) (Dweck, 1999). Students with a growth mindset show a preference for challenging tasks; they choose learning goal tasks over performance goal tasks, and they show a mastery pattern of behavior and higher engagement in learning (e.g. Blackwell et al., 2007; Yeager et al., 2019). Research on mindset theory shows that one's beliefs about the fixedness or malleability of traits are not global. For example, Cheng & Hau (2003) report that students hold differentiated mindsets on intelligence, personality, creativity, and emotional intelligence. There are only a few studies examining students' mindsets in different academic domains, but they implicate a tendency of a more fixed view on STEM subjects (e. g. Cimpian et al., 2007; Jonsson et al., 2012; Leslie et al., 2015; Meyer et al., 2015). Also, some data reports gender-specific differences in implicit theories, e. g. Gunderson et al. (2013) found girls to be more likely to hold a fixed mindset and Archer et al. (2020) found that especially female students strongly believe in a natural ability in physics as a premise for success. While a majority of mindset research is focused on interventions to foster an incremental belief, there is only limited knowledge about changes in distributions of incremental and entity beliefs in different age groups, and especially domain specific. Since such knowledge would allow a more targeted setting of growth mindset interventions, the present study aims to investigate physics learners' mindset distributions in different age groups: How do students' domain specific beliefs about fixedness versus malleability of their physics-ability change without the influence of a mindset intervention?

THE STUDY

To address student's domain specific theories of intelligence in physics, N = 1606 students from different secondary schools in Hesse (Germany) participated in a pen and paper mindset survey between November 2019 and February 2020, while for the purpose of better comparability only the subgroup of N = 900 (430 of them female) students from the participating 12 academic high schools are considered. Students from seventh grade, which is the first year of physics lessons in Germany, to graduation class had been participating, to examine the whole age span of physics learners. The mindset survey contains the commonly used four items of the "Theories of Intelligence Scale" (Dweck, 1999), asking about students' beliefs about general intelligence, e. g. "You have a certain amount of intelligence and really can't do much to change it" (α = .80). To focus on the students' physics specific beliefs two more scales have been developed. The scale "Giftedness in Physics" consists of four items such as "You need a certain giftedness for being successful in physics" (α = .81). The other scale with seven items is labelled as "Effort in Physics" (α = .83) and contains statements like "Everyone can understand physics, you just have to put in enough effort" (Goldhorn et al., 2020).

To identify students' physics specific mindsets a hierarchical cluster analysis (Ward's method with squared Euclidean distances) was conducted using the average ratings of the three scales. Four types of physics specific mindsets can be identified, two of them are manifestations of a fixed mindset. Students with a *fixed mindset "general intelligence"* believe that general intelligence as a fixed trait is accountable for one's success in physics. Students with a *fixed mindset "giftedness in physics"* believe in a domain specific giftedness, a special talent in physics, that is necessary for one's success in this area. Students with a *growth mindset in physics* neither believe in intelligence as a fixed trait nor that one needs a special giftedness in physics to be successful. The fourth cluster is called a *mixed mindset* since it doesn't fit the characteristics of a growth or a fixed mindset.

RESULTS

Overall, 45.8 % of the participating students hold a growth mindset in physic, 16.2 % hold a fixed mindset "general intelligence" and 13.7 % a fixed mindset "giftedness in physics". 24.3 % of the students don't match the criteria for fixed or growth mindset and are therefore assigned to the mixed mindset. For more detailed results, table 1 shows the mindset distributions ordered by grade.

Table 6. Mindset distributions for different classes from seventh grade to graduation class.

	fixed mindset "general intelligence")	*fixed mindset "giftedness in physics"*	*mixed mindset*	*growth mindset*
7th grade	13.8 %	4.3 %	12.8 %	69.1 %
8th grade	16.2 %	13.4 %	26.9 %	43.5 %
9th grade	19.8 %	10.1 %	28.6 %	41.5 %
10th grade	17.9 %	19.0 %	24.4 %	38.7 %
introductory phase	9.7 %	16.7 %	13.9 %	59.7 %
graduation class	12.8 %	18.0 %	27.1 %	42.1 %

The youngest participants are in seventh grade, since physics lessons in Hesse (Germany) start in this grade. While 69.1 % of the seventh-grade students hold a growth mindset in physics after only a few months of learning experience in this subject, the growth mindset percentage decreases during the following years. The largest gap is between seventh and eighth grade (from 69.1 % to 43.5 %) and the minimum of the growth mindset percentage is in the last year of middle school (tenth grade) with only 38.7 %. During the same time, the number of students holding a physics specific fixed mindset (the so-called fixed mindset "giftedness in physics") is drastically increasing. Only 4.3 % of the participating seventh graders hold this mindset, but after just one year of physics learning the percentage of the fixed mindset "giftedness in physics" is up to 13.4 % in eighth grade. And while the growth mindset percentage has its minimum in tenth grade, the fixed mindset "giftedness in physics" is at its maximum with 19.0 % at the same time. Besides the changes in the mindset distribution during middle school also the percentages in introductory phase are noticeable. Introductory phase is the first year of the upper school level. The number of students holding a growth mindset increases in this grade to 59.7 %, the next highest percentage after starting physics classes. But this much stronger growth mindset does not seem to be long-lasting and in the next grade, graduation class, the growth mindset percentage is decreasing to 42.1 % which is not significantly higher than in middle school.

The following diagrams are showing the changing percentages of growth mindset (figure 1) and fixed mindset "giftedness in physics" (figure 2) comparing female and male students. The girls start physics lessons with a higher percentage of growth mindset (72.7 %) than the boys (63.2 %). In ninth grade the growth mindset percentage is the same for female and male students (42.1 %) and in higher classes there is a larger percentage of boys holding a growth mindset in physics.

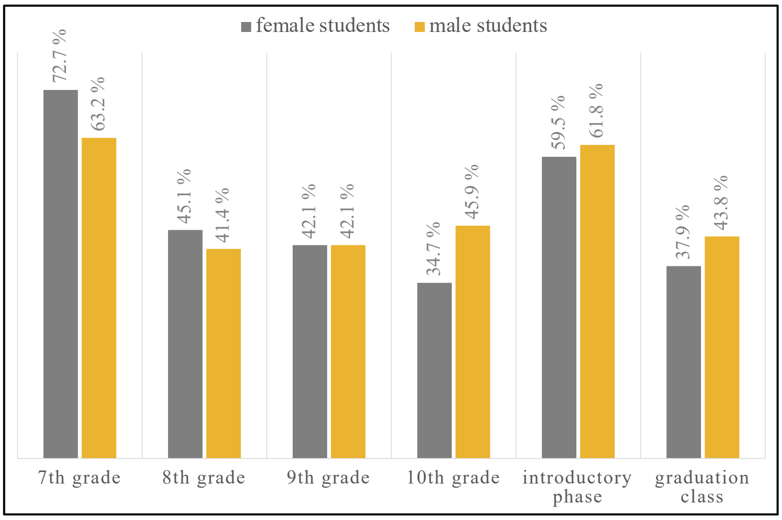

Figure 5. Growth mindset percentage for different grades, comparing male and female students.

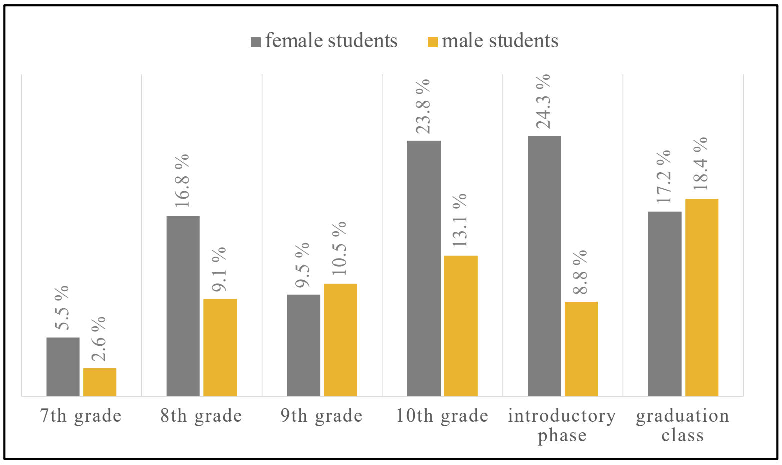

Figure 6. Fixed mindset "giftedness in physics" percentage for different grades, comparing male and female students.

DISCUSSION

Since there are students from seventh grade to graduation class participating in this study, the results show how students' mindsets in physics are changing over time. There are three main findings.

1. *Over the years the growth mindset percentage decreases and students show a higher percentage of fixed mindset in graduation class relatively to the first year of physics.*

While in seventh grade, when starting with physics lessons, there is a high percentage of students holding incremental beliefs (69.1 % in seventh grade), this growth mindset percentage decreases drastically over the next years. Similar findings are reported for domain-general mindsets, comparing the percentage of students with incremental beliefs in high school versus late elementary school (Cheng & Hau, 2003). Also, for domain-specific mindsets in math a decrease of the growth mindset is reported by Gunderson et al. (2017). Since there is some literature suggesting a higher percentage of fixed beliefs in STEM fields for adults (e.g. Jonsson et al., 2012; Meyer et al., 2015), monitoring mindset distributions over time is interesting in order to learn more about the development of the implicit theories. Our data indicates that this fixed mindset tendency in STEM is not given from the beginning but evolves with more exposure to physics lessons.

2. *The biggest mindset shift is observable during the first year of physics lessons.*

Looking more closely at the results of our study, the numbers show that there is a sharp decline of growth mindset percentage between the seventh and eighth grade (from 69.1 % to 43.5 %). Limeri et al. (2020) showed that undergraduate students' domain specific incremental beliefs decrease when faced with a challenging STEM-course. Physics lessons in general are described as challenging (e.g. Ornek et al., 2008), so middle scholars' beliefs may be influenced by starting physics classes in the same way. This, again would support the hypothesis that students' mindsets are influenced by physics lessons and are not just changing age-dependent during middle and high school.

3. *Girls hold stronger beliefs about an innate talent for physics.*

Comparing the gender specific mindset distributions, our results indicate that girls hold stronger beliefs about a fixed giftedness in physics (compare figure 2). And, as well as the sharp decline of the incremental belief during the first year of physics, there is a sharp increase in the domain-specific entity beliefs visible: the percentage of fixed mindset "giftedness in physics" rises from 5.5 % to 16.8 % for female students and from 2.6 % to 9.1 % for male students. These results are consistent with other studies asking about students' beliefs about talent in physics, e. g. Archer et al. (2020). In the first years of physics learning, the percentage of girls holding incremental beliefs is higher than the percentage of boys, but this changes from ninth grade onwards, when more boys tend to have a growth mindset. Several studies are supporting this result and found that boys held more incremental beliefs than girls (e.g. Gunderson et al., 2013). But there are also studies showing no gender specific differences (e.g. Gunderson et al., 2017). So, it will be important to examine this further and get more knowledge on the circumstances of possible gender differences in (domain-specific) mindsets.

CONCLUSION

In this study we reported students' domain-specific mindsets and how they change over time without any intervention taking place. Students' beliefs about the fixedness versus malleability of physics ability changes throughout their school years, and male and female students show a higher percentage of fixed beliefs in graduation class relatively to the first year of physics lessons. Even though there is no gender difference in the overall trend of an increasing domain-specific fixed mindset and a decrease of the growth mindset, girls seem to hold stronger beliefs about a fixed and innate talent in physics. The biggest shift in mindsets is visible between the seventh and eighth grade, while physics as a new school subject is introduced in seventh grade. Being faced with this new subject, often reported as challenging, seems to strengthen students' domain-specific entity beliefs about intelligence and ability. These findings are consistent with the results of other studies about fixed and growth mindset, especially with research concerning the STEM-field and mindset. Since the present study only collected data about physics specific mindset, we cannot say if the observable mindset changes over time are just age-dependent or being influenced by the academic setting and physics lessons in particular. Still, taken research about other non-cognitive factors into account (e. g. Hoffmann et al., 1998) our findings can be interpreted as another indication of physics lessons influencing students' non-cognitive physics related factors.

Overall, our results about these mindset shifts are an important basis for upcoming research on the effectiveness of mindset interventions and to answer the question which age group of students can benefit the most from interventions to foster a growth mindset in physics.

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THE INTEGRATION OF TEXT AND ILLUSTRATIONS IN BIOLOGY TEXTBOOKS USED IN GREEK LYCEUM

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Considering the fact that (a) science textbooks tend to rely heavily on illustrations and (b) textbooks determine largely what is taught and learned in science classrooms, this paper reports on exploring the illustrations included in four biology textbooks used in Greek lyceum (K10-12). Drawing on the Graphical Analysis Protocol (GAP), we coded the 581 illustrations identified in mutually exclusive categories concerning the text-illustrations integration – i.e. (a) the level of contiguity between illustrations and text, (b) the extent of in-text reference to illustrations, and (c) the captions' function regarding the connection of text and illustrations. The analysis of results suggests that (i) the majority of illustrations are contiguous with the relevant text in all four textbooks, (ii) the majority of illustrations are referenced in two of the textbooks we researched but there is only one referenced illustration in the other two, and (iii) the majority of illustrations in all textbooks have captions that are mostly used to identify or describe the illustrations.

Keywords: Graphical Representations, Curriculum, Science Education

INTRODUCTION

The communication of scientific and technical information has widely relied on illustrations since as early as the 1500s. Engineers of that time used notebooks and technical manuals to convey relevant information; to be more effective, as a general rule they were largely illustrated. In fact, sometimes text was not even included; when there was text, it only served to explain the illustrations. Following the invention of printing press in the 15th century, these illustrated books became available to large audiences and some historians of science support that their increased availability may have resulted in the technological advancements of 16th to 18th century (Hegarty, Carpenter, & Just, 1991).

In current times, images of science seem to play an important role in scientific inquiry itself, media reports of scientific news, and science textbooks (Slough, McTigue, Kim, & Jennings, 2010). Focusing on textbooks, we notice that the majority of science textbooks rely largely on illustrations (Ampatzidis & Armeni, 2021; Liu & Khine, 2016). Lee (2010) argues that among the printed materials used for the communication of science, textbooks are the ones that dedicate most of their space for illustrations. Mayer, Steinhoff, Bower, & Mars (1995) mention that nearly half of the page space in the textbooks they investigated is covered by illustrations. Moreover, Dimopoulos, Koulaidis, & Sklaveniti (2003) claim that the more recent a science textbook is, the more illustrations it contains, while Martins (2002) argues that that the diversity and representation of illustrations contained in science textbooks has been increased over the years. The increase of their use in recent years reflects the increasing importance of illustrations in education (Postigo & López-Manjón, 2019). Illustrations are important in science education because they seem to help students build understanding about scientific concepts which are inherently complex and abstract (Devetak & Vogrinc, 2013). It has been long appreciated that well-designed illustrations play an instrumental role in the teaching and learning of demanding scientific ideas (Khine, 2013).

Slough et al. (2010) argue that despite their importance in text comprehension, there are no consistent definitions of illustrations. Illustrations may be defined as polysemic and monosemic representations (Guo, Zhang, Wright, & McTigue, 2020) including a wide range of visual-spatial representations such as graphs, images, photographs, tables, diagrams, drawings and maps (Postigo & López-Manjón, 2019). They may be classified based on presentation (i.e. diagrams, maps, etc.) (Vekiri, 2002) on their function (i.e. diagrams, charts, graphs etc.) (Hegarty et al., 1991) or, following a mixed approach, in four types (i.e. pictures, pictorial diagrams, flow diagrams and mixed graphics) (Guo et al., 2020). Graphical demands of textbooks have been considerably explored concerning university education (Ampatzidis & Armeni, 2019; Bowen, Roth, & McGinn, 1999), secondary education (Liu & Treagust, 2013), and primary education (Liu & Khine, 2016; Slough et al., 2010).

Considering the above and drawing on previous research we have done with science textbooks used in a distance learning undergraduate course (Ampatzidis & Armeni, 2019) we decided to explore the illustrations included in biology textbooks used in Greek school. Our focus here is set in evaluating how well illustrations integrate with text in the Greek lyceum's biology textbooks; more specifically, the research questions (RQs) we address are:

- (RQ1) What is the level of contiguity between illustrations and text within Greek lyceum's biology textbooks?
- (RQ2) To what extent are illustrations referenced in the text within Greek lyceum's biology textbooks?
- (RQ3) In what manner are captions used to connect illustrations with text within Greek lyceum's biology textbooks?

METHODS

For this study, we investigated the 4 biology textbooks used in Greek lyceum (K10-K12) during the school year 2020-21:

- Biology for the 1st grade of Lyceum (Kastorinis, Kostaki-Apostolopoulou, Mparona-Mamali, Peraki, & Pialoglou, 2011): textbook-1.
- Biology for the 2nd grade of General Lyceum-General Education (Kapsalis, Bourmpouchakis, Peraki, & Salamastrakis, 2013): textbook-2.
- Biology for the 2nd and 3rd grade of General Lyceum (Adamantiadou et al., 2013): textbook-3.
- Biology for the 3rd grade of General Lyceum-Health Studies Specialization (Aleporou-Marinou, Argyrokastritis, Komitopoulou, Pialoglou, & Sgouritsa, 2013): textbook-4.

In order to answer our research questions, initially we counted the illustrations included in all four textbooks – the illustrations included in cover pages, appendices and assessment activities pages were excluded from our analysis. We identified 169 illustrations in textbook-1, 135 illustrations in textbook-2, 155 illustrations in textbook-3 and 122 illustrations in textbook-4. The 581 illustrations identified were coded in mutually exclusive categories formed drawing on the Graphical Analysis Protocol (GAP) proposed by Slough & McTigue, 2013). Table 1 shows our coding scheme after removing one empty category (i.e., 'unconnected' category) and merging categories with little content (i.e., 'proximal' and 'direct' categories were merged into the 'same page' category).

Both authors coded independently 150 (i.e., about 26%) randomly chosen graphics and the inter-rater agreement was about 98% for 'contiguity', 100% for 'indexical reference' and about 93% for 'captions' (see Table 1 for details on categories). The rest of the analysis was carried out by the first author.

Table 1. The coding scheme.

Contiguity	**Category**	**Description**
	Distal	Illustration and relevant text are in different pages (the reader needs to turn page)
	Facing	Illustration and relevant text are in facing pages
	Same page	Illustration and relevant text are in the same page
Indexical Reference	Referenced	Text does not reference the illustration
	Not referenced	Text references the illustration (e.g., 'See Figure 3.1')
Captions	No caption	There is no caption
	Identification	Caption identifies the target of the illustration but does not provide details
	Description	Caption provides a description of the illustration with details
	Engagement	Caption actively engages the readers (e.g., poses a question, asks them to read a specific part of the text, gives instructions)

RESULTS

Most illustrations are rather contiguous with the text in the textbooks investigated; illustrations positioned in the same page as the relevant text are more than distal and facing illustrations in all four textbooks (Figure 1). The biggest percentage of non-contiguous (i.e. distal and facing) illustrations are found in textbook-4 (41/122) while the smallest percentage are found in textbook-3 (20/155).

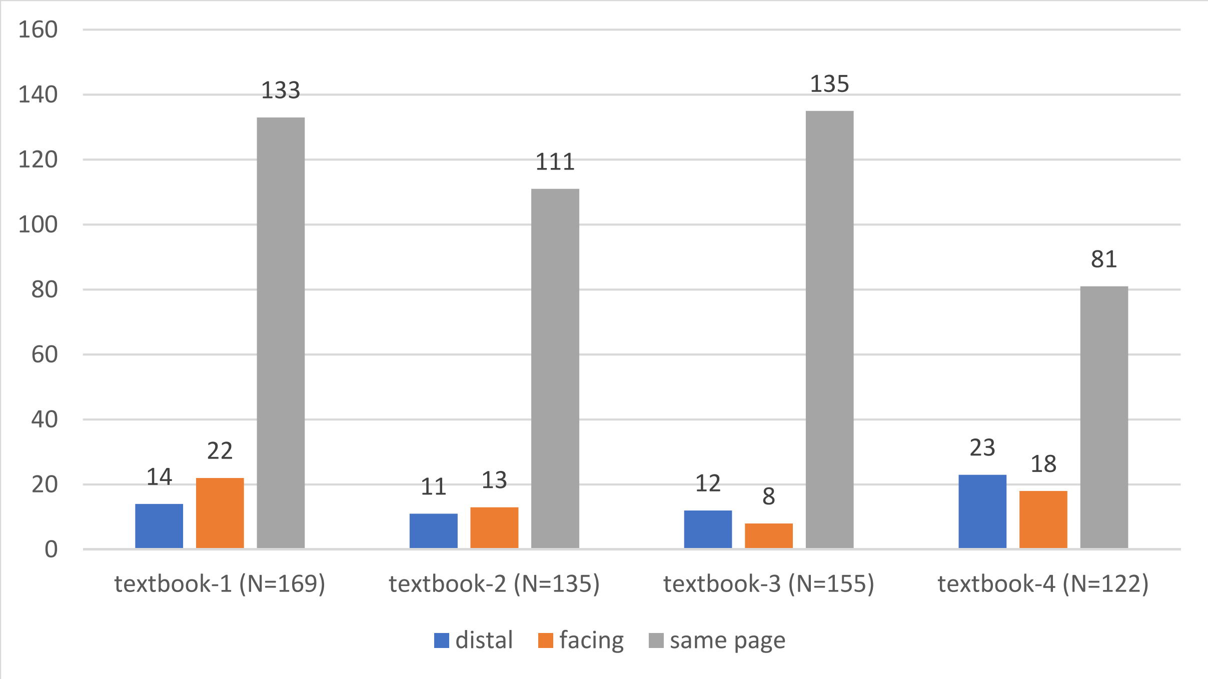

Figure 1. Frequencies of categories of illustrations regarding contiguity.

The majority of illustrations in two textbooks are referenced in the text. In parenthesis – e.g., '(Figure 1.13)' – or not – e.g. 'The excretory organs appear in Figure 6.1…' –the authors of textbook-1 and textbook-4 signal the reader when to view the relevant illustration. On the contrary, illustrations in textbook-3 are never referenced in the text while only 2/135 illustrations are referenced in the case of textbook-2 (Figure 2).

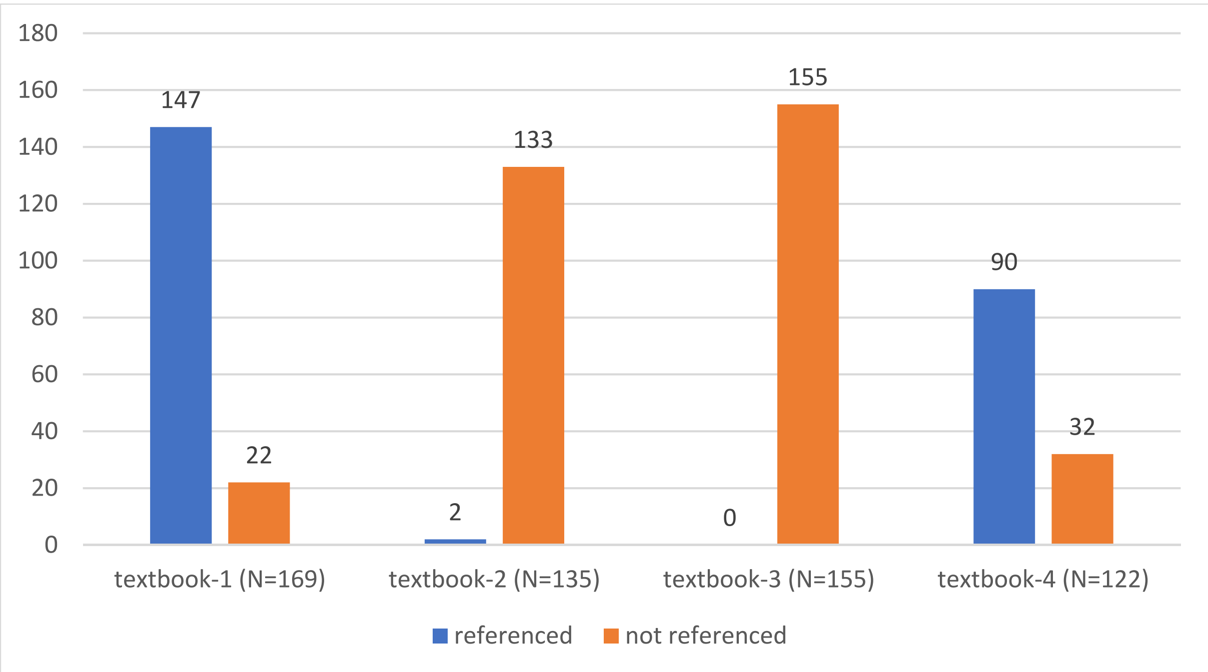

Figure 2. Frequencies of categories of illustrations regarding indexical reference.

Most illustrations in all textbooks have captions. When they exist, captions are used (a) to identify and (b) to describe the illustration in almost all cases. An example of (a) is the following: 'Capillary network that feeds a group of somatic cells' and an example of (b) is the following: '1. Cells are surrounded by the interstitial fluid which provides them with nutrients and in which they discharge waste products 2. Blood pressure at capillaries is high comparing to the interstitial fluid and as a result, small molecules of the plasma exit capillaries 3. Erythrocytes, as well as large molecules such as proteins, remain inside the capillaries.' There is only on caption that intends to engage the reader by giving instructions on performing a breast self-examination under a relevant illustration of textbook-1: 'Stand in front of the mirror and carefully examine your breasts for any change in their shape or colour. Lie down on your bed, having previously placed a pillow underneath from your right shoulder. Put your right hand under your head.'

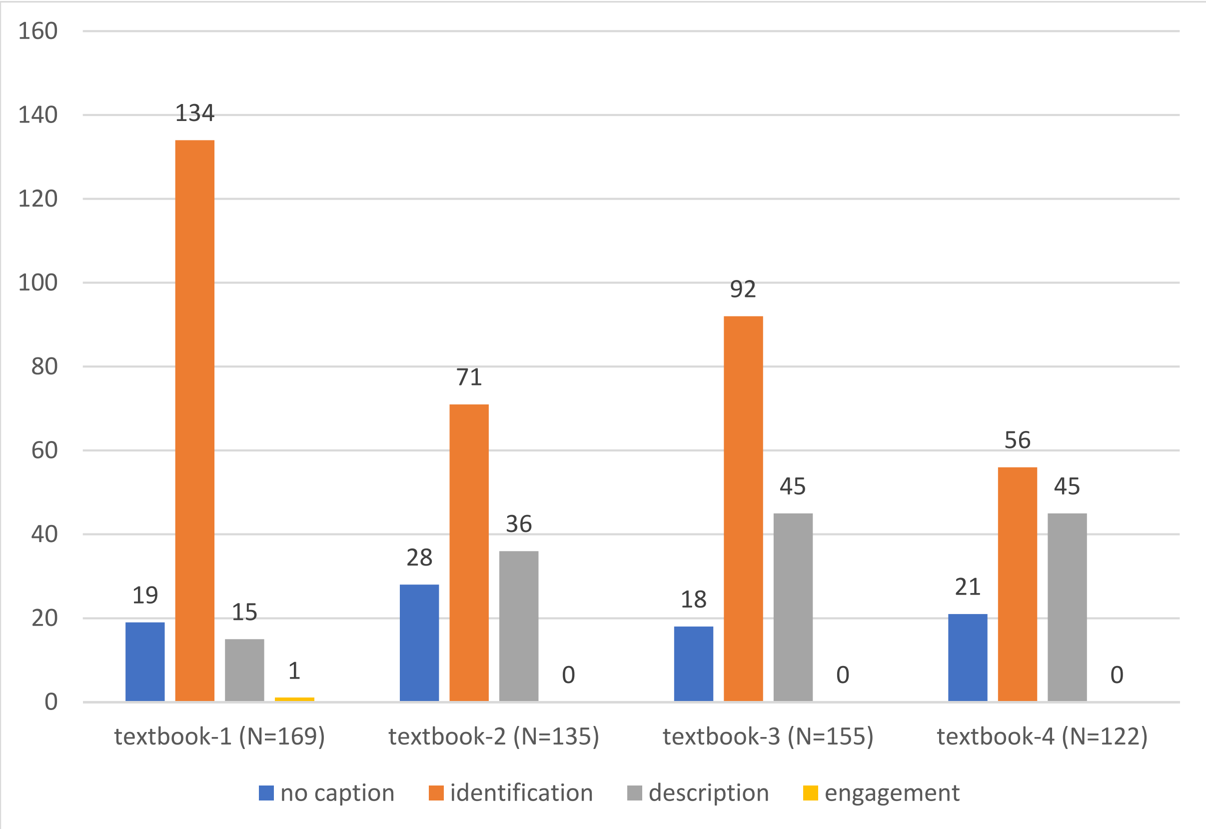

Figure 3. Frequencies of categories of illustrations regarding captions.

DISCUSSION

Mayer (2001) supports that the proximity between text and illustrations contributes to their effectiveness; students are believed to perform better at tasks when illustrations and relevant text are placed close to each other. Studies based on eye-tracking technology show that, in case of illustrated text, readers need to refer back and forth between text and illustrations many times. This observation seems to suggest that placing the two sources of information close to each other may help their shift of attention (Slough et al., 2010). It has been argued that design features which help students as they read the textbooks, such as proximity between text and illustrations, not only enhance the text-illustrations integration, but they also decrease cognitive load linked with instructional design (Nyachwaya & Gillaspie, 2016). It seems that the authors of the textbooks we investigated effectively achieve both goals in terms of proximity between text and illustrations, since in all four textbooks that concern our study most illustrations are positioned at the same page with relevant text.

Another feature that help students as they read the textbooks is indexing of illustrations within text (Nyachwaya & Gillaspie, 2016). References within running text is considered an effective way to signal the reader when to observe the illustration, arguably offering a form of guide of how the reader is supposed to integrate textual and visual information (Slough & McTigue, 2013). We note that the authors of the textbooks we researched form two distinct groups in regards to referring to illustrations within text: in two textbooks (textbook-1 and textbook-4) there are references to the majority of illustrations while in the rest (textbook-2 and textbook-3) there are no or almost none reference.

Finally, the use of the use of captions is also considered to help students as they read the textbooks. Captions are thought to be an efficient way to inform the reader when to refer to a relevant illustration and they provide a guide about how the readers may integrate the information conveyed by text and illustrations (Slough & McTigue, 2013). Our results suggest that most illustrations included in the textbooks we researched have captions that identify or describe what is depicted. Peeck (1993) notes that when captions simply signal readers to refer to illustrations, they do not do much to effectively support them in processing the visual information. He suggests that captions should ask the readers to do something with them – i.e. he notes that illustrations should have engaging captions. In our study we identified only one caption intending to engage the readers (textbook-1).

Exploring some aspects of the text-illustration integration in biology textbooks of Greek lyceum, we have made interesting observations regarding the effectiveness of illustrations. Although we have discussed how the effectiveness of illustrations is influenced by specific variables, we make no claim about whether and how the text-illustration integration results we discuss are linked with an improved or not students learning. Moreover, we do not assume our results to be generalizable, since our research concerns a limited number of textbooks originated in one country. However, this study follows previous research we have done asking similar research questions concerning textbooks used in a distance learning undergraduate science course (Ampatzidis & Armeni, 2019). We plan to further extend our study by investigating more science textbooks used in secondary and higher education.

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DEVELOPMENT OF A SCIENCE TEACHING AND LEARNING AVERSION SCALE (STLAS) AND CLASSIFICATION OF UNDERGRADUATE STUDENTS

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This study has two purposes: (i) to examine the reliability and validity of a newly developed scale, 'Science Teaching and Learning Aversion Scale (STLAS)' (Study 1), and (ii) to classify undergraduate students according to their attitudes and extract their characteristics (Study 2). In Study 1, we developed 28 items based on data collected from 22 freshmen and sophomores at a public university. A total of 320 undergraduate students completed the survey. The results indicated that STLAS contained seven factors (performing calculations, applying abstract concepts, failure in experiments, grades and understanding, subjects for study, life irrelevance, and teachers' characteristics); of them, four (performing calculations, applying abstract concepts, failure in experiments, and life irrelevance) demonstrated reliability and validity. In Study 2, we identified five profiles with STLAS for 1075 undergraduate students based on model fit and interpretability: extreme (14.0%), mild (28.7%), neutral (26.4%), science OK (23.4%), and science lover (7.5%). We observed a similar pattern in the scores on two types of needs for cognition (in general and science). This observation generated two hypotheses about the relationship between learners' attitudes towards science and general academics that require further examination. Subsequent analysis revealed three topics: 1) science lovers and science OKs are more interested in these six topics than mild and extreme anti; 2) for many topics, the degree of interest of neutral and mild anti was almost similar; and 3) the possibility of attracting the interest of extreme anti by introducing these six topics in science classes seemed quite low. These findings indicate a need to reconsider the means to pique the interest of the neutral, mild, and extreme anti groups.

Keywords: attitudes towards science; latent profile analysis; ANOVA

INTRODUCTION

The lack of interest in science has been viewed as a serious issue for several decades (Osbourne, et al. 2003; Vedder-Weiss & Fortus, 2011; Tytler, 2014, Tytler & Osbourne, 2012). Several intervention programs have been developed, including problem-based learning, hands-on activities, and summer camps (Harackiewicz et al. 2016; van den Hurk et al., 2019). Nevertheless, as demonstrated by international survey results (e.g., Mullis et al., 2019), the solution to this issue remains elusive. The author believes that a more detailed examination of negative attitudes towards science may lead to a solution. Recently, several studies have been conducted to categorise attitudes towards science using a person-centred approach (Perez et al. 2018; Radišić et al., 2020; Rangel et al., 2020), but these studies used highly granular items. The lack of an appropriate scale to measure negative attitudes towards science on a fine-grained scale and studies using these scales to classify learner types has resulted in limited insights into whether an intervention is effective for all types of students.

Therefore, two studies were conducted. Study 1 developed the 'Science Teaching and Learning Aversion Scale (STLAS)'. We aimed to examine the reliability and validity of this scale. Study 2 aimed to categorise students based on their attitudes towards school science and attempted to reveal the features of each profile. Specifically, we measured attitudes towards science teaching and learning using STLAS to classify students. We then conducted a latent profile analysis, a person-oriented approach, to identify the participant's profile. To examine the characteristics of each group, an analysis of variance (ANOVA) was used to examine associations among the resulting profiles and three outcomes: needs for cognition in general, needs for cognition in science, and students' interest in studying science-related topics.

METHOD (STUDY 1)

Study 1 aimed to examine the reliability and validity of a newly developed scale: the STLAS.

1. Measurements

a. Science Teaching and Learning Aversion Scale (STLAS)

First, as a preliminary survey for item development, an interview survey was conducted with 22 first- and second-year undergraduate students. All the participants were university students at a public university who had previously experienced disliking science. Items, developed using the information collected, were classified into seven groups (performing calculations, applying abstract concepts, failure in experiments, grades and understanding, subjects for study, life irrelevance, and teachers' characteristics).

Next, items were deleted or added, such that each group would have four items each, with a total of 28 items (Table 1). The instructions were as follows: 'We would like to ask you about the science classes you took in high school (including "Basic physics" and "Chemistry"). To what extent do you agree with each of the following statements?' For each item, respondents were asked to choose from five options: strongly disagree (1), disagree (2), cannot say either (3), agree (4), and strongly agree (5). The numbers in parentheses are the scores assigned for quantitative analysis. In this study, we defined 'science teaching and learning aversion' as 'feelings of aversion, hate, or dislike to various events in school science teaching and learning situations.

b. Enjoyment of science

We used the 'Enjoyment of Science' indicator from the Programme for International Student Assessment survey (National Institute for Educational Policy Research, 2016, for the Japanese version) for validity examination. We assumed that the higher the 'Enjoyment of Science' score, the higher the score of the ATLAS. An example item is 'I like reading about science'. Although this indicator originally contains five items, one item ('I am happy working on <broad science> topics') was excluded because humanities students tend to have limited opportunities to solve scientific problems. Students were asked to choose from the following four options: strongly disagree (1), disagree (2), agree (3), and strongly agree (4). The numbers in parentheses are the assigned scores. The mean value for the four items was used as a score for subsequent analysis.

2. Participants

An online survey was administered in August 2020 among university undergraduates (grades 1–4) registered in Cross Marketing Inc., a Japanese Internet research company. The data of 320 students (96 men, 220 women, and 4 others) were analysed after excluding those who continuously selected the same number, those who showed missing values, and those who gave inappropriate answers to the trap question (i.e., 'Select the leftmost option for this item'). The average age of the respondents at the time of the survey was 20.35 years (SD = 1.51).

3. Data analysis

The reliability of the STLAS was examined using Cronbach's alpha coefficients. First, a factor analysis was used to examine the validity. Then, the correlation coefficient between each factor and the indicator of 'Enjoyment of Science' was calculated. If the STLAS is valid, there should be a negative correlation. We used the free statistical software, HAD (Shimizu, 2016).

RESULTS (STUDY 1)

1. Descriptive statistics

First, the mean and standard deviation values for each item were calculated (Table 1). There were no ceiling or floor effects.

2. Factor analysis

An exploratory factor analysis (maximum likelihood method and Promax rotation) was conducted on the data for all 28 items. Based on the decline of the eigenvalues, the Kaiser criterion, the minimum average partial correlation, and interpretability, a seven-factor structure was determined to be appropriate. However, during this process, one reverse item that behaved differently from our assumption ('hated conducting experiments to understand abstract concepts') and one item with a factor load below 0.4 ('hated being asked to memorise contents without understanding them') were extracted. Therefore, these items were excluded, and the 26 items were again subjected to exploratory factor analysis, but the model was not optimised. The data were then reanalysed using the least squares method. Finally, the initially assumed seven-factor structure was extracted (Table 1). The cumulative factor contribution rate was 69.88%. The mean value of each factor was used for the analysis.

3. Reliability

The alpha coefficients were estimated as a measure of the reliability of each scale score; for six sub-concepts, the alpha was .75 or higher (Table 2). Only 'study as a subject' had a low alpha coefficient of .58.

4. Validity

To examine the validity, we calculated the correlation coefficients between the seven factors in STLAS and 'Enjoyment of Science' (Table 2). There were significant moderate negative correlations between 'performing calculations', 'applying abstract concepts', and 'life irrelevance' and 'Enjoyment of Science', and significant small negative correlations between 'failure in experiments' and 'subjects for study' and 'Enjoyment of Science'. There were no significant correlations between 'grades and understanding' and 'teachers' characteristics' and 'Enjoyment of Science'.

Table 1. Descriptive Statistics.

	Items	M	SD	F1	F2	F3	F4	F5	F6	F7
F1	hated solving complex calculation problems	3.52	1.30	**0.89**	0.01	-0.05	0.06	0.01	-0.01	-0.04
	hated solving a lot of calculation problems	3.27	1.26	**0.82**	-0.08	0.04	-0.01	0.03	0.02	0.02
	liked classes that were conducted with mathematical formulae*	3.15	1.27	**0.61**	-0.05	-0.06	-0.07	-0.03	0.02	0.02
	hated taking lectures about calculation problems	2.85	1.29	**0.58**	0.18	0.09	-0.04	0.01	-0.06	0.00
F2	hated learning invisible concepts	2.99	1.20	-0.06	**0.91**	0.04	-0.08	0.03	0.01	-0.03
	hated learning concepts that were hard to imagine	3.27	1.12	0.00	**0.78**	0.05	0.08	-0.05	-0.04	0.04
	hated learning concepts that could not be replaced by the things around me	3.05	1.22	0.18	**0.67**	0.02	-0.03	0.04	0.04	-0.07
	liked learning abstract concepts*	2.90	1.05	-0.04	**0.44**	-0.19	0.01	-0.10	0.04	0.05
F3	hated failing to manipulate experiments	3.01	1.19	0.00	-0.09	**0.90**	0.01	-0.11	0.11	-0.06
	hated failing to obtain an expected result from an experiment	2.98	1.20	0.07	-0.05	**0.80**	0.02	0.03	-0.08	0.01
	hated not knowing the purpose of experiments	3.22	1.21	-0.15	0.08	**0.47**	0.03	0.09	-0.02	0.14
F4	hated getting low scores on tests	3.71	1.17	-0.13	0.04	0.02	**0.94**	-0.14	-0.05	-0.10
	hated getting poor grades compared to classmates	3.19	1.32	-0.02	-0.04	0.02	**0.76**	0.07	-0.02	0.03
	hated being unable to understand what your classmates understood	3.66	1.17	-0.01	0.02	-0.03	**0.74**	0.08	0.02	-0.01
	hated getting low test scores despite studying hard	3.58	1.17	0.15	-0.07	0.02	**0.68**	-0.07	0.04	0.05
F5	hated studying while worrying about test scores	3.22	1.21	-0.01	0.06	-0.04	0.11	**0.73**	-0.01	0.04
	liked making efforts only to improve your grades	2.81	1.16	0.02	-0.09	-0.01	-0.13	**0.54**	-0.03	-0.09
	hated studying for entrance exams as a subject	3.19	1.17	-0.02	-0.07	0.02	0.11	**0.44**	0.13	0.11
F6	hated learning content that appeared irrelevant to my future	3.23	1.20	-0.03	-0.02	0.01	-0.02	0.05	**0.97**	-0.07
	hated learning content that appeared useless to learn	3.22	1.22	0.02	-0.07	0.02	-0.05	-0.05	**0.94**	0.05
	hated learning content seemingly unrelated to my daily life	3.22	1.17	0.01	0.04	0.03	-0.01	0.14	**0.81**	-0.10
	hated learning content unworthy of learning	3.34	1.14	0.02	0.17	-0.05	0.07	-0.17	**0.72**	0.13
F7	hated having teachers who did not answer your questions properly	3.08	1.21	-0.03	-0.09	0.06	-0.07	0.02	-0.06	**0.87**
	hated being taught what teachers did not understand	3.16	1.22	-0.13	0.05	0.01	-0.05	-0.01	-0.01	**0.78**
	hated receiving lectures wherein teachers did not teach solid fundamentals for solving problems	3.28	1.18	0.06	0.08	-0.01	0.03	-0.09	0.04	**0.75**
	hated having teachers whose teaching style was difficult to understand	3.59	1.16	0.14	-0.02	-0.05	0.05	0.01	0.02	**0.71**

Note. F1 = Performing calculations, F2 = Applying abstract concepts, F3 = Failure in experiments, F4 = Poor grades and understanding, F5 = Study as a subject, F6 = Life irrelevance, and F7 = Teacher's characteristics

Table 2. Correlation Coefficient

	M	SD	α	F1	F2	F3	F4	F5	F6	F7	ES
F1	3.20	1.03	0.81	1.0							-.444**
F2	3.05	0.90	0.78	.459**	1						-.421**
F3	3.07	0.98	0.75	.231**	.260**	1					-.197**
F4	3.54	1.01	0.85	.185**	.154**	.417**	1				-0.019
F5	3.07	0.87	0.58	.234**	.218**	.221**	.388**	1			-.114*
F6	3.26	1.07	0.92	.418**	.528**	.325**	.305**	.345**	1		-.434**
F7	3.28	0.99	0.85	.128*	.175**	.257**	.358**	.194**	.337**	1.0	-0.019

Note. ES = Enjoyment of Science; ** p < .01; F1 = Performing calculations, F2 = Applying abstract concepts, F3 = Failure in experiments, F4 = Poor grades and understanding, F5 = Study as a subject, F6 = Life irrelevance, and F7 = Teacher's characteristics

METHOD (STUDY 2)

Study 2 aimed to classify learners according to their attitudes and extract their characteristics.

2.1. Measures

a. Science Teaching and Learning Aversion Scale (STLAS)

In Study 1, out of seven factors, we could not obtain reliability evidence for one factor ('study as a subject') and validity evidence for two factors ('grades and understanding' and 'teachers' characteristics'). Therefore, we used only four factors (performing calculations, applying abstract concepts, failure in experiments, and life irrelevance) in Study 2.

b. Need for cognition

Need for cognition is defined as 'an individual's tendency to engage in and enjoy effortful cognitive endeavours' (Cacippo et al., 1996, p.197). The sample item is 'I tend to set goals that can be accomplished only by expending considerable mental effort'. This scale was originally developed by Cacippo and Petty (1982), and the 15-item short Japanese version by Kouyama and Fujihara (1991) was used in this study. For each item, respondents were asked to answer on a five-point scale: strongly disagree (1), disagree (2), cannot say either (3), agree (4), and strongly agree (5).

c. Need for cognition in science

Need for cognition in science is defined as 'an individual's tendency to engage in a series of problem-solving through observation and experiments and enjoy it' (Unzai and Nakamura, 2018, p.302). This study aimed to not only classify people but also obtain insights for interventions. Therefore, two measures were useful: science-specific (need for cognition in science) and domain-general (need for cognition). The sample item is 'It is enjoyable to explain natural phenomena with scientific knowledge'. This scale was developed by Unzai and

Nakamura (2018) in Japanese as an embodiment of the Need for Cognition Scale by Kouyama and Fujihara (1991) in the context of science. Ten items were prepared for primary and junior high school students. Thus, to adopt it for undergraduate students in this study, minor corrections and exclusion of a few inappropriate items were conducted. For each item, respondents were asked to answer on a five-point scale: strongly disagree (1), somewhat disagree (2), cannot say either (3), somewhat agree (4), and strongly agree (5).

d. Interest in studying science-related topics

In Relevance of Science Education, an international survey, 108 items were used to collect students' interest in science (Schreiner & Sjoberg, 2004). In this study, we included 48 items that seemed related to science but not conventional ones (e.g., 'medical use of plants', 'how computers work'). For each item, respondents were asked to answer on a four-point scale: not interested (1), less interested (2), somewhat interested (3), and interested (4). After factor analysis, we identified six factors, including environmental protection and health.

2.2. Participants

A total of 1075 undergraduate students (825 women, 243 men, and 7 unknown) responded to the survey in September 2020 who had registered at the Cross Marketing, an Internet research system in Japan. We excluded those who continuously selected the same number, who showed missing values, and who gave inappropriate answers to the trap question (e.g., 'Select the leftmost option for this item'). The average age of the respondents at the time of the survey was 20.37 years (SD = 1.38).

2.3. Data analysis

A latent profile analysis was used to identify several attitudinal profiles. ANOVA was then used to examine how participants' profile membership was related to their need for cognition, need-for-cognition in science, and interest in studying science-related topics. Figure 1 shows the analysis model.

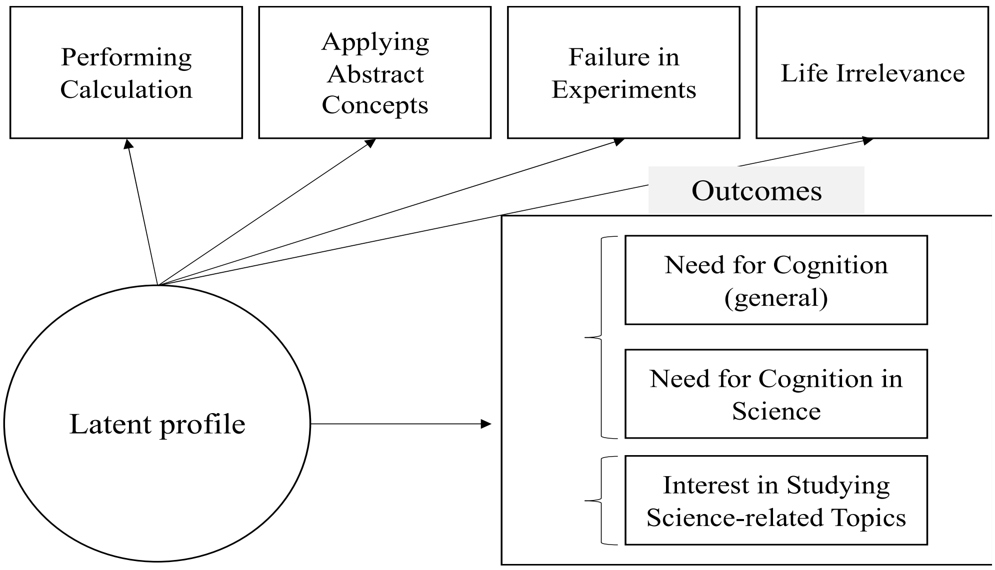

Figure 1. Analysis Model.

RESULTS (STUDY 2)

3.1. Structure of profiles

The structure of profile fit indices for potential profile solutions revealed that a five-profile solution was the best fit for the data from the current sample (Table 3).

Figure 2 demonstrates the five profiles. The first profile was characterised by the highest scores for all four factors; hence, we labelled this profile as 'extreme anti' to reflect their negative attitude towards all aspects. The second profile was characterised by a moderately negative attitude towards the four aspects. This profile was the largest. We labelled this as 'mild anti'. The third profile was characterised by neutral attitudes towards the four aspects. We labelled this profile as 'neutral'. The fourth profile was characterised by its moderately positive attitudes towards the four factors. Therefore, we labelled this as 'science OK'. Scores on all factors in the fifth profile are the smallest, implying that they generally have an extremely positive attitude towards school science. We labelled this profile as 'science lovers.

Table 3. Fit Indices for Different Latent Profile Solutions

# of profiles	BIC	ABIC	p for LMR	p for Bootstrap
1	12131.011	12105.601	N/A	N/A
2	11629.918	11588.627	0	0
3	11498.379	11441.208	0.043	0
4	11446.76	11373.707	0	0
5	11264.597	11175.664	0	0
6	11440.189	11335.374	0.3869	0
7	11463.757	11343.061	0.1914	0.5
8	11263.038	11126.462	0.1411	0
9	11155.228	11002.771	0.0004	0
10	11295.342	11127.004	0.2344	0.6667

Note. The five-profile solution was selected as the best-fitting solution.
BIC: Bayesian information criterion;
ABIC: adjusted Bayesian information criterion;
LMR: Lo–Mendell–Rubin adjusted likelihood ratio test.

3.2. Profile membership and two needs-for-cognition

The results from ANOVA in Figure 3 indicate that for both need for cognition (general) and need for cognition in science, the highest mean values are, in order, science lovers, science OK, neutral, mild anti, and extreme anti. Statistically significant differences were found among all the groups.

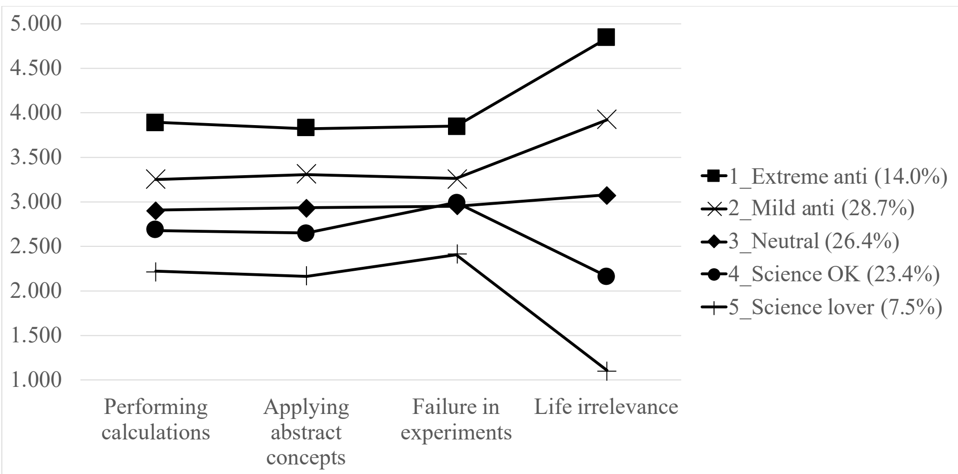

Figure 2. School Science Attitudinal Profile.

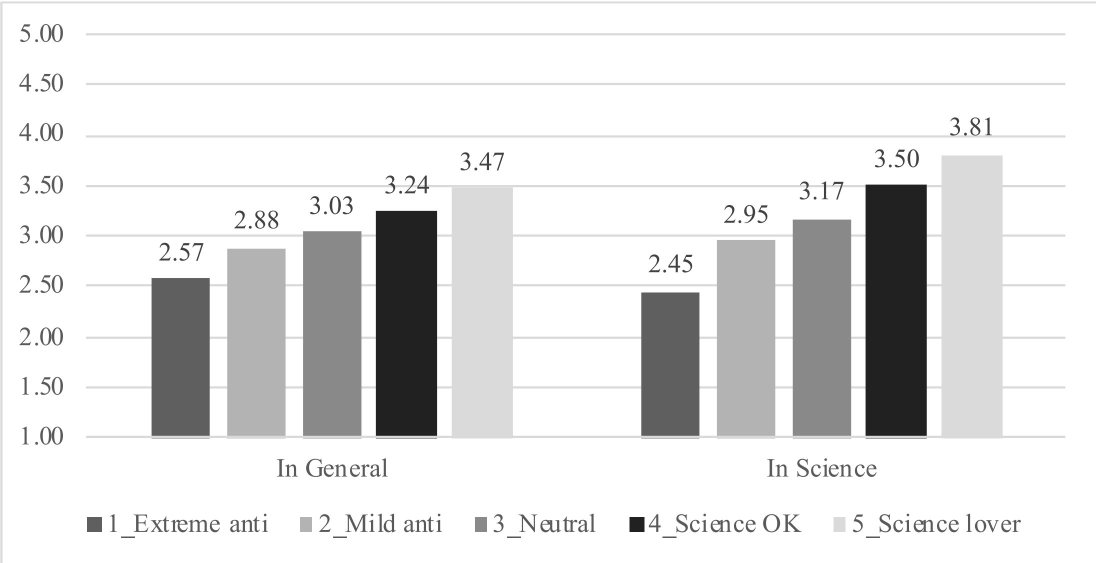

Figure 3. ANOVA: Profile and Need-for-Cognition.

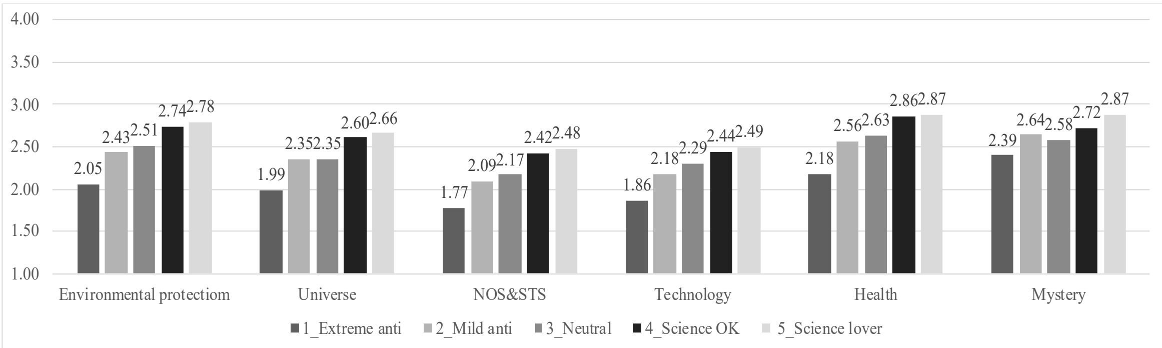

Figure 4. ANOVA: Profile and Interest in Studying Science-related Topics

3.3. Profile membership and interest in science-related topics

We performed an ANOVA to test the differences between participants' interest in studying science-related topics for the participants' profiles. The results in Figure 4 show that the mean values were larger in the order of science lovers, science OK, neutral, mild anti, and extreme anti. Mild anti did not differ significantly from the neutral on the remaining six topics except for mystery, and mild anti did not differ significantly from the science lover and science OK groups on mystery. There was no significant difference between the mild anti and neutral groups for the six topics, or between the science lovers and the science OK group for mystery. However, extreme anti was significantly different from the mean values of all profiles except for mystery. There was no significant difference between the extreme anti and neutral groups.

4. DISCUSSION

Study 1 examined the reliability and validity of the newly-developed ATLAS, which focused on students' negative attitudes towards school science on a fine scale. We developed a 28-item scale and confirmed the reliability and validity of the following four factors out of seven: performing calculations, applying abstract concepts, failure in experiments, and life irrelevance. We could not obtain reliability evidence for 'study as a subject'. Any exclusion of items under 'study as a subject' did not improve the alpha coefficient, thus requiring further examination. Likewise, validity evidence for 'grades and understanding' and 'teachers' characteristics' was not obtained. The reason might be that the negative attitudes towards these two factors are typical among participants and do not directly lead to their response to the 'Enjoyment of Science' indicator. Therefore, additional evidence should be collected to establish the validity of these two factors.

Study 2 categorised participants into five profiles with STLAS: science lovers, science OK, neutral, mild anti, and extreme anti. Interestingly, the lines of the five profiles did not intersect, except for one point of failure in the experiments. In other words, unlike our initial assumptions, we did not detect any profile that scored high on one factor but low on another factor. Additionally, when compared to the other three factors, life irrelevance was characterised by a substantially larger difference in scores between profiles. This result suggests that emphasising the relevance of learning content to real life would be highly effective in attracting the interest of the mild anti and extreme anti groups. A similar pattern of scores on the two types of need for cognition (in general and in science) suggests two interesting hypotheses that need further examination: 1) Attitudes towards science may influence their attitude towards academics in general, and 2) attitudes towards science may be influenced by attitudes towards academics in general. If the first hypothesis is supported, issues related to students' attitude towards science must be promptly addressed since it affects their attitudes towards other subjects beyond the context of science. If the second hypothesis is supported, issues related to students' attitude towards science are hardly resolved only in the context of science and require taking other subjects into consideration. The results of the analysis between the profiles and interest in studying science-related topics revealed the following three topics: 1) Science lovers and science Oks are more interested in these six topics than mild anti and extreme anti; 2) for many topics, the degree of interest of neutral and mild anti was almost similar; and 3) the possibility of attracting the interest of extreme anti by introducing these six topics in science classes seemed quite low. While science, technology, engineering, and mathematics (STEM) education is expected to increase students' interest (Martín-Páez et al., 2019), this study raises concerns about the effectiveness of STEM education interventions for extreme anti and mild anti profiles. Given the above results, there are two possible future research directions. First, the four factors in STLAS used in Studies 1 and 2 must get attention from program developers. For example, if students find it difficult to perform calculations, an instruction focusing on improving their calculation skills may be effective in improving their attitude towards science. Another approach includes involving other subjects to solve attitudes towards science issues. The results suggest that science-related topics (e.g., environmental protection, Technology) are insufficient; hence, we may need to transcend beyond the context of science and include more distant subjects, such as language arts, history, politics, and so on. These two directions need to be examined in more detail in the future.

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Part 3 / Strand 3
Science Teaching Processes

Editors: *Sabine Fechner & Dimitris Stavrou*

Part 3. Science Teaching Processes

Relations between teaching practices and students' cognitive and affective development, design of teaching interventions. Research based intervention and its role for curriculum planning, instructional paths and learning outcomes. Laboratory-based practice. Video studies in science education.

Part 3: Science Teaching Processes

Editors: *Sabine Fechner & Dimitris Stavrou*

Introduction

Strand 3 "Science Teaching Processes" presents contributions shedding light on current trends in science education research. The presented papers emphaze the relations between teaching practices, teachers' professional knowledge and students' cognitive and affective development. In one focus area, projects report on the design of research-based teaching interventions and their role in learning outcomes. However, this year, several papers also focus on frameworks of teaching processes or investigations on professional knowledge relevant to teaching processes. Methods embrace multiple approaches, including in-depth interviews with teachers at different stages to reconstruct professional knowledge.

The eight contributions submitted to strand 3 of the ESERA 2021 ebook consist of theoretical or empirical papers presenting research and development projects from all over Europe, Chile and South Africa. The eight research and development papers can roughly be divided into three groups with different foci of investigation: While two papers evaluate a novel or adapted teaching intervention and their impact on students, such as teaching experiments on electromagnetic radiation or an inclusive approach to practical work, others focus on teacher competencies and in-depth analyses of professional knowledge. In the remaining papers, an emphasis is placed on theoretical approaches that aim at establishing a framework, e.g. on the ethical knowledge of teachers. Methodologically, the studies show a diverse scope, from case studies collecting and interpreting qualitative data to studies with a broader design-based research design.

In the papers presenting novel frameworks or synthesizing approaches, one paper presents a theory-driven approach to the ethical knowledge of teachers with a subject-related lens (Laub et al.). Another presents a systematic review of embodied learning with plants to compare teaching approaches with each other (Stagg). Furthermore, Reith and Nehring present a model of competencies in the process of experimentation and suggest a triad of dispositions, processes and products to describe it. In their approach, the theoretical suggestion is underlined by empirical data from student responses.

Another two papers investigate novel or adapted teaching approaches to foster student affective and/or cognitive outcomes. An inclusive teaching concept to teach optics in physics lessons is evaluated by Sührig and colleagues, while another approach presents a teaching-learning sequence for teaching electromagnetic radiation using a design-based research approach with teaching experiments (Zloklikovits & Hopf).

The three remaining papers focus on professional knowledge in different domains: Sibanda analyses how in-service physical science teachers taught chemical bonding, Alarcon-Orozco and colleagues investigate pre-service teachers' self-reported emotions during the inquiry process at different stages, and Lopez and colleagues present a case study using the TPACK model in teacher practice.

SUBJECT-RELATED ETHICAL KNOWLEDGE OF TEACHERS AS BACKGROUND FOR DEALING WITH UNCERTAINTIES

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Science education aims at developing students' capability to make ethical-judgements, which requires an opening towards a critical and reflexive examination of ethical complexity and ethical aspects. Especially focussing on scientific citizenship and the ability of students to deal with uncertainties, ethical arguments gain importance. Despite specialized knowledge in the field of professionalization research, which is considered to be an important determinant of education quality, it is unclear whether teachers possess these professional skills (namely ethical knowledge) needed to deal with this challenge.

Based on the analysis of ethical approaches such as the 'Moral Sensitivity Approach' the contribution deduces essential structures of a 'subject-related professional ethical knowledge': Knowledge of the distinction between ethical aspects and descriptive aspects, knowledge about the diversity of ethical aspects within a scientific topic and, last but not least, basic ethical skills needed to abstract ethical aspects from personal experiences and skills concerning the use of technical, ethical language when talking about these aspects. The contribution analyses the relation of this professional knowledge to other facets of teachers' professional knowledge. Furthermore, it asks for existing empirical evidence on the question of whether the degree of this professional knowledge may explain difficulties in dealing with uncertainties.

Keywords: professional knowledge, ethical judgement, competence area 'evaluation'

ETHICAL KNOWLEDGE AS BACKGROUND FOR DEALING WITH UNCERTAINTIES

Many personal and political decisions have to be made on the background of uncertain scientific evidence, for example within decisions how to deal with climate change or the corona-pandemic. So ethical question arises, how we should deal with such uncertainties, how we can distribute resulting risks in a just way, e.g., between countries, and who has to be considered by distributing the risks? Many further ethical questions can be named in similar contexts, e.g., have animals' own rights, which have to be considered by choosing a specific way within the energy transition to mitigate climate change or by killing animals on a precaution because these animals might be infected by the corona-virus?

Issues like "climate change" or "corona pandemic" are related with the challenge of "*double complexity*" (Bögeholz & Barkmann, 2005, p. 211). This means that such topics show a factual and an ethical complexity, because these issues focus not only on the question of whether climate change exists, how it is to be measured and what its extent is, but at the same time how we should deal with it, what consequences scientific knowledge about it should have for our actions.

Within science and geography education, it is widely accepted, that science and geography lessons both should consider both, factual, and ethical aspects of these "socio-scientific issues" (e.g., Fowler et al., 2009; Mehren et al., 2015). The requirement for teaching is now to design the topics didactically for students in such a way that they can experience an increase in their ability to judge in such contexts.

This paper also deals with the question, what kind of professional knowledge teachers need, to be able to prepare lessons, that take ethical aspects of scientific issues into consideration. First, we analyse the situation of dealing with ethical aspects in subject lessons. Then, we determine this knowledge by referring to philosophical and psychological theories and models and by contextualising this knowledge within the broader background of teachers' professional knowledge. Finally, we concretise this knowledge, which we call "subject-related ethical knowledge".

How teachers deal with ethical complexity

There are several indications that teachers have difficulties in dealing with the complexity of the ethical dimension of teaching topics. For example, analyses of lessons on socio-scientific issues (SSI) show that teachers of natural science subjects approve basic objectives of SSI, but their actual SSI lessons are characterized by a strong focus on teaching subject content. SSI contexts often only function as a motivating framing for learning or applying subject knowledge (Levinson et al., 2001; Lee, Abd-El-Khalick, & Choi, 2006; Sadler, Amirshokoohi, Kazempour, & Allspwa, 2006; Forbes & Davis, 2008; Ekborg, Ottander, Silfver, & Simon, 2013; Tidemand & Nielsen, 2017). This also applies to teachers or student teachers who have previously attended a training course or a course on SSI (Ekborg et al., 2013; Evagorou & Puig Mauriz, 2017; Kilinc, Demiral, & Kartal, 2017). The objectives of SSI require a necessary explication of the ethical dimension within SSI with students. Interviewed teachers of natural science subjects hardly ever show such an explication (Sadler et al., 2006), which is also comparable for teachers in the language area (here: Swedish) when addressing an SSI (Christenson, Gericke & Chang Rundgren, 2017), This could also be shown predominantly for German political teachers when teaching the topic of climate change (Hartmann-Mrochen, 2013) and for English teachers in all subjects except religion and psychology teachers (Levinson et al., 2001). Asked to name possible SSI for biology teaching, Danish biology teachers named 209 different topics, but only 28 of them actually showed a socially discursive structure (Tidemand & Nielsen, 2017).

The ability of students to recognize a moral problem within a situation is considered important by German biology teachers (Alfs, 2012; Heusinger von Waldegge, 2016), but these teachers express uncertainties on how to deal with ethical issues (Alfs, 2012; Steffen & Hößle, 2017). For geography teachers in Germany, studies by Budke, Kuckuck and Wienecke (2016) and Applis (2016) trace the above findings of a discrepancy between an affirmation of objectives in this field and their actual implementation in the classroom: On the one hand, geography teachers regard political judgement as significant, but feel overwhelmed by the complexity and sometimes assess their own political knowledge as low. However, political judgement is not part of their training (Budke et al., 2016). Applis (2016) reconstructs that while geography teachers explicitly regard the ability to endure controversy and complexity as an important goal, they implicitly orient themselves towards creating order in the classroom.

Philosophical and psychological perspectives on ethical knowledge

Within issues of double complexity, the level of information and scientific descriptions have to be differentiated from an ethical level. The special status of ethical knowledge, which is needed to determine this ethical level and to make judgements about it, is reflected in both the historical depth of the thematic debate surrounding this competence and in the development of a discipline which is responsible for the statement systems in question, namely philosophical ethics. The distinction between descriptive and prescriptive (normative) statements, the core of ethical judgement, goes back at least to Aristotle, who distinguished between the areas of theoretical and practical philosophy. What remains fundamental is the insight into the need for an analytical distinction between the modes of descriptive and prescriptive statements, and the problem of inferring descriptive from normative statements (Hume, 1978). This is particularly evident in ethical conclusions (practical syllogism, Toulmin scheme) (Dietrich, 2004). In its consideration of the questions of "desirable" or "good action" ethics represent a rational examination of questions of morality (Ott, 2001; Nida-Rümelin, 2005). Corresponding to other disciplines, an ethical technical language has developed in the systematic examination of questions of morality, which includes a long history of problems and concepts and shows its own culture of the use of standardized technical terminology. Ethical judgements are always required when questions arising in practice contain normative aspects. For this reason, ethical arguments are of enormous importance in pedagogical contexts and in dealing with certain teaching topics (Pöppel, 1990; Oser & Althoff, 1992; Rekus, 1993).

Ethical knowledge, like the specialist discipline with its own traditional history from which it originates, is complex in terms of content. In addition to technical language regulations and terms, there are also central arguments, derivation processes and meta-ethical concepts, that can be seen in various thematic areas and problems (Benner & Nikolova, 2016). However, it seems "heuristically appropriate to consider larger complexes of human practice, each of which has specific characteristics in common are to be subjected to an independent analysis" (Nida-Rümelin, 2005, p. 63) and to speak of area ethics, e.g., ethics of risk or environmental ethics (Nida-Rümelin, 2005). These area ethics can provide a differentiated access to ethical aspects within concrete issues by providing relevant ethical questions, positions and arguments for certain contexts. Various ethical fields are relevant for subject areas of science lessons, each of which relates to core areas of ethical argumentation: ecological ethics (e.g., environmental ethics, animal ethics, climate ethics), justice (e.g., social ethics, political ethics, business ethics, such as distribution of goods, opportunities, disposal of space, but also risks, etc.), questions of personal responsibility in a globally connected world (e.g., consumer ethics) and scientific ethics. Typical topics in geography lessons for example relate to several ethical fields (Felzmann & Laub, 2019; Laub, Horn & Felzmann, 2021). Climate change, for example, opens questions for social ethics (how can a just distribution of costs and benefits be), political ethics (who can decide in which way, on what future we want?), ecological ethics (in which way should we save ecological systems?) (Birnbacher, 2016). Ethical expertise as part of professional knowledge can be considered as "systematized and structured knowledge of ethical arguments and common positions of ethical statement systems on individual affected area ethics" (Laub, Horn & Felzmann, 2021).

Within moral-psychology, Rest (1986) developed a model of ethical decision-making which consists of four processes. “Moral sensitivity” is the first of these four processes and points to the ability of a person to identify a situation as a moral situation. Definitions and terminology of current research on the construct of “moral sensitivity” are inconsistent (Hattersley, 2019). Hattersleys’ (2019) analysis of 68 definitions shows that “recognizing the moral or ethical issues of a situation” is found in 43 definitions and is thus the most common definition element. Coming from this definition, “moral sensitivity” has cognitive aspects and can be regarded as including a specific moral or ethical knowledge. This knowledge is accordingly shaped by previous experiences and learning processes in the respective context and can consequently be further developed e.g., through further context-specific training (Clarkeburn, 2002). This view is confirmed by empirical findings on the effect of further training courses on moral sensitivity for students of social work, natural sciences, students in science classes and teachers in the context of inter-cultural education (see review in Hattersley 2019).

Asking what kind of knowledge teachers need when they are preparing a lesson, in which the ethical aspects of a socio-scientific issue are going to be addressed, we can conclude: This knowledge helps identifying ethical aspects of an issue. This knowledge is accessible to training. The discipline that can provide this knowledge is the discipline of ethics. So, we can call this knowledge “ethical knowledge”.

Because the ability to identify ethical aspects within an issue is context-specific (e.g., Fowler et al. 2009) and because ethics provide context-specific ethical knowledge (“area ethics”), we conclude further, that ethical knowledge, a teacher needs for his specific subject, is also subject-specific or content-specific. Therefore, we call it “subject-related ethical knowledge”.

This subject-related ethical knowledge does not concern the teachers’ personal judgements and evaluations of regarding ethical questions within the relevant issue, but rather the ability to recognize, systematically explicate and reflect on them. Teachers must be able to identify ethical aspects within a relevant teaching topic in order to make educational decisions on what and how ethical judgements can be promoted within a specific teaching topic. Ultimately, this ability represents a form of professional knowledge.

SUBJECT-RELATED ETHICAL KNOWLEDGE AS PART OF PROFESSIONAL KNOWLEDGE

Professional knowledge is seen as an essential element of teacher professionalism (e.g., Clandinin & Connelly, 1995; Neuweg, 2011). Baumert and Kunter (2006) subdivide this into the knowledge areas “content knowledge”, “pedagogical content knowledge” and “pedagogical knowledge”. The knowledge addressed in this article is not included within this systematisation. Shulman (1987, p. 227) regards “knowledge of educational ends, purposes and values (...) and their philosophical and historical grounds” as a facet of professional knowledge.

But "subject-related ethical professional knowledge" does not represent a classical content knowledge. Content knowledge refers to the question „what is?” as already explained, ethical knowledge deals with the question „what should be?” that it not part of the classical scientific perspective. It also does not represent pedagogical knowledge, since it is not related to the question of guiding children in school. Neither does it represent pedagogical content knowledge, since - like content knowledge – it does not imply any questions about educational decisions. Although this is declarative and procedural specialist knowledge, it is not specialist knowledge of the academic disciplines like biology, chemistry, physics or geography, which is assigned to the subject as an academic counterpart.

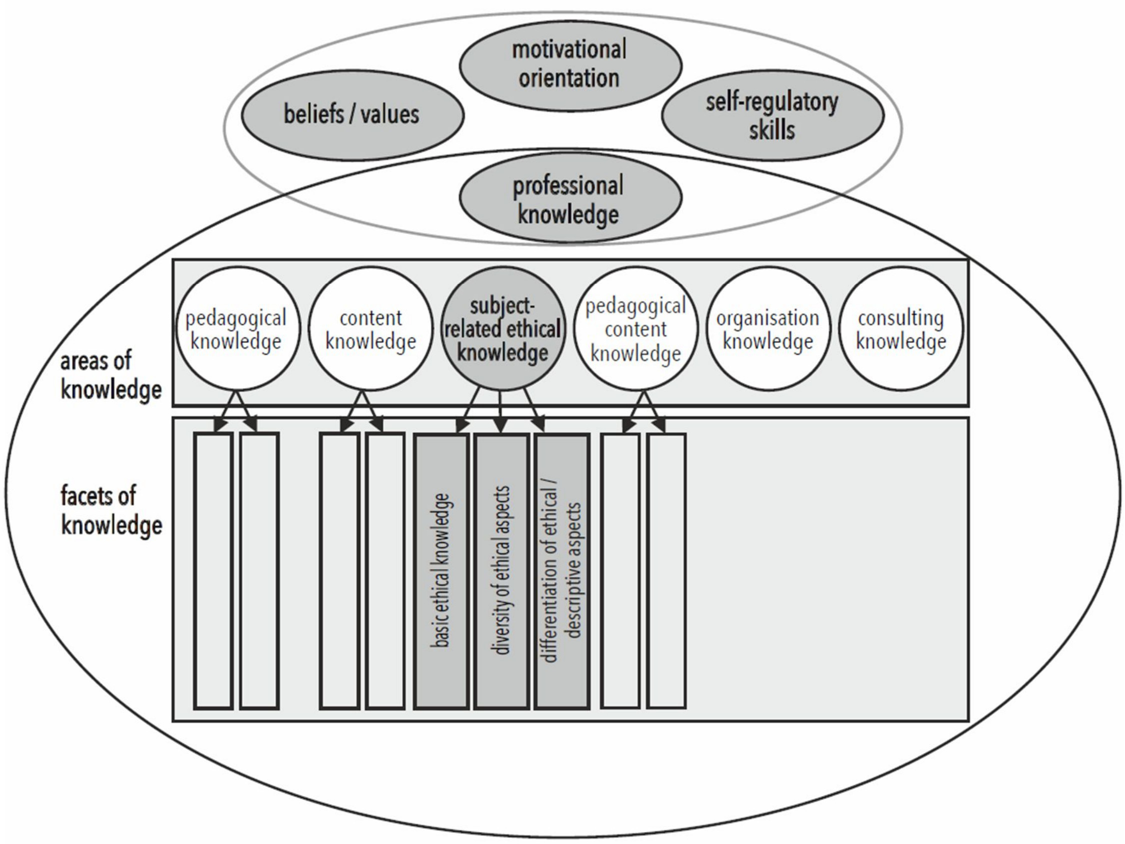

Figure 1. Subject-related ethical knowledge as part of professional knowledge of teachers (Laub et al. 2021).

Meyer (2011) also recognizes this problem and, following Bromme (1992), reacts to it by expanding Shulmans' (1987, p. 227) knowledge facet "knowledge of educational ends, purposes on values (...) and their philosophical and historical grounds". Meyer (2011) suggests that teachers should be able to identify ethical issues associated with teaching topics. Dietrich (2004) calls this "ethical-philosophical basic skills". In this very sense, these have a thematic connection to content of the respective specialist discipline, are therefore subject-related, but show ethical systems of argumentation or systematics that deviate from the subject logic. The ethical professional knowledge relates precisely to content-related technical aspects and does not mean the teachers' subjective beliefs.

Dimensions of subject-related ethical knowledge

From the empirical evidence that teachers have difficulties in promoting ethical judgement in the subject class (Alfs, 2012) and from the analysis, that subject-related ethical professional knowledge threatens to be disregarded in the current models of teacher profession research, the importance of a deeper understanding of this knowledge gets clear.

Therefore, we developed a further concretion of this subject-related ethical knowledge for the subject "geography". Combining this concretion of this knowledge with approaches to measure moral sensitivity a test instrument can be developed to measure the subject-related ethical knowledge of geography teachers. According to the research on moral sensitivity, context-specific vignettes have to be developed, in which teachers have to formulate ethical questions. Such a test instrument can be used to check whether teachers' difficulties in teaching ethical aspects in subject teaching are also due to knowledge deficits in this area and to analyse the connection between this knowledge and other facets of teacher professional knowledge. From the outline of the structure of this knowledge, it can be deduced, that the following dimensions must be measured:

- Knowledge of how to differentiate between ethical aspects and descriptive aspects within a geographical issue (e.g., "tropical rainforest"), measured as the proportion of normatively formulated questions to all formulated questions.
- Knowledge of the diversity of ethical aspects within a geographic teaching topic, measured as the proportion of area ethics taken into account in all relevant area ethics.
- Basic ethical knowledge, with which the ethical aspects can be abstracted from personal experience and formulated in ethical terminology, measured using the levels from the ETiK competence model (Benner & Nikolova, 2016), as these differentiate the focused area of ethical knowledge.

The gradations of basic ethical knowledge relate to the degree of abstraction from ones' own experience and thus to the degree of systematization, which is reflected both in terms of content and the integration of abstract, technical terms. "Technical language is [...] linked to: - the thought elements of the subject, which consist of the technical terms, - the thought structures of the subject, - the communication structures that are common in the subject." (Buhlmann & Fearns, 2000, p. 12). Especially in science education, findings confirm a close connection between specialist knowledge and technical language (Engbert, 2002; Rincke, 2010). The basic ethical knowledge can consequently be assigned by categorizing the formulated ethical questions according to the three developed levels from Benner and Nikolova (2016).

CONCLUSION

As the contribution shows "subject-related ethical knowledge" as a part of professional knowledge of science teachers, it emphasises that fundamental knowledge is important to be able to deal with uncertainties on the content level and the ethical level of scientific questions. The "subject-related ethical knowledge" can be characterized by at least three dimensions: a. ability to differentiate descriptive and prescriptive aspects, b. variety of ethical aspects and c. basic knowledge of ethical terminology.

Deeper insight in the professional knowledge and empirical results might be an important aspect to get more appropriate teacher education and training. The studies of Budke, Kuckuck and Wienecke (2016) and Applis (2016) do not provide any indications as to whether these difficulties in dealing with the competence area of assessing and evaluating also result from problems with the identification of ethical aspects, such as this subject-related ethical professional knowledge would enable. However, for various reasons and based on empirical results as reported by Schiering et al. (2021), we assume that teachers have insufficient knowledge to adequately deal with the ethical complexity of topics with uncertainties and ethical openness, since the necessary content.

Contents of teacher education show fundamental differences between different countries. Even within national borders, contents of teacher education may differ a lot. With regard to ethical knowledge, Mikhail (2015) shows that content of courses in Germany differs fundamentally and that ethical content, which is addressed here, is only part of the curriculum in some universities.

According to this argumentation, promoting subject-related ethical knowledge among teachers seems to be a way of relieving them and improving teaching with regard to the ethical dimension of current scientific results and developments. In addition to the aforementioned further research into teacher professionalism, the differentiated and evidence-based development of various training offers (subjects and previous knowledge of the teachers) certainly an important step in order to enable teachers to deal with uncertainties in the classroom.

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EMBODIED LEARNING TO COUNTERACT PLANT BLINDNESS: A REVIEW

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Embodied cognition describes learning that is based on the body's sensorimotor processes. Evidence suggests that plant blindness, a well-studied barrier to learning in biology education, is linked to diminished experience with plants. I examined the characteristics of embodied experience with plants in the educational literature using systematic review methods. I identified 52 studies based on instructional approaches that provided direct experience of plants in a field or laboratory context. The most common embodied activities in the review sample were the close observation and handling of plants and the use of field or digital equipment. Whilst all experimental approaches contributed to learning to some extent, the review highlighted the need for embodied activities relevant to plants in order to address plant blindness. Six studies used approaches based on multisensory experience which is particularly promising for counteracting plant blindness.

Keywords: plant blindness, embodied learning, plant biology.

INTRODUCTION

Embodied cognition theories suggest that learning is grounded in the body's sensory-motor processes (Shapiro, 2014, Varela, Thompson & Rosch, 2017). The interplay between physical action, perception, and the environment influence our mental representations of the world. Integrating embodied activity such as movement, gestures and sensory arousal with a cognitive task is known to enhance learning (Skulmowski & Rey, 2018). Whilst the relevance of embodied cognition for language learning, music and mathematics has been established, its role in science education has received less attention but has considerable potential (Weisberg & Newman, 2017).

Plant blindness is the lack of interest in or inattention towards plants, or the belief that plants are inferior in importance to animals (Wandersee & Schussler, 1999). It is a common problem in learners of all ages in urban populations with diminished direct experience of plants. Traditional societies with a strong reliance on natural resources do not exhibit plant blindness (Stagg & Dillon, 2022).

Meaningful processing that evokes strong associations, and experiencing materials in multiple modalities, are well known to enhance memorability (Keifer & Trumpp, 2012). These principles suggest that embodied experience of live plants has the potential to enhance learning. However, it is important that embodied experience is directly relevant to learning, otherwise it becomes an extraneous cognitive load.

This study examines direct experience of plants in the recent experimental educational literature. The research questions are: (1) What were the characteristics of the embodied aspects of learning? (2) How relevant and integrated was the embodiment, in relation to the learning task? (3) What was the impact (if any) of embodiment on plant blindness?

METHODS

The literature for this study was derived from a broader, comprehensive review of plant blindness and pedagogic approaches for plant biology. The literature review was based on the methods described in Bennett et al. (2005) and aimed to be thorough and objective in scope. An overview of the methodology is shown in Figure 1 and presented in depth in Stagg and Dillon (2022). A thematic analysis was used to identify the main characteristics of each study, informed by Neuendorf (2019). I embarked on the task with an initial suite of *a priori* codes which I developed and revised upon close examination of a sample of texts. Randomly–selected samples of studies were replicate-screened and coded by another investigator as a reliability measure following Bennett et al.'s recommendations.

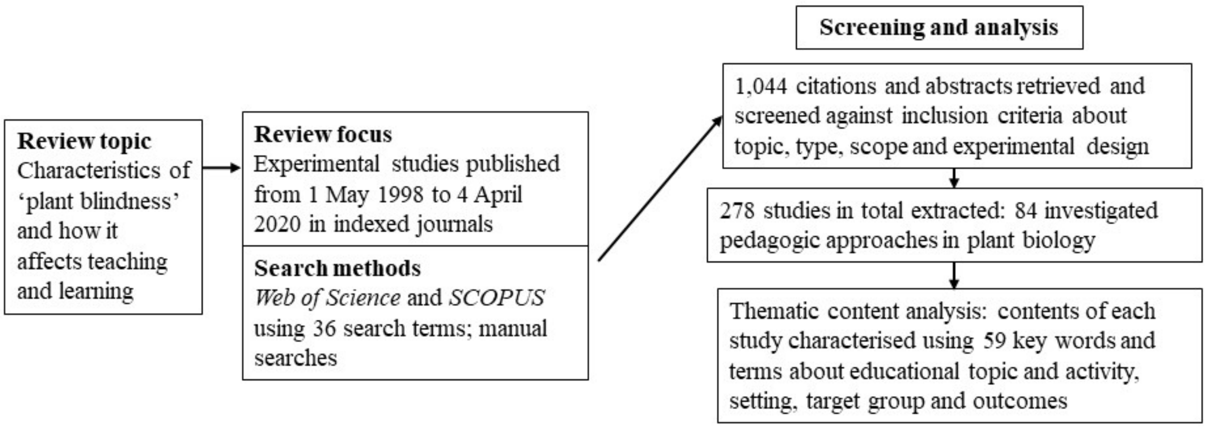

Figure 1. Overview of research methodology (reproduced from Stagg, 2020a).

RESULTS

The literature review identified 84 studies that investigated pedagogic approaches for plant biology. 43% of studies were carried out with children aged 5 to 11 years, 37% with 11 to 18 year-olds and 31% were with undergraduates. 52 of the studies were based on instructional approaches using live, whole plants in the classroom, laboratory or the outdoors. Three studies used instructional approaches based on dialogic (verbal) learning with no embodied experience apart from brief, incidental observation of plants. The remaining studies were based on a variety of approaches detailed in Figure 2. Embodied experiences included the handling and inspection of plants, drawing or writing, walking around field sites and the sensorimotor activities associated with field and laboratory techniques and mobile devices.

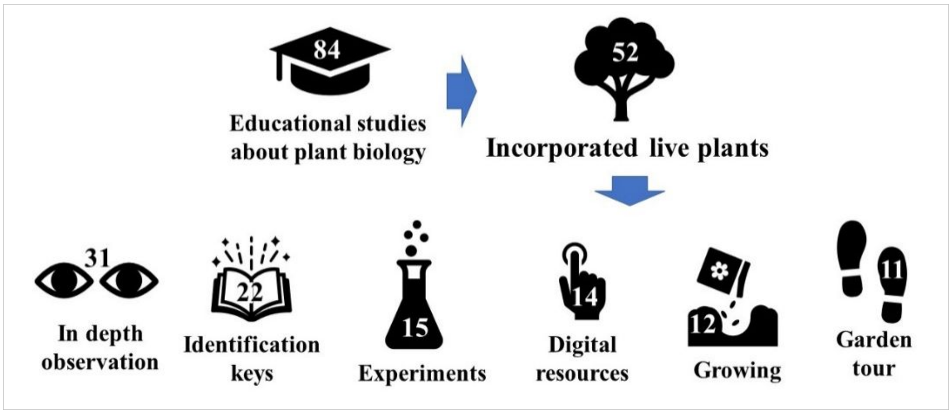

Figure 2. Summary of pedagogic approaches that incorporated whole, live plants in the review sample.

All studies reported an increase in cognitive and/or affective learning as a result of the experimental intervention, as compared to a control group or a pre-intervention assessment. In 29 studies, there was a statistically significant difference in learning between the post-assessment and pre-assessment or control group. Many studies alluded to the benefits of 'hands-on' learning but only a few mentioned embodied cognition theories or the implications for their research.

The close observation of plants over time was found to be highly engaging, particularly if the students were responsible for caring for them; for example, 'The Pet Plant Project' (Krosnick, Baker & Moore, 2018) which significantly increased US undergraduates' appreciation of and attention to plants. Lindemann Matthies (2002) highlighted the importance of repeated observations of plants over time in her evaluation of the 'Nature on the Way to School' programme in Switzerland. An alternative approach is to utilise time-lapse investigations of plant growth and development which Brenner (2017) found to be effective for increasing US undergraduates' interest in plants.

Whilst a large number of studies promoted close observation or handling, only six studies employed a multi-sensory approach where students were introduced to plants with distinctive odours, textures or tastes. Such approaches were found to be highly effective in increasing interest and attention to plants. One example is Stagg (2020b), a drama workshop about Linnaeus in the UK, where children explored a range of plants and helped to classify them. Two thirds of the children interviewed mentioned embodied experiences, particularly olfactory and tactile ones, and how these had contributed to learning or enjoyment. Pre and post tests and delayed post tests indicated a significant, durable increase in positive attitudes to plants.

A 2015 study by Cil in Turkey, in which children explored aromatic and medicinal plants in the field and used them to make soap, natural dyes and mosaics, was shown to be effective for reducing plant blindness and stimulating interest and appreciation of plants. Lai et al's (2007) study in Taiwan evaluated a mobile app that introduced children to a series of plants in the field and guided them through an immersive exercise in experiencing the plants with all their senses. Children were shown to develop in depth knowledge of plants' morphological characters using this approach.

In some studies, interactions with novel laboratory instruments or digital technologies contributed to learner satisfaction, whilst in others they were a distraction from the plants. Kissi and Dreesman (2018) believed that the reason why their experimental approach failed to significantly increase appreciation of plants was because the mobile devices in their outdoor learning activity were too much of a distraction. Stagg and Donkin (2017) found that mobile computer keys were distracting to use due to problems with screen size and reflectance. Stagg, Donkin, and Smith (2015) noted that a computer key involving multiple mouse clicks and page scrolls was likely the reason for the low identification rate and high completion time with this key. By contrast, paper and mobile computer keys could be positioned close to the plants and they relied on finger movements for navigation, thus providing more opportunity for plant handling and inspection.

Approaches based on the observation and handling of the plant's constituent parts may impede the recognition or appreciation of the plant in its entirety. Examples include laboratory techniques based on plant dissection and measurement and the use of identification keys. An identification key was less effective than approaches based on mnemonics ('memory devices') for UK undergraduates learning to memorise plant species (Stagg & Donkin, 2015). The key required the learner to use working memory to move between the different steps as well as make sense of, locate, and compare the identification cues described in the key. The key could therefore reduce working memory resources available for observation and sensorial experience. Learning to use a key is invaluable for students intending to pursue the study of botany but could prove off-putting for novices due to the embodied cognitive load.

DISCUSSION

Most learning approaches in the review sample relied heavily on visual processing, for example drawing or the use of identification keys, which could detract from multisensorial experience with plants. The handling and close inspection of live plants simulates the process of identifying a species in the natural environment which can benefit the production of mental models for plants according to transfer–appropriate processing (Morris, Bransford & Franks, 1977). Bodily activities need to be related to a learning task in a meaningful way. There is a risk that mobile devices and research instruments may detract from the embodied experience with plants particularly if a high level of interaction is required with these accessory devices. Some studies found this to be a constraint for increasing interest or attention for plants. Identification keys were found to pose a similar challenge.

A leading reason for inattention to plants is their lack of obvious movement. But plants are rich in perceptual characteristics because of their sessile life–style. By learning to interact with plants using all the senses, these characteristics may serve to increase attention and interest (Figure 3). As Honey (1987) noted: "As animals draw attention to themselves, plants need to have attention drawn to them and there is a need to show things related to plants which are interesting and varied." Nyberg, Brkovic and Sanders (2019) highlighted the importance of sensory appeal for creating memorable 'plant encounters.' Auer (2008) proposed that employing all the external senses assists plant identification by promoting associative memory, enabling a physical stimulus (e.g., smell) to cue information retrieval (e.g., species name).

Because lack of experience is a key impediment in plant blindness, introducing learners to appropriate ways of examining and interacting with plants may encourage them to draw on these behaviours in the future. Students require guidance to develop the perceptual-motor patterns that experts rely on automatically to complete a task (Abrahamson and Lindgren, 2014).

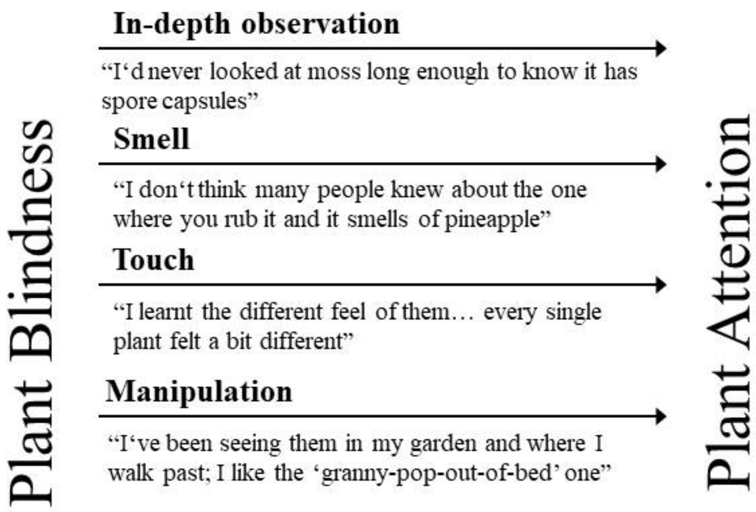

Figure 3. A model for reducing plant blindness using embodied experience (quotations are interview excerpts from Stagg, 2020b)

CONCLUSION

Embodied aspects of learning in the review sample was shown to have a positive impact on plant blindness, with multisensory experience showing most potential for counteracting plant blindness. Experiences benefit from being structured in a way that promotes a productive exploration of plants and minimises physical or cognitive distractions. Embodied aspects of learning in the review sample were shown to have a positive impact on plant blindness, with multisensory experience showing most potential for counteracting plant blindness. Experiences benefited from being structured in a way that promoted a productive exploration of plants and minimised physical or cognitive distractions. Embodied cognition theory was under-used as a theoretical perspective for examining the problem of plant blindness and related pedagogic approaches but could provide a useful framework for the future.

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EXPERIMENTAL COMPETENCIES AS A TRIAD OF DISPOSITIONS, PROCESSES AND PRODUCTS

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An important field in science education research deals with how the ability to use acquired knowledge and skills for solving problems can be fostered. In the domain of experimentation, this ability can be conceptualized as experimental competencies. These competencies are defined as latent, dispositional constructs that comprise knowledge, skills and motivational-affective components necessary to engage in experimentation successfully. They manifest in performances shown in solving experimental problems. So far, it is not well understood how the solutions emerge from the underlying dispositions. Therefore, we propose the model of the "competency triad" describing experimental competencies in a trifold approach: It comprises the facet of dispositions as latent knowledge, skill and motivational-affective components, the facet of processes as their purposeful activation in specific situations and the facet of products as the problem solutions that arise from these processes. We assume that further insights into why students experiment successfully can be gained by modeling experimental competencies using the competency triad. In this contribution, we describe the model of the competency triad and present an approach to test it empirically.

Keywords: Scientific Competences, Scientific Experimentation, Science Inquiry

INTRODUCTION

A central goal of science education is to enable students to engage in scientific practices (Hodson, 2014; NGSS Lead States, 2013). One of these scientific practices is experimentation which allows investigating causal relationships between variables (Kind & Osborne, 2017). In an idealized procedure, it consists of identifying questions, generating hypotheses, planning, carrying out and evaluating experiments, and reflecting the whole investigation (Emden & Sumfleth, 2016). Experimenting can be conceptualized as complex problem solving (Mayer, 2007), which requires not only specific knowledge and skill components, but also the ability to use and integrate these components purposefully in particular situations. The latter aspect is increasingly emphasized in science education: It not only aims at teaching scientific content but also at enabling students to use the acquired knowledge (e.g. KMK, 2005a, 2005b, 2005c; NGSS Lead States, 2013).

One approach is the competence-based approach, which has received a lot of attention, especially in Germany (Klieme & Leutner, 2006; Koeppen, Hartig, Klieme, & Leutner, 2008). In this approach, competencies are understood as latent constructs (Koeppen et al., 2008), that comprise comprise various knowledge, skills and motivational-affective components and enable students to solve domain-specific problems (Weinert, 2001). These dispositions manifest in the observable behavior in a problem-solving situation (performance) (Blömeke, Gustafsson, & Shavelson, 2015). So far, however, there is little knowledge about how the performances emerge from the dispositions. This is true for competencies in general as well as for experimental competencies in specific.

Considering similar approaches in other research fields (e.g. Blömeke et al. (2015) in professional competences of teachers), we propose the model of the "competency triad" of experimental competencies. This model is intended to contribute to clarifying the relationship between dispositions and performances and, therefore, to support assessing, modeling and fostering experimental competencies.

THE MODEL OF THE COMPETENCY TRIAD

Experimental competencies are conceptualized as dispositions that become observable in how students act in problem-based situations that emerge in scientific experiments. The problem solutions developed in the course of the problem-solving process are the products of these performances. It is plausible that the connections between the dispositions and the products are strong, but by no means deterministic. Production deficiencies, i.e., students possess the required knowledge and skills, but do not generate high-quality problem solutions, are well documented in the field of experimentation (Marschner, Thillmann, Wirth, & Leutner, 2012). Therefore, favorable dispositions do not necessarily result in adequate products. To differentiate between more or less promising dispositions, more or less expedient processes and more or less successful solutions, it appears to be fruitful to add a linking, third competency facet which links dispositions and products. The model of the competency triad constitutes such an approach to model experimental competencies comprehensively and in a differentiating manner (see Figure 1).

Figure 1. Model of the competency triad.

Applying the model of the competency triad on experimental competencies, dispositional components comprise cognitive and motivational-affective components, which are prerequisites for engaging successfully in experimentation. Based on the current state of research, procedural understanding, content knowledge, laboratory-technical knowledge, self-concept, and interest can be identified as relevant components.

The processes facet mediates as a linking element between the latent dispositions and the observable problem solutions (products). It comprises processes in which the dispositional components that are required in the specific problem situation are activated and linked in a goal-oriented manner. It should be emphasized here that the processes in this context are not to be equated with the process of experimentation as a whole. On the contrary, the processes describe the extent to which latent dispositional components are used to solve (partial) problems during experimentation.

Finally, the products are the problem solutions that are developed in the course of the processes and remain at their end. Unlike processes, products are static. They do not consist in the result of the process of experimentation as a whole, i.e., the answer to the research question, but in the solution of (partial) problems of the process of experimentation, for example a written hypothesis in the course of a scientific investigation or the solution to a task in a competence assessment, e.g., which experiment would be suitable to test a given hypothesis.

In this understanding, competent persons possess the required knowledge and skill components as well as favorable motivational-affective factors, purposefully use these dispositional components in specific situations and thereby generate adequate problem solutions.

Experimental problem solving in the understanding of the competency triad: the example of reaction rate

In the following, we will describe how experimenting is understood in the model of the competency triad. For this purpose, we will use an example of our study described below.

In the context of experimenting in the field of kinetics, the students are confronted with the research question asking for the influence of reactants concentration on reaction rate. They are expected to follow (more or less) the idealized procedure of experimentation to answer the research question. According to this procedure, the next step after identifying a question is to generate a hypothesis.

On the facet of dispositions, generating an adequate hypothesis requires procedural understanding and content knowledge. Students should, for example, know that a hypothesis should answer the research question, that it should include a causal relationship between an independent variable and a dependent variable, that it should be potentially falsifiable by scientific experiments, and that it should be a justified assumption based on prior knowledge (Arnold, Boone, Kremer, & Mayer, 2018). All these aspects relate to procedural understanding. However, to generate a justified assumption, content knowledge is required as well. For the given example, knowledge in the field of kinetics is a prerequisite. Students could, for example, have a more or less elaborated idea of the collision theory as a theory that can be utilized to explain and to predict reaction rates.

The next requirement to generate an adequate hypothesis is that the necessary knowledge is not only available but is also used purposefully, which corresponds to the processes facet of the competency triad. This facet includes identifying information relevant to solving the specific problem (activating) and incorporating it into the problem-solving process (integrating). So, for the given example, students should consider the criteria for an adequate hypothesis (procedural understanding). In order to fulfill the criterion that the assumption is well-founded, the content knowledge must also be activated and integrated into this problem-solving process. For example, submicroscopic consideration of how reactants concentration influence's reaction rate based on collision theory need to be made (content knowledge).

In the course of this process of hypothesis generating, the hypothesis might be refined little by little and it is also possible that students generate several different hypotheses. At some point, they opt for a particular hypothesis and write it down in the lab report. This is when the processes are transferred into a product respectively result in a product. In this example, the written hypothesis represents the problem solution, i.e., the product of the problem-solving process.

Analogous descriptions can be given for problem solving for the remaining phases of experimentation. Depending on the phase, other knowledge components can become relevant.

For example, when planning an experiment, laboratory-technical knowledge is essential as well: Based on their knowledge concerning potentials and limitations as well as the handling of instruments, students have to decide which instruments they use in which way to vary the independent variable, measure the dependent variable and control confounding variables.

RESEARCH QUESTIONS

The model of the competency triad is a hypothetical model that is to be tested empirically. Therefore, this project aims at generating data on the three facets of the competency triad. The following research question is focused on:

RQ1: Does empirical data support the three facetted representation of experimental competencies using the competency triad?

METHODS

In order to answer this research question, we conduct a quantitative study. In this study, undergraduate students of chemistry, biochemistry, and life science individually take paper-and-pencil tests and conduct a scientific investigation using an experiment. This approach allows to measure dispositions, processes and products separately.

Participation in the study was voluntary. The study took place in accordance with local data protection regulations. All collected data were pseudonymized by a code generated by the students immediately during the data collection.

Measuring dispositions

As described above, relevant dispositional components in the field of experimentation are procedural understanding, content knowledge, laboratory-technical knowledge, self-concept, and interest. These components can be measured separately by paper-and-pencil tests. For this purpose, we deployed already published instruments, adaptions of already published instruments, and instruments developed in our research project. Table 1 gives an overview of the deployed instruments.

Adaption of already published instruments includes removing ill-fitting items in terms of content (e.g., removal of items from the procedural understanding test that refer to biological content) and adding self-constructed items. Self-constructed items (including those for the self-constructed test instruments) were designed according to criteria for multiple-choice items (Haladyna, Downing, & Rodriguez, 2002) such as avoiding trick items and using only plausible distractors. The items were furthermore optimized in several revision loops: Based on cognitive interviews (Beatty & Willis, 2007), the observed cognitive processes of the participants while item solving were compared to the intended processes. Whenever there was a discrepancy, items were revised and checked anew until no discrepancies were detected anymore.

Table 7. Paper-and-pencil-tests for dispositions measurement.

Dispositional component	Test instrument and source
Procedural understanding	Adaption of the Procedural Understanding Test (Arnold, 2015)
Content knowledge	Content knowledge test (self-constructed)
Laboratory-technical knowledge	Adaption of the Lab Skills Test (Elert, 2019)
Self-concept	Ability self-concept test (Elert, 2019)
Interest	Test of interest in chemistry and chemistry-related topics (self-constructed)

Measuring processes

The facet of processes is conceptualized as the purposeful usage of knowledge and skill components while solving experimental problems. So, in order to measure the facet of processes, students need to be confronted with experimental problems. In our study, this is achieved by providing a research question to the students and then asking them to conduct a scientific investigation using an experiment to answer this research question. The provided research question asks for the influence of the sodium thiosulfate concentration on the reaction rate in the reaction between sodium thiosulfate and hydrochloric acid. To ensure that the students take specific steps of experimentation, we provide a pre-structured lab report. We thereby follow the principle of guided inquiry (Bell, Smetana, & Binns, 2005).

The aim of processes measurement is to gain insights into the usage of the knowledge and skill components while coping with a given problem. This requires an analysis of cognitive processes. Due to the nature of cognitive processes, they cannot be observed directly. Often used methods to deal with this issue are concurrent thinking aloud or retrospective reporting. Although both methods exhibit limitations and are discussed controversially, they provide a reasonable way to capture the thought processes in a good approximation.

The two approaches come with individual potentials as well as limitations. In the concurrent thinking aloud method, participants verbalize their thoughts during problem solving, whereas in retrospective reporting participants solve the problem and verbalize their thought processes afterwards. The latter is criticized for limited validity concerning reproducing the actual thoughts that occurred during problem solving, while the validity of concurrent thinking aloud is considered to be higher. Data produced by retrospective reporting can be distorted by *post hoc* rationalizations due to the filtering and interpretation by the participants that can occur thanks to the time delay (van Gog, Paas, van Merrienboer, & Witte, 2005; van Someren, Barnard, & Sandberg, 1994). However, in our study we decided to deploy retrospective reporting for two reasons:

First, the aim of processes measurement is to gain insights into to what extent students make use of their knowledge rather than reproducing the entirety of thoughts, which means we are interested in the target-oriented thoughts that actually lead to the products rather than a comprehensive picture of all the ideas that come to the participants' mind at any time during problem solving. Since retrospective reporting produces data that does not necessarily resemble all thoughts but rather the thought processes that seem relevant to the participants, it can be assumed that it is suitable to gain insights into what kind of thoughts lead to the problem solutions.

Second, the entire study follows a quantitative approach. Therefore, the supervision effort required for concurrent thinking aloud for the targeted number of participants of about 100 would be challenging to manage.

In line with the consideration described above, in our study the students are asked to create an audio recording in which they describe which thoughts led to the problem solutions they wrote in their lab report. This task is written down in the pre-structured lab report immediately after every step of the scientific investigation. For example, after writing down a hypothesis in their lab report, they are asked which thoughts led to this hypothesis and why they wrote it down the way they did. The risk of forgetting and fabricating typical for retrospective reporting is reduced by administering this task immediately after every partial step and providing a mental aid through the lab report (van Gog et al., 2005). In addition, retrospective reporting is practiced in a warm-up task before the start of the experiment.

Measuring the facet of processes requires creating a score from the audio recordings. To do so, we are developing a coding manual according to the qualitative content analysis (Kuckartz, 2016). The coding procedure is divided into a sequence of seven steps:

Transcription: The audio recordings created by the participants are transcribed according to the rules of content-semantic transcription by Dresing and Pehl (2015).

Splitting: According to Saldaña (2013) two approaches can be deployed when coding qualitative data: Coders can analyze the data in small steps line-by-line, which is called splitting and provides detailed insights. Alternatively, coders can follow the lumping approach and operate more generalizing by coding longer segments according to the core of their content. In order to minimize the limitations of both approaches, we decided to first split the transcripts into short segments of (partial) sentences to facilitate a fine-grained analysis (step 2). Afterwards, the split segments are lumped, which means they are merged into one if they address the same content to avoid over-emphasizing single aspects that were split into several segments (step 6).

Coding for the knowledge component: All segments are assigned to the knowledge components to which they are related (content knowledge, procedural understanding, laboratory-technical knowledge). Each segment can be related to none, one or more than one knowledge component. Segments that relate to none of the above-listed knowledge components are not included in the subsequent steps of analysis.

Thematic coding: In accordance to the content structuring qualitative content analysis (Kuckartz, 2016), all remaining segments are assigned to a thematic code. Thematic codes are derived deductively and/or inductively for each knowledge component. The coding is conducted based on the aspect that is thematized in the segment. Thematic coding, therefore, has a rather descriptive than evaluative character and is not sufficient to generate a score. However, it is necessary to determine final coding segments (step 6) and supports evaluative coding (step 7).

Distinguishing processes and products: Participants sometimes tend to not only refer to the cognitive processes that led to their problem solutions but also describe their problem solutions. As the problem solutions are conceptualized as products in the model of competency triad and the facets of products and processes are to be measured separately, the quality of products should not be incorporated in the processes score. Therefore, descriptions of the problem solutions have to be identified and excluded from evaluative coding.

Lumping: As described above, the beforehand spilt segments are now fused into one coding segment if they are assigned to the same thematic code and are within close proximity to each other. Segments labeled as products are not integrated into the final coding segments.

Evaluative coding: In order to generate a score, an evaluative qualitative content analysis in accordance to Kuckartz (2016) is deployed. The evaluation is conducted using two deductively derived dimensions: Correctness and relevance. Correctness is an important criterion: Regardless of whether a person has more or less elaborated ideas on the facet of dispositions in principle, on the facet of processes it matters on how elaborated the ideas are that are actually activated and used for problem solving. But the ideas used for problem solving should not only be correct, but also relevant: In order to solve a problem in kinetics, drawing on knowledge in the field of electrochemistry is not helpful. The two dimensions correctness and relevance are further specified for each knowledge component to facilitate coding objectivity. Only segments labeled as processes are taken into account for evaluative coding. Segments labeled as products are only considered if they are necessary for understanding the processes segments.

In the following, we present an example that illustrates what kind of data is produced in our approach of retrospective reporting and how this data is analyzed according to the seven steps described above. Table 2 shows what participant SIROGR02 reported concerning the thoughts that led to the generated hypothesis:

Table 2. Transcript from the retrospective report of SIROGR02 for the phase of hypothesis generation (translated by the authors from German into English).

1	"In the next task, we are to briefly explain our thinking about the hypothesis we have generated.
2	My hypothesis is:
3	The higher the concentration of reactant, or sodium thiosulfate, the higher the reaction rate.
4	My thoughts on this were that the more reactants there are in the solution, the more likely it is that thiosulfate anions will collide with the protons, or hydrogen.
5	And accordingly more particles react with each other
6	and accordingly the reaction rate is faster.
7	And I wanted to say about this again,
8	that the increased concentration simply increases the probability of collisions
9	and that in turn causes the reaction rate to increase.
10	I formulated my hypothesis in this form,
11	because the more…, the more… relationships are actually always easily testable."

The report is already transcribed and split into short segments (steps 1 and 2). In the following, the transcript is further analyzed:

Coding for the knowledge component: The next step is to identify knowledge components the participant draws on: Segments 1, 2, 3, and 10 refer neither to procedural understanding nor content knowledge nor laboratory-technical knowledge and therefore are excluded from further steps of analysis. Segments 4 to 9, on the other hand, describe thought processes that show that the hypothesis was based on content knowledge from the field of kinetics. Furthermore, SIROGR02 drew on procedural understanding concerning how to formulate a hypothesis (segment 11).

Thematic coding: The segments are analyzed in further detail in the step of thematic coding: Segments 4 to 9 consist of an explanation of the hypothesis based on the collision theory and therefore are assigned to the code "collision theory" from the thematic codes in the category of content knowledge. In the same way, segment 11 receives the code "falsifiability" from the thematic codes in the category of procedural understanding.

Distinguishing processes and products: Since the segments 4 to 9 and segment 11 do not contain a description of the products, but only of the processes, they are assigned to the code "process".

Lumping: Based on their common thematic code, segments 4 to 9 are merged into one segment.

Evaluative coding: In the segment concerning collision theory (formerly segment 4 to 9) it is explained how reactants concentration influence's reaction rate and therefore this segment is coded as "relevant". Furthermore, it is adequate in terms of correctness as it corresponds to the actual argumentation on the relationship between reactants concentration and reaction rate based on collision theory. The same applies to segment 11: The aim of generating a testable hypothesis refers to a generally accepted criterion of scientific investigations (correctness) that has to be taken into account for hypothesis generation (relevance).

Measuring products

The products are accessible through the lab reports: The participants write down their problem solutions for each step of experimentation (hypothesis, planning, etc.) in the lap reports and thereby explicate the products they generated. The products are coded based on a coding manual. The codes of the manual are derived deductively from quality criteria for experimentation (e.g., Arnold, Boone, Kremer, & Mayer, 2018; Pedaste et al., 2016; Schlatter, Molenaar, & Lazonder, 2021) and specified inductively through several revision loops. They take into account relevant aspects of procedural understanding, content knowledge, and laboratory-technical knowledge.

CURRENT STATE AND OUTLOOK

The study was conducted with a total of N = 111 undergraduate students of chemistry, biochemistry, and life science at two universities of Lower Saxony, Germany (Leibniz Universität Hannover (December 2020, December 2021), Stiftung Universität Hildesheim (June 2021)).

As next steps, the coding manuals for analyzing the processes and the products are being finalized. Reliability examinations as well as a procedure on how to generate scores from the coding are still to be completed. Statistical methods like factor analyses and regression analyses will be deployed to answer the research question.

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PRACTICAL WORK FOR ALL LEARNERS

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Practical work is a central element of physics lessons and offers great opportunities to create positive learning environments for pupils in inclusive learning groups. In order to support teaching staff in designing practical work for learners in heterogeneous ability groups, we have developed a teaching concept for inclusive practical work. The concept combines diverse approaches through different modes of experimentation for different learners. To trial this concept, the topic of "(in)visibility" was chosen, an introductory topic in optics in lower secondary school. Materials for five sets of practical activities were developed. The developed materials were then piloted in four classes in the German state of Hesse. The results show, that combining different modes of experimentation in a teaching unit works overall, but the success depends on the teacher.

Keywords: Inclusion, Practical Work in Science, Teaching Methods in Science

INTRODUCTION

Practical Work in Inclusive Science Lessons

There are differing ideas about which activities are considered as practical work in science education (e.g., Baur et al., 2019). We define practical work as an activity that involves an "intervention to produce the phenomenon to be observed or to test a hypothesis" (Hacking, 1983, as cited in Millar, 2010, p. 109).

Practical work is an essential component of science education (Committee on High School Science Laboratories: Role and Vision, 2004) and for many teachers a central aspect of physics lessons. As a result, a large part of typical lessons is spent carrying out experiments (Tesch & Duit, 2004). Practical work provides an opportunity for personally experiencing phenomena and engaging with nature of science (Kircher et al., 2015). Consequently, teachers already include practical work as a part of their regular delivery of a topic. There are, however, many reasons for the use of practical work not only in non-inclusive learning groups, but in inclusive ones as well. It leads to a positive working atmosphere (Baumann et al., 2018), to the development of social skills (Di Fuccia, 2007) and learning gains (Rott & Marohn, 2016). Holding ourselves to the high standard of enabling all learners to develop skills should also apply to practical work. However, to design practical work in such a way that it meets the requirements of heterogeneous ability groups, adaptations to the types and design of experiments as well as supporting materials are necessary.

Teaching Concept for Inclusive Practical Work

When it comes to education, one size does not fit all. So, it is important to tailor our materials to our learners. A stated aim of the physics curriculum in Germany is to provide all pupils with a basic education in physics.

To make it easier for teachers to design learning activities in physics lessons, we have developed a concept for inclusive practical work (see Figure 1). The concept combines five modes of investigation to address a specific context.

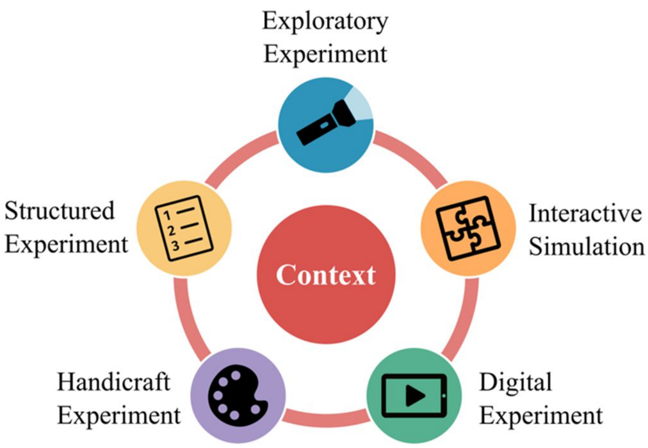

Figure 1. Teaching Concept for Inclusive Practical Work.

The development of the concept was inspired by various theoretical concepts for planning inclusive lessons. Our main inspiration is the *Universal Design for Learning* (UDL). UDL (Meyer et al., 2014) is an approach that aims to make learning environments accessible (Nelson et al., 2013) and encourages flexibility and choice. Thus, our concept consists of different modes of experimentation, from which the pupils can choose.

To create meaningful learning opportunities for all, it makes sense to plan physics lessons with a particular context as a starting point. We define context as the embedding of a content in an authentic, ordinary and beneficial environment in order for the pupils to acquire *Scientific Literacy*. Contexts should be based on striking phenomena (van Vorst et al., 2013) and be relevant for all learners (Ferreira Gonzales et al., 2021).

In our concept, all the modes of experimentation are centred around a single context and serve the purpose of explaining and leading to a better understanding of this context. They are briefly outlined in the following.

The *exploratory experiment* is intended to encourage autonomous discovery and a trial-and-error approach. The pupils do their own investigation with a self-selected question using familiar household materials. The exploratory experiment is simple to perform, and observations are of a qualitative nature. When using the *interactive simulation,* pupils change variables in a model with a stronger focus on scientific formulas to engage in mathematical modelling. Models, such as those created with *GeoGebra* (www.geogebra.org), are an idealisation of reality (Winkelmann, 2021). Pupils who work with a *digital experiment* interact with a barrier-free video of an experiment, which contains interactive elements such as buttons, offering additional help or controls for the experimental process. The pupils are guided through the experiment, which is ideal for learners who are limited in their ability to carry out experiments independently, e.g., easily distractible pupils. *Handicraft experiment* means a playful approach to the context. Pupils are provided a different perspective, increasing motivation through a more creative hands-on activity. In the *structured experiment* the pupils follow step-by-step instructions to gain experimental competences. These competences include the ability to properly use common experimental apparatuses. In contrast to the exploratory experiment, the outcome and execution of the structured one are clearly predetermined, and the focus is on the manual aspect of experimentation.

All modes of experimentation have the same learning objective. The idea behind this is that pupils choose which experiments they want to do based on their individual interests, preferences, and abilities. The goal is to enable all pupils to make scientific observations.

METHOD

The Teaching Unit

To trial the concept, we designed a teaching unit for the context "(in)visibility", which centres around light refraction. The context of the unit is a phenomenon, in which so called water beads appear invisible when put into water. The teaching unit spans two double periods and is used to assess if the materials developed using the concept lead to improvements in certain variables.

Figure 2. **Water beads.**

The unit starts with a demonstration experiment. Water beads are made to appear invisible by pouring water over them. The reason for their apparent disappearance is that water beads and water have a similar refractive index. After the demonstration, the teacher collects assumptions about the phenomenon which lead to the development of a question for further investigation. This investigation is carried out in the following experimental phase, in which the pupils are required to perform at least two different modes of experimentation. The experiments are shown in Table 1 below.

The pupils can choose which experiments they want to do and in which order. To make this possible, the teacher introduces the five experiments in more detail after collecting the assumptions about the phenomenon. The pupils need to know what they can expect from the experiments to make their choice. All experiments are accompanied by barrier-free experiment manuals and worksheets.

Table 8. Experiments in the Teaching Unit.

Mode of Experimentation	Experiment Purpose and Content
Exploratory Experiment	Pupils explore water beads through self-initiated enquiry. They are provided with several items for this task. This experiment allows an experience through different senses. It is not guided through an experiment manual to enable freedom to explore the topic.
Interactive Simulation	Pupils investigate the refraction of light in a GeoGebra model of a water bead. They vary the refractive index of the surrounding medium and observe the influence on a ray of light that traverses the bead.
Digital Experiment	Pupils determine the material of a rod in an interactive video experiment. The rod is dipped into various transparent liquids in the video. The pupils observe in which liquids the rod appears visible or invisible. Using the refractive index of the liquid in which the rod appears invisible, the pupils can determine the refractive index of the rod and thereby its material.
Handicraft Experiment	Pupils produce clear slime using glue, baking soda and contact lens solution. They investigate the refractive and transparency properties of the slime, which are influenced by enclosed air bubbles.
Structured Experiment	Pupils make a test tube seemingly disappear. The guiding manual tells the pupils to place a test tube in a tumbler filled with glycerol. Then they fill the test tube with different substances (air, water and glycerol) and observe whether the test tube "disappears".

After the experimentation phase, the results are collected comparing them to initial predictions. The individual contributions from each of the five experiments are combined to form a *big picture*. Guiding questions subsequently help the pupils to create a summary sheet being the final result of the unit.

To ensure that the teachers know how to conduct the lesson, they are provided with support material in advance.

The Study

The piloting of the unit took place in four lower secondary classes ($n_{\text{Pupils}} = 66$) with two different teachers across two grammar schools in the German state of Hesse. Both teachers taught the same unit but with a slight variation in social forms: The classes of teacher A had fixed groups due to Covid restrictions. The classes of teacher B had a fluid group dynamic, and the pupils were able to change their social form (groupwork, partner work, single person work) with every mode of experimentation.

In order to determine the success of the unit, an intervention study with pre-post-design was carried out. The variables measured included conceptual knowledge of light refraction (Weber et al., 2018), pupil perception of the teaching and learning conditions (SINUS-Transfer program), pupil social integration (Venetz et al., 2014), pupil intrinsic motivation (Wilde et al., 2009) and perceived self-efficacy for practical work (Körner & Ihringer, 2016). In addition, guided interviews with the pupils were conducted to obtain information for the further development of the teaching unit.

RESULTS

Paired samples t-tests were calculated to determine which variables (pupil conceptual knowledge of light refraction, perception of the teaching and learning conditions, social integration, intrinsic motivation, and perceived self-efficacy for practical work) were affected by the teaching unit.

We found no statistically significant difference in pupil social integration (p = .908, *Pearson r* = 0.014) and pupil intrinsic motivation (p = .079, *Cohen's d* = 0.227) caused by the unit. The classes of both teachers showed a high intrinsic motivation after the teaching unit with no statistically significant difference between both.

In the overall results, however, there was an improvement in the perception of the teaching and learning conditions (p = .033, *Cohen's d* = 0.268) and perceived self-efficacy for practical work (p = .005, *Cohen's d* = 0.376).

Analysing the data by teacher reveals that the unit had a more positive impact on the classes of teacher A (see Figure 3). In these classes, we found an improvement in the perception of the teaching and learning conditions, the perceived self-efficacy and the conceptual knowledge (see Figure 4). The classes of teacher B showed no improvement in any measured variable. These classes had been taught some of the topics covered by the teaching unit during the same school year, which explains the higher knowledge prior to the teaching unit (as shown in Figure 4). It might also be that this caused the lack of improvements in affective variables, as the topic might have become too repetitive for the pupils.

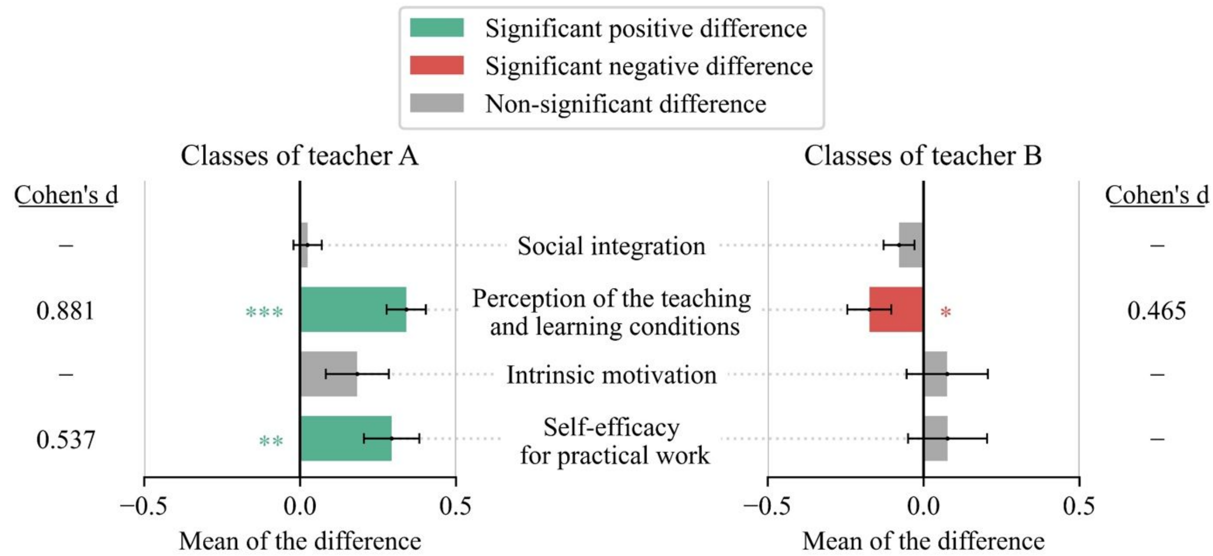

Figure 3. Mean of the difference in measured variables before and after the unit. Effect size calculated with Cohen's d. The asterisks denote the statistical significance (p-value).

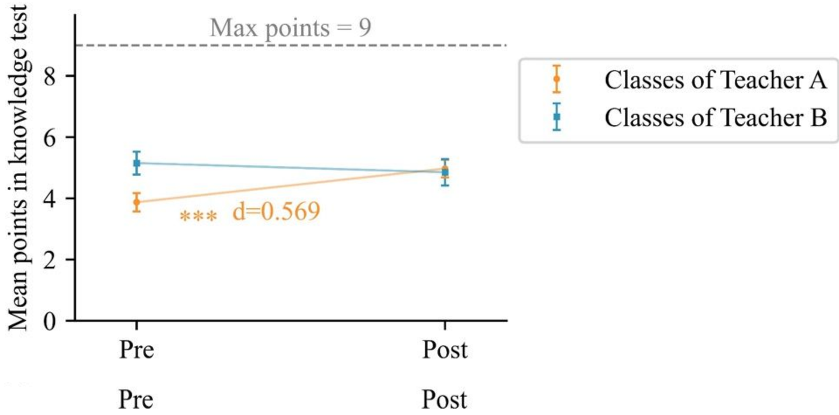

Figure 4. Results of the conceptual knowledge test. Effect size calculated with Cohen's d. The asterisks denote the statistical significance (p-value). The difference of the mean points in the knowledge test was significant in the classes of teacher A with Cohen's d=0.569 and was not significant in the classes of teacher B.

During the guided interviews, pupils provided only superficial comments on the materials. Therefore, almost none of their remarks were used for the further development of the teaching unit.

DISCUSSION AND CONCLUSION

As expected, the relatively short teaching unit has no significant effect on the social integration of the pupils, because it takes time to improve the social situation in classes. We found no statistically significant difference in the pupil intrinsic motivation, which surprised us at first. The test we used to measure the intrinsic motivation is an adapted version (Wilde et al., 2009) of the "Intrinsic Motivation Inventory" by Deci and Ryan (2003) and is designed as a post-test. We used it for both the pre- and post-test settings.

The evident dependence of such a unit's success on the individual teacher leads to the conclusion that not only a well-designed concept is needed but also an in-depth teacher training for it. Without this, a positive impact on pupils' learning outcomes is not guaranteed. We will offer professional development followed by an evaluation of its effect on the successful application of our concept.

Inclusive teaching in general needs suitable contexts that form the basis of lessons centred around practical work. Furthermore, practice is needed that allows for a high degree of adaptivity, and also encourages (while not requiring) cooperation and co-construction. Inclusive practical work seeks a compromise solution between the desire of schools for a standardised education and the desire of inclusive education for individualisation and adaptivity. In a teaching concept like the one presented here, pupils can move freely within a framework and complete individual learning paths. The framework guarantees the teacher that the intended content is delivered and that the lesson goals are pursued.

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USING LOCAL INSTRUCTION THEORIES FROM INTRODUCTORY OPTICS TO DEVELOP A COURSE ON ELECTROMAGNETIC RADIATION

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Although electromagnetic radiation is omnipresent in modern-day society, it is typically only part of upper secondary education. We are developing a teaching-learning sequence that provides students at the lower secondary school level with a basic understanding about electromagnetic radiation. The development builds on results from a research project on introductory optics. Guided by the design-based research paradigm, we refined our initial design in four research circles. The implementation and evaluation of our design was realised in form of one-on-one teaching experiments (n = 37). In this paper we focus on the design principles we adapted from research on teaching and learning introductory optics and the results from our evaluations regarding those principles. Our findings demonstrate that the "optics approach" to teaching electromagnetic radiation is advisable.

Keywords: Design-Based Research, Physics, Evidence-Based Approaches

INTRODUCTION

Electromagnetic radiation (EMR) is a relevant topic in our modern, everyday life: A majority of the electronic devices we use connect to the internet via EMR. We try to avoid to absorb too much UV radiation. Many medical applications are based on EMR. To understand basics about climate change, the mechanisms of the greenhouse effect have to be discussed. So, in our opinion, even younger students should have the opportunity to learn about EMR in their science curricula.

Considering of the importance of EMR in our daily life, it really is interesting that only a sparse body of research of teaching and learning EMR exists, most of which focusses on students' conceptions of EMR (for an overview see Plotz, 2017). Very little research concentrates on teaching-learning sequences (TLS) for EMR with the majority covering the teaching and learning of blackbody radiation (e.g., Reinfried & Tempelmann, 2014, Tasquier, 2015 or Haglund et al., 2017) and/or focus on higher secondary education (e.g. Fitzgerald & Plotz, 2020). An exception is the work of Plotz, in which separate teaching units were developed for each type of radiation for lower secondary education (Plotz, 2017). We are partly building on his work.

To the best of our knowledge, no evidence-based strategies to teach the entire electromagnetic spectrum to younger students exist so far. Therefore, we are developing a TLS that allows the implementation of the topic in mandatory education, more specifically in grade eight. Our work is guided by the design-based research paradigm (DBR): Based on theories of learning and teaching of the specific topic, design principles that guide the design process are formulated. DBR processes consist of continuous cycles of design, implementation, evaluation and refinement (The Design-Based Research Collective, 2003). We carried out four iterations of such cycles, assessing the TLS with a total of 37 students in one-on-one teaching settings with the method of probing acceptance (Jung, 1992).

To structure our TLS, we are following the basic principles students should now about EMR as formulated by Plotz (2017). Thus, the TLS covers the introduction of the term "electromagnetic radiation", the interaction with matter, the electromagnetic spectrum, its omnipresence and the effect of radiation on the human body. A special focus was to develop age-appropriate explanations and the utilization of experimental materials that are affordable and easily available. A detailed description of the TLS can be found in Zloklikovits and Hopf (2020) and Zloklikovits and Hopf (2021).

One of the challenges we faced when developing the TLS was how to explain EMR to younger students, as students in grade eight are not familiar with the particle or the wave model, since it is not part of the Austrian lower secondary school curriculum. In order to meet this challenge, we have built on findings from educational research of introductory optics. The teaching of visible light is well established in lower secondary school curricular and has been the subject of numerous studies in physics education research (e.g., Fetherstonhaugh & Treagust, 1992; Jung, 1992; Galili & Hazan, 2000; Haagen-Schützenhöfer, 2017). Our intention was to apply educational knowledge about visible light to the rest of the electromagnetic spectrum. Therefore, we developed five design principles for our TLS. We based those principles on the local instruction theories for introductory optics developed by Haagen-Schützenhöfer and Hopf (2020). An overview of the local instruction theories we used and the adaption for our design principles can be found in Table 1.

Table 1. Overview of local instruction theories adapted for our TLS.

Local instruction theories for introductory optics (Haagen-Schützenhöfer & Hopf, 2020)	Conceptualisation for our TLS on EMR
The distinction of matter and radiation should be explicated: "Light is different".	Along with "EMR travels with the speed of light", "EMR is something completely different than matter" is used to give a simple explanation for the term EMR.
"Whenever possible, learning paths start from subjectively perceived phenomena."	Whenever possible, learning paths start from everyday experiences. The students perform experiments with visible light, then work with infrared radiation and/or UV radiation, using simple materials. Only afterwards, we move forward to more abstract types of radiation, like radio waves ("radio radiation") and mobile phone radiation.
Light rays are only used later. In the beginning, light is depicted as cone-shaped arrows.	Cone-shaped arrows are used to illustrate radiation. No "EMR rays" are used.
Absorption is depicted with wiggly arrows entering the object.	Absorption is depicted with wiggly arrows entering the object.
The sender-receiver model is implemented in the beginning and applied throughout the instruction. Usually, the eye is the receiver.	Every explanation and experiment is accompanied by a sketch where the source, the radiation (in form of arrows, as stated above) and the receiver are always depicted. Different types of radiation need a different receiver. If the receiver detects radiation, a checkmark is drawn, otherwise a small x.

In this paper, we illustrate how those theories were adapted for our TLS on EMR and how the design principles were refined over the course of four DBR-cycles. We strive to answer the following research question:

- How do lower secondary school students learn about EMR if local instruction theories from geometrical optics are adapted to form a curriculum on EMR?

We are confident that our findings are of interest for practitioners and curriculum designers alike.

METHODS

We evaluated the TLS using the method of probing acceptance (Jung, 1992), which is a variation of one-on-one teaching experiments. The aim is to investigate if the students find a given explanation plausible, if they can transfer the explanation to other contexts, which parts of the instruction are helpful, and which seem to hinder learning. The investigation consists of the following steps: An explanation is presented to the student and illustrated with some examples. The student then is asked if they find the explanation comprehensible. If the student resists the explanation, this can already be observed here, as in such cases students will point out that they do not like the given explanation. Next, the student is asked to paraphrase the explanation. To the researcher, it is of interest which parts of the explanations are changed or left out, as these are indices that the student does not find that part of the explanation helpful or understandable. Afterwards, the student is presented with one or two tasks. Here, one can see if the student applies the given explanation or some pre-instructional knowledge instead, and if the student can apply the explanation appropriately. An insight into the explanations and tasks used in our investigation can be found in Zloklikovits and Hopf (2021).

Four research cycles (C1 - C4) were conducted and, overall, 37 students from grade 8 and 9 participated (C1: n

= 6, C2: n = 8, C3: n = 6, C4: n = 17). Due to the pandemic, the teaching experiments of Cycle 4 were carried out online. For this purpose, demonstration experiments were prepared in the form of videos. The experimental tasks were realised as interactive screen experiments (ISE) using tet.folio (Neuhaus et al., 2013). During the teaching experiments, the ISE was controlled by the interviewer; the students indicated what they would do if they had the experiment in front of them in real life, and the interviewer simulated this using the ISE.

The recordings of the sessions were transcribed and analysed using evaluative qualitative text analysis (Kuckartz, 2014). We coded for every rating, rephrasing and task whether the student's performance was good (3), satisfactory (2) or insufficient (1). In cases no data was available for a step in the investigation, it was coded as missing (0). This analysis strategy for evaluating a TLS was adapted from Haagen-Schützenhöfer (2016) and Burde (2018). The calculations of Cohen's Kappa of a double coding in a subsample with two raters showed a good interrater reliability, with values varying from 0.71 to 0.81 for the different cycles (Landis & Koch, 1977). It should be noted that due to the variations of the TLS in the different cycles, not every part of the TLS was investigated in every cycle.

RESULTS

In the following, we will discuss our findings for the adapted design principles from Table 1 separately.

Distinction between matter and radiation

Students often tend to think of light as a substance – therefore, the difference between matter and light is explicated in the optics curriculum (Haagen-Schützenhöfer & Hopf, 2020). We build on this idea in order to offer an explanation for the term EMR independently of the wave or particle model. Electromagnetic radiation is introduced as being something completely different from matter and having the property of travelling with the speed of light. To mention briefly, we found that most students are not familiar with the term "matter", so an explanation of this term should be given in this context. We used the explanation "matter is everything that can be touched, practically or theoretically" as proposed by Wiener et al. (2015). This description of the word "matter" was well received by the students.

The result of the investigation of this part of the TLS is depicted in figure 1. The results demonstrate that it was well received by the students, as almost all students' answers were rated with a "3". We could also observe that in later parts of the instructions, students often referred to this explanation in their reasonings. That the students were easily convinced that visible light is EMR using this "definition" is strong evidence for its success, as research found that students typically think that visible light is different than radiation (Neumann & Hopf, 2012). In addition, this idea offers an easy distinction between electromagnetic radiation and particle-radiation.

Cycle 1	Amina	Beyza	Chris	Denise	Emma	Fatima
Assessment "What is EMR?"	3	3	3	3	3	0
Rephrasing	3	3	3	3	2	3
Task solving	3	3	3	3	1	2
	2	2	3	1	3	3
Assessment "visible Light is EMR"						

Cycle 2	Gülcan	Hoda	Ivan	Julia	Kathi	Lukas	Monika	Nina
Assessment "What is EMR?"	3	3	3	3	3	3	3	2
Rephrasing	3	3	3	3	3	3	3	3
Task solving								
Assessment "visible Light is EMR"	3	3	3	3	3	3	3	3

Cycle 3	Olga	Petra	Quentin	Rosa	Stefan	Timo
Assessment "What is EMR?"	3	3	3	3	3	3
Rephrasing						
Task solving						
Assessment "visible Light is EMR"	3	2	3	3	0	3

Cycle 4	Alice	Barbara	Cecilia	Daphne	Emmy	Florence	Gladys	Henry	Ida	Jane	Kathy	Lewis	Marie	Nettie	Orna	Patricia	Quinn
Assessment "What is EMR?"	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Rephrasing	3	3	3	3	3	2	0	3	3	3	3	3	3	2	3	3	3
Task solving																	
Assessment "visible Light is EMR"	3	3	3	3	3	3	3	3	3	3	3	3	3	2	3	3	3

Figure 7: Results for "EMR is something completely different than matter. It travels with the speed of light."

Starting with subjectively perceived phenomena

An important feature of the optics curriculum is that "whenever possible, learning paths start from subjectively perceived phenomena" (Haagen-Schützenhöfer & Hopf, 2020). Those phenomena are the basis for establishing "abstract subject matter principles" (ibid.). This presents a challenge for the topic of EMR, as the majority of wavelengths cannot be experienced directly. That is why we made the decision that the introduction of new concepts is first illustrated with experiments with visible lights. In the first two iterations of the TLS, we then moved on to investigate the concepts with infrared radiation. In order to avoid the misconception that infrared radiation is red light (Libarkin et al., 2011), we worked with ceramic lamps that are usually used in terrariums. We then proceeded with other types of radiation, such as mobile phone radiation and X-ray radiation.

A typical difficulty we observed in C1 and C2 was that students, after working first with visible light and then infrared radiation, seemed to think that radiation can be felt as heat in general. In order to avoid this problem, we decided to work with UV radiation instead of infrared radiation in C3. To avoid the misconception that UV radiation is blue (Libarkin et al., 2011), a lamp with a blue light filter was used in the teaching experiments. This lamp only emitted UV radiation.

When conducting the teaching experiments, we experienced that moving from light to UV was too big of a step. One of the occurring problems that lead to this conclusion was that students tried to observe the outcomes of the experiments with their eyes, despite the radiation being non-visible. We concluded that experimenting with infrared was an important step in the TLS, as it offered students the opportunity to realise that not every type of radiation is visible while still perceiving the radiation with their hands, as the heating effect was clearly noticeable. For this reason, we pursued the following strategy in C4: Light proves to be an ideal starting point as it offers plenty of opportunity to easily perceive the properties of EMR. We then move on to infrared, as this type of radiation can be sensed with the body but cannot be seen. Next, UV radiation, a type of radiation that is neither visible nor perceptible but easy to experiment with in the classroom, is introduced, before moving on to other types of radiation. To better illustrate what this means for the TLS, we will give one example of the utilisation of this design principle: When the interaction of radiation with matter is introduced, the students first perform an experiment with a flashlight where they observe that parts of the radiation can be transmitted, absorbed and/ or reflected by matter. They also observe a dependency on the material on which the flashlight is aimed. Next, the students perform similar experiments with infrared radiation, using their hands to detect the radiation and experiencing, that this type of radiation interacts differently with the used materials as compared with light. For example, they observe that while light is mostly transmitted by water, infrared radiation is mostly absorbed. Then, similar experiments with UV radiation are performed, using UV-detecting beads to register the radiation. Finally, these concepts are applied on a more abstract level to explain how an X-ray image is generated.

During the teaching experiments, the students stressed that the experiments helped them to make sense of the explanations. We found that in C4, the problems that were mentioned before did not arise, although it has to be noted that the limited experimental setting offered by the ISE might have prevented some of the problems from occurring.

Depicting radiation as cone-shaped arrows and utilizing the sender receiver model

The implementation of the sender receiver model, the depiction of radiation as cone-shaped arrows and the representation of absorption as wiggly arrows are closely linked. In the optics curriculum, light rays are only used later in the curriculum. In the beginning, light is depicted as cone shaped arrows, while absorption is depicted with wiggly arrows entering the object (see figure 2). The sender receiver model is implemented which means that the observer always follows the path of light from the sender to the receiver (Haagen-Schützenhöfer & Hopf, 2020). We adapted those ideas for EMR over the course of the research cycles.

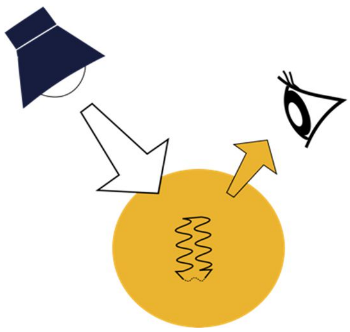

Figure 8: In the optics curriculum, the path of light is followed from the source to the receiver. Radiation is depicted as cone-shaped arrows, while absorbed radiations is portrayed as wiggly arrows (Haagen-Schützenhöfer, 2016).

In the first two iterations, we used the depiction of radiation as arrows in order to illustrate the interaction of radiation with matter. We always included the source and the matter in the drawings (see figure 3). Those illustrations accompanied every explanation and experiment. The results showed only some minor problems (see figure 4).

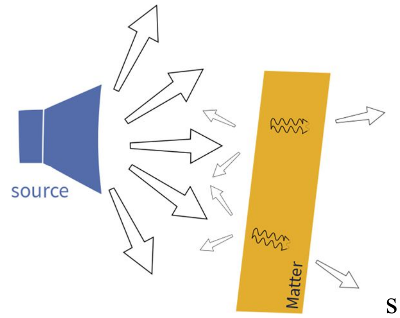

Figure 9: Application of the depiction of arrows in C1.

	Cycle 1						Cycle 2							
	Amina	Beyza	Chris	Denise	Emma	Fatima	Gülcan	Hoda	Ivan	Julia	Kathi	Lukas	Monika	Nina
Assessment "interaction with matter"	3	3	3	3	3	2	3	3	3	3	3	3	3	3
Assesment pictorial representation	3	3	3	3	3	2	3	3	3	3	0	3	3	3
Rephrasing "interaction with matter"	3	3	0	2	3	3	2	2	3	3	3	3	0	2
Applying pictorial representation to task	3	2	1	3	3	3	2	2	3	3	3	2	3	3

Figure 10: Results for "Interaction with matter".

We found that when students struggled to interpret the results of an experiment, urging them to depict the outcomes of their experiments with the introduced pictorial representation helped them to overcome their problem. Many students emphasised that they found these drawings extremely helpful. A problem that remained, as already mentioned before, was that students tried to use their eyes to observe non-visible radiation. Therefore, in the third iteration, we implemented the idea that a detector is needed to detect EMR, and that different types of radiation require different detectors. However, the students did not use the word "detector" in their paraphrases and answers and we did not see the desired improvements. Therefore, in the fourth and final iteration, we exchanged the words "source" and "detector" with "sender" and "receiver", as those terms were used in the optics curriculum. Furthermore, we implemented the receiver in every illustration, thus applying the sender receiver model to its full extent. In order to depict different types of radiation in the same drawing, we added the labelling of the arrows. A crucial addition was to mark if the receivers receive the radiation (see figure 5). Another refinement in the fourth iteration was to put emphasis on the fact that light is special as it is the only type of EMR that is visible. The results from this research cycle demonstrate that this idea was well received (see figure 6). The students were eager to use the words "sender" and "receiver" in their answers. The remaining problems that you see in the table are due to students not labelling the arrows in their drawings, and we are confident that this is something that can be solved easily.

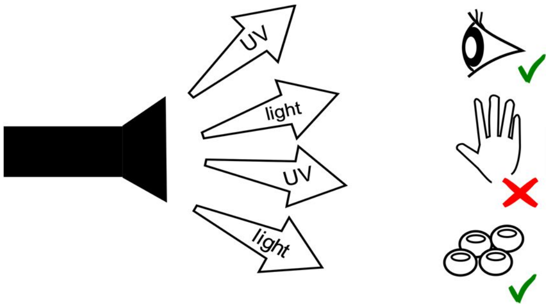

Figure 11: Depiction of radiation including labelling of arrows and marking whether the receivers (eye for visible radiation, hand for infrared radiation, and UV-detecting beads for UV radiation) detect radiation.

	Cycle 4																
	Alice	Barbara	Cecilia	Daphne	Emmy	Florence	Gladys	Henry	Ida	Jane	Kathy	Lewis	Marie	Nettie	Orna	Patricia	Quinn
Assessment "sender-receiver"	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Rephrasing "sender-receiver"	3	3	3	3	3	3	2	3	3	3	3	3	3	3	3	3	3
Applying pictorial representation to task	3	3	2	2	3	2	3	3	2	3	3	3	2	3	3	1	3

Figure 12: Results for implementing the sender-receiver model.

DISCUSSION

In this paper we outlined how we adapted well-founded instructional theories on introductory optics for a novel approach to teaching EMR to younger students. Our data shows that local instructional theories from geometrical optics can easily be adapted for the teaching of EMR to lower secondary school students. We found that at least in C4, all students showed a good learning gain due to the intervention. We think that a large part of these result stems from the adaptation of the local instruction theories from geometric optics.

Of course, our study has limitations, as we conducted one-on-one interviews with a comparably small sample of students. However, we are currently researching students' learning gain in the physics classroom on a larger scale in order to ascertain our TLS' feasibility and usability. Thus far, it appears that we are on a good way to make EMR understandable for younger students.

The consequences for physics teaching in lower secondary school are clear: The argument that lower secondary school students cannot understand EMR cannot be supported any more. So, we strongly propose to rethink lower secondary school physics curricula to include aspects of EMR. In our eyes there is almost no physics topic which has a similar relation to everyday experiences.

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HOW PHYSICAL SCIENCE TEACHERS SUPPORT LEARNERS' UNDERSTANDING OF CHEMICAL BONDING AT HIGH SCHOOL

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Research into teaching chemical bonding has been conducted for decades, but to date, there is no single agreed approach to teaching the topic. The study reports on how in-service teachers provide support to learners when teaching chemical bonding at high school. An interpretive qualitative approach was used to collect data. Interviews were conducted with eleven in-service physical science teachers drawn from different schools. Qualitative analysis was used to determine how in-service physical science teachers help learners to learn chemical bonding at high school. Analysis of data suggested that teachers consider the curriculum demand, context of schools, and apply teaching strategies that are determined by the level of the learners. The findings indicate that the in-service physical science teachers clearly articulated the purpose of teaching, used a variety of models (representation), and supported earners using a variety of pen and paper activities. The teachers, although working within the same context, developed different teaching sequences. The findings from this study may inform continuous professional development.

Keywords: teaching chemical bonding, learner support, in-service teachers

INTRODUCTION

Chemical bonding is one of the key basic chemistry topics whose understanding has a direct influence on other topics. The teaching and learning of chemical bonding still poses a challenge for both students and teachers (Tsaparlis et al., 2021). The existence of different types of bonding (covalent, polar, and nonpolar bonding, metallic, ionic, and intermolecular bonding) seems to be central to the conceptual difficulties an experienced by students. This in turn leads students to develop misconceptions and resorting to memorizing the information concerning the topic (Levy Nahum, et al., 2007). Research has shown that some difficulties experienced by students in understanding chemical bonding are due to the way the topic is taught (Levy Nahum, Mamlok-Naaman, & Hofstein, 2010). Substantial research has been done on students' understanding of chemical bonding and a limited number of studies have focused on how teachers help learners understand the topic (Bergqvist, et al., 2016). Studies have shown that teachers teach chemical bonding using different representations to simplify abstract concepts (Taber & Coll, 2002). Teachers teach chemical bonding using physical models that are presented as proven facts instead of using appropriate theories (Treagust, et al., 2002). However, Tsaparlis et al. (2021) insist that static visual representations on chemical bonding contribute to better understanding of the topic. The use of visual representation plays a pivotal role in the teaching of chemical bonding (Holme & Murphy, 2012). According to De Jong, et al., (2005) the teaching of a topic is more effective if the teachers' pedagogical content knowledge of the topic is developed. Levy Nahum, et al., (2013) developed a teaching approach for chemical bonding concept aligned with current scientific and pedagogical knowledge. The authors suggest that chemical bonding should be taught based on the elementary principles based of the idea of the continuum bond. This disrupts the dichotomous division between the different types of bonding. The literature has shown that understanding chemical bonding is complicated because the different types of bonds are viewed to exist in different compounds. Sibanda and Hobden (2015) reported that teachers taught chemical bonding from a theoretical standpoint with a sequence starting from the microscopic to 'the macroscopic (Levy Nahum, et al., 2013). Debates on students understanding of the topics show that an emphasise on the ball and stick model can cause more confusion for students in terms of visualizing the correct shapes of molecules (Nimmermark et al.,2016). The teaching of chemical bonding still poses a lot of challenges in terms of learning difficulties and misconceptions. Recently, Molvinger, Lautier, and Ayral, (2021) carried out a study that focused on the understanding and learning difficulties associated with representation of molecules and chemical bonding for 10 th grade learners. In the current study I examine teachers views on how they teach chemical bonding in order to support students' understanding of the topic at high school.

Interpretive analytical Framework

A Learning Demand Tool (LDT) was used as an analytical framework to establish the nature of support teachers provide to learners when teaching chemical bonding. LDT was used to establish the nature the of teaching activities. Leach and Scott (2002, p. 127) claim that certain rules should inform a teaching sequence. These are; (1) identifying the school science to be taught, (2) considering how this area of science is to be conceptualized in the everyday social language of students, (3) identifying the learning demand by appraising the nature of any differences between steps 1 and 2, and (4) developing teaching activities.

Aim of the study

The purpose of this study is to determine and report on the nature of support in-service teachers provide to learners when teaching chemical bonding at high school. The paper answers the following research questions,

1. What are teachers views on learners experiencing difficulties understanding chemical bonding at high school?
2. What teaching activities are used by in-service physical science teachers to teach chemical bonding at high school?

METHOD

In this mixed method study 227 in-service physical science teachers completed a survey questionnaire, and 11 participants were selected for semi-structured interviews. This paper only reports on the qualitative data. According to Patton (2002) qualitative data analysis allows researchers to uncover emerging themes, patterns, concepts, insights, and understandings. The teachers were specifically asked to explain how they teach chemical bonding at high school. They were further required to describe the teaching activities that they use to teach chemical to support learners' understanding.

Curriculum for Grade 11 physical sciences

The curriculum developers provide guidelines in terms of the content that need to be taught in schools. A list of the concepts for teaching chemical bonding is presented in Figure 1.

Molecular structure (a chemical bond; molecular shape; electronegativity and bond polarity; bond energy and bond length).
Intermolecular forces (chemical bonds revised; types of intermolecular forces; states of matter; density; kinetic energy; temperature; three phases of water (macroscopic properties related to sub-microscopic structure).
Ideal gases (motion and kinetic theory of gases; gas laws; relationship between T and P)

Figure 1. Chemical bonding topics and concepts (DBE,2011, p 15).

This sequence focusses on three key topics, molecular structure, intermolecular forces, and ideal gases. The list of topics presented in the curriculum does not follow a particular sequence and the teacher needs to decide as to how to teach the concepts starting from what students know and building to the new knowledge. The key concepts for each topic are listed in brackets. The proposed sequence prescribed in the curriculum does not support students learning that focus on teaching from the known to the unknown (Abiola & Dhindsa, 2012).

Data analysis

The teachers interview focused on how they teach chemical bonding at high school.Specifically, (i) how they teach chemical bonding so that they promote learners understanding of the topic. And (ii) What teaching activities they use when teaching bonding.The teachers' responses were analysed using a computer software INVIVO 12. The responses were coded as nodes on INVIVO 12 based on the LDT components.

RESULTS

Teachers views on learners experiencing difficulties understanding chemical bonding

Teachers agreed that learners find the topic difficult to understand citing chemical bonding as an example of an abstract concept, link between the different concept and limited everyday examples of the topic.

Table 9: Reasons why learners finding chemical bonding difficult

Reason why chemical bonding is difficult for learners	Number of teachers
Chemical bonding is abstract and difficult for learners to understand and visualize the concepts	7
The relationship between different concepts of chemical bonding provides a challenge for learners	2
Chemical bonding does not closely relate to our everyday lives	2

In Table 1, seven teachers indicated that chemical bonding was abstract and difficult for learners to understand at high school.

The following excerpts from the interviews illustrate what teachers said about chemical bonding as being problematic to learn at high school.

> I would think it is difficult to teach chemical bonding. For me the most difficult part is when the child has to synthesize all the concepts together and then start linking it to forces and shapes. Then it becomes problematic for them as they progress from [one] process to another. The concept of ionic bonding is not so bad but when they have to differentiate between the concepts so that they can be able to know where this one and that one occurs. And how intermolecular forces relate to bonding and how they relate to shapes of molecules that are the problematic part (John-interview).

> It is not difficult to teach, but it is difficult for the learners to understand, another problem is that it does take time and I do not think that our teachers have lots of time, the pressure of getting through the syllabus and the work is quite enormous so you allocate a certain amount of time to get through that and often you tend to leave pupils behind that have not fully grasped the concepts, but it something that you need to revisit regularly, I can see that it is difficult for the pupils because it not easy to visualize those things and that is why I use a lot of software quite a bit to try and re-enforce those (Peter-interview).

In the two quotes, both teachers indicated that presentation of information on chemical bonding in textbooks is problematic. In the second quote the teacher indicated that chemical bonding also required a lot of time to teach. From the two quotes there is an indication that it is not easy to link chemical bonding to learners' prior knowledge.

In a further attempt to understand why teachers indicated that chemical bonding was difficult to teach, teachers were requested to compare the teaching of chemical bonding to other topics. One teacher said that chemical bonding was difficult to teach because the topic was not well sequenced in the teaching documents. The following quote illustrate what the teachers said.

> When comparing chemical bonding to organic chemistry, organic chemistry is well structured and logical, you can teach a few rules and they can apply to a vast chain of work. The pupils seem to apply those rules to different situations. Chemical bonding seems to be so much in the air so difficult to visualize because students cannot see the atom and electron and orbital and things like that. In organic chemistry they can draw the structure, covalent bonds, you got your stem, your bonds, and they seem to grasp that easier (Sazizo-interview).

In the quote by Saziso it is evident that the sequencing of topics in the curriculum document still poses some challenges in supporting students learning of abstract concepts.

Teaching activities used by in-service physical science teachers

The research further inquired of kinds of teaching activities used by teachers to teach chemical bonding so that learners can better understand the topic.

Table 2. Responses on teaching chemical bonding (n= 11)

Aspects	References	Themes	Number of responses
Step 1	Relevant sources of information	Textbook and policy documents/internet	11
Step 2	Misconceptions	Identification of specific misconceptions	2
Step 3	Language of school science and everyday social language	None	0
Step 4a	Purpose of teaching science	Make learners understand	8
		Use different methods	3
Step 4b	Teaching a particular topic (chemical bonding)	Bohr/Models/Role play	10
		Practical work	7
		Chalkboard	3
		Demonstration/simulations	7
Step 4c	Supporting students	Exercise/ Quizzes/ Homework	10
Step 4d	Making students take responsibility for their learning	Examination/Test	7
		Assignments and research	3

It is evident from Table 2, that the teachers did not refer to issue related to language of school science and everyday social language as a barrier when teaching chemical bonding. It is also interesting to note that teachers use a variety of teaching activities to support learners when teaching chemical bonding. The results show that nine teachers did not consider the learners' conception of chemical bonding at the planning phase. Data show that teachers view learners engaging with other learning activities such as homework and completing study worksheets as important in fostering understanding of the topic on chemical bonding. The findings show that teachers used a variety of representations in the form of practical work, models, and demonstrations to simply abstract concepts.

Illustration of variety of representation to chemical bonding

Further responses from teachers on representations used include the following;

> I would have shown them formation of ionic compounds, practical activity burning of properties of compounds. Making sodium chloride & properties
> I had asked students to pretend to be electron, I had eight students around one, sort of like a role model thing once. I have used transparencies quite a lot, orbital boxes, where they got electrons, they see how many electrons they can pair and they have got, you could physically take an electron from one and put it to the box to the other, make a model of something where they can make them overlap (Sihle-interview).
>
> I use the chalkboard; do discussions and write down important key words/ concept; I use models and illustrations (e.g., *Lewis dot* method and get the learners to make models and compounds to show how bonding takes place). I do not use OHPs and projectors because our school don't have them. I believe these are good tools. I also give them notes. What I found in the past was -: I use to give learners worksheets with content written on them, and I discovered that learners don't relate to these very well. I've started writing out the notes in my own writing, with more simple explanations. They take these down as part of the lesson and they do not take notes when I am teaching (John-interview).
>
> My teaching approach I encourage leaners to ask lots of questions, and to keep asking questions, but there certain need to be some control around that also, the questions are related to the topic at hand. In my teaching I try and get through the work as meaning as possible and get learners to understand the concepts. Sometimes I work through exercise in the textbook with them. I use a lot of it is visual, I try and have some visual things up most of the times, whether you are doing a simple demonstration in front of the class or using a smart board, but certainly with chemistry a lot of it must be visual so that they can see and think about (Peter-interview).

It is evident from Sihle's quote that she uses practical activities and different models. The quote from John show that he has adopted a teaching approach that he thinks will help his students to focus when he is explaining some key concepts. Again we see that Peter uses a lot of visuals and demonstrations. Peter also put a lot of overemphasis on getting the learners to understand the concepts.

DISCUSSION

The findings indicate that most teachers interviewed reported that chemical bonding is abstract and difficult for learners to understand. These findings are similar to those of (Taber, 2002). Teachers in the current study used different representations of chemical bonding such as practical work, models, and demonstrations to unpack the abstract topic the findings on the use of models do not necessary promote learners understanding of chemical but contribute to mere complex situation since learners have problems with visualizing the atoms. These findings concur with those of Gabel (1993) who found that teachers used transparencies and worksheets as visual aids in the representation of the particulate nature of matter. The students enrolled in that study were able to make connections between the macro-, micro, and symbolic. She concluded that static representations had limited value in enhancing knowledge of chemical bonding. Levy Nahum, Mamlok-Naaman, and Hofstein, (2010) also found that teachers used models to represent some reality on abstract topics.

CONCLUSION

Teachers were able to establish the areas that pose learning difficulties, and to prepare teaching activities that promote learners' understanding of abstract concepts. The teachers used different representations to simplify the abstraction in teaching chemical bonding. Extended class activities were viewed as a support mechanism for enhancing understanding of chemical bonding. The implication is that there is need for additional for teachers to correctly sequence topics to enhance meaningful learning. There is a need for further studies to fully understand the nature and full extent of the support that teachers provide to make abstract concepts accessible to students.

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INSECURITY FOR THE INQUIRY EXPRESSED BY EARLY CHILDHOOD EDUCATION TEACHERS IN INITIAL TRAINING

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Emotions are fundamental in the teaching-learning process of science. The interest in science and teachers' confidence in carrying out inquiry practices in the classroom can determine whether they are implemented. This work focuses on analysing the change in the insecurity emotion expressed by 47 pre-service early childhood teachers at the University of Málaga (Spain) when they inquire as students and design it as teachers for early childhood education. Its purpose is to detect at which stages of the inquiry pre-service teachers show the greatest insecurity. As an instrument for the collection of data, an emotion questionnaire was used in which they had to indicate among a list of several emotions whether they had felt insecurity at one or both moments and for each of the usual phases in a sequence of inquiry (setting out the problem, designing the experience, choosing variables, carrying out the experience, collecting the data, analysing the data, drawing conclusions and making decisions). The differences in the values of the emotion of insecurity expressed in both moments were compared. The results show that the insecurity expressed by early childhood teachers is quantitatively different according to the phase of the research they are carrying out. However, we have only found statistically significant differences in the phase of conclusions and decision-making favouring the moment they design.

Keywords: Inquiry, Emotion insecurity, Pre-service early childhood teachers.

THEORETICAL FRAME

Children in early childhood education (EC) have a natural predisposition to explore the world around them, and they enjoy observing, thinking, and questioning the natural world. For this reason, recent research highlights the possibility of developing scientific practices in the EC classroom (Monteira et al., 2016) and starting at the age of 3, including methodologies based on inquiry and questioning as the base of the scientific activity in the classroom (Hsin and Wu, 2011; Rodríguez et al., 2021). Samarapungavan et al. (2008) showed how children with EC who receive specific science education could demonstrate “a functional understanding of scientific inquiry processes and of important life science concepts during their investigations” (p.868), especially when a qualified adult intentionally structures these (Gropen et al., 2017).

However, the implementation of a methodology requires specific training. Inquiry education studies of EC teachers show a lack of preparation to design and implement science proposals in their classrooms, which leads to a lack of confidence in science education (Gerde et al., 2018). Teachers at this stage report feeling unprepared to teach science, which may be due to their limited education and a shortage of support and professional development resources. (Hamlin and Wisneski, 2012; Gerde et al., 2018). Therefore, it is essential that teachers in training understand what inquiry is, know the benefits and challenges of this teaching strategy and have the experience, during their training, with this scientific practice.

On the other hand, the role played by emotions in the teaching-learning process is becoming increasingly relevant. Yeigh et al. (2016) state that to fully understand learning it is necessary to include affective measures that allow the identification of cognitive-emotional aspects of learning that affect interest, persistence in the face of difficulty, the ability to listen to others actively and to be able to respond to comments critically and constructively.

In the case of science education, studies have shown that engaging students in science hands-on practice sparks interest in inexperienced students (Antonio, 2018) and promotes increased confidence and satisfaction (Riegle-Crumb et al., 2015). Emotions become an integral part of the process of learning science and learning how to teach science (Jiménez-Liso et al. 2021). Therefore, it is crucial to involve teachers in training in experiences that support them in understanding the advantages of using scientific practices as a pedagogical approach and give them opportunities for emotional engagement.

Although there is already a vast literature on emotions and their influence on teaching-learning processes, the literature on the role of emotions in the IBSE training of prospective EC teachers is scarce (Bellochi et al., 2014; Smit et al., 2021). Some studies show that teachers do not feel confident about engaging in inquiry activities (Lee and Shea, 2016), although there has been little discussion of what particular inquiry aspects produce greater or lesser degrees of insecurity in teachers. On the other hand, not much attention has been devoted to differentiating the emotions felt by pre-service EC teachers according to the roles they adopt, as learners or teachers, in the training programmes.

Based on these premises, this work is part of a broader study in which, while involving pre-service EC teachers in IBSE, the emotions expressed during the development of a training programme are assessed. At this point, we are interested in knowing whether and how the emotion of insecurity changes at the beginning and end of the programme for each of the phases of an inquiry.

METHODOLOGY

Participants and context training

The participants in this study were 47 pre-service EC teachers, all women with an average age of 23. The training programme was implemented in the academic year 2018-2019 in the subject of Didactics of the Natural Sciences in the third year of the Degree in Early Childhood Education at the University of Málaga (Málaga, Spain). This course is intended to provide pre-service EC teachers with scientific and pedagogical knowledge that will enable them to teach science at this educational stage. The specific competences of this subject include knowledge of scientific methodology and promoting scientific thinking and experimentation in pre-school children.

The training programme consisted of five stages: (I) carrying out a guided inquiry on how to cook homemade yoghurt, adapted from Muñoz-Campos, Franco-Mariscal and Blanco-López (2020), (II) educational analysis of the inquiry carried out, (III) exemplification and analysis of an inquiry for EC, (IV) adaptation to EC of the inquiry carried out in stage I and (V) design of an inquiry for EC. As can be seen, the participants act in two roles during the training: as students when carrying out an inquiry (I) and teachers in the other stages.

The programme includes activities oriented towards the class group, individual and teamwork. It led to the adoption of a cooperative learning structure in which we, as teachers, organised the working environment by deciding the number of members of each working team (between 4 and 5 persons) and the groupings of pre-service EC teachers.

Data collection instrument

To identify the emotions experienced by the teachers-in-training, an adaptation of the questionnaire designed by Martínez-Chico et al. (2019), in which participants self-report their emotions as they experience them, was used. This procedure is considered one of the most valid for measuring emotions in education (Bellocchi, 2015; Mauss and Robinson, 2009). We incorporate into this questionnaire the aspects of the inquiry that were of interest to assess at each moment: setting out the problem, designing the experience, choosing the variables, carrying out the experience, collecting the data, analysing the data, drawing conclusions, and making decisions. They were asked to identify the emotions felt, one or more, during its realisation for each aspect and indicating the reason.

Data analysis

The responses of the pre-service EC teachers were divided for tabulation into as many dichotomous variables as there were options (emotions), with each dichotomous variable tabulated as 0 (not chosen) or 1 (chosen). In this work, we focused exclusively in the quantitative data on the emotion of insecurity at the beginning of the training programme (stage I, in which they carry out an inquiry as students) and at the end (stage V, in which they carry out a design as teachers).

The Shapiro-Wilks test was used to analyse the distribution of the data obtained. This test showed that none of the variables conformed to a normal distribution, so McNemar's non-parametric test was used to study the possible statistically significant differences between stages I and V in each phase of the IBSE. These analyses were performed using SPSS 23.0 statistical software.

RESULTS

In general terms, it should be noted that 29 participants showed insecurity in one or more of the inquiry phases when acting as students (stage I), while 28 did so as teachers designing inquiry activities (stage V).

According to the inquiry phases, the figure 1 shows the percentages of pre-service EC teachers who identified insecurity at each phase of the inquiry for stages I and V.

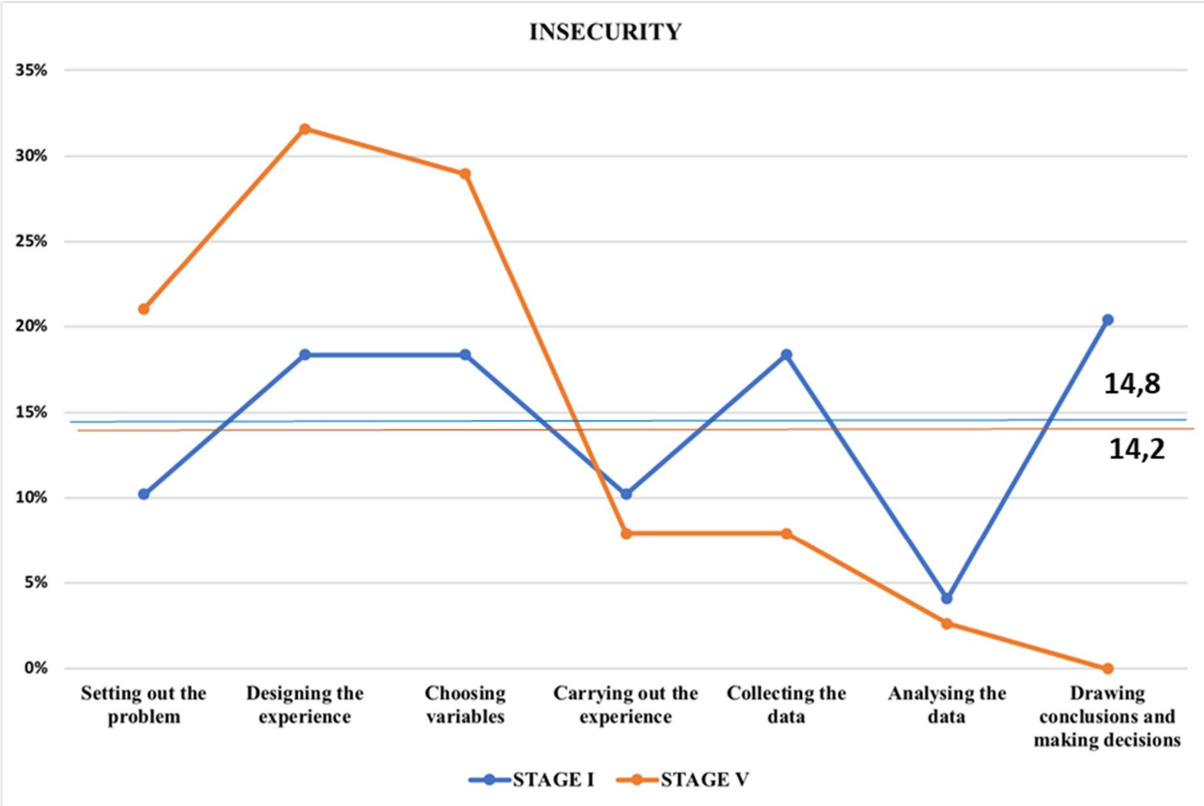

Figure 1. Percentages of pre-service EC teachers who identified insecurity at each phase of the inquiry for stages I and V.

Insecurity is manifested, both in students' role and in the role of teachers, for the different phases of the inquiry at different grades, although in global terms, the average percentages of insecurity expressed in the different stages are very similar (14.8% in stage I, and 14.2% in stage V).

The differences are manifested in a more significant dispersion of the percentages of insecurity shown in stage V compared to stage I and in the specific differences for each of the phases of the inquiry between the two stages. Thus, the phases of problem setting, experience design and choice of variables when acting as teachers designing inquiry activities (stage V) stand out more than 20% and are higher than the percentages that appear in these phases when they are involved as students (stage I). The opposite is observed for the other phases of the inquiry (carry out the experience, data collection, analysis of results and conclusions) in which insecurity percentages are higher when they are involved as students (stage I) than as teachers designing inquiry activities (stage V).

Although in the figure there are differences between percentages according to whether they are acting as students or teachers, the statistical analysis only showed significant differences for drawing conclusions and decision making (χ^2=9.025; p =0.003), which indicate that in this phase of the inquiry pre-service EC teachers felt more insecure when acting with students (stage I) than when acting as teachers designing inquiry activities (stage V) where they did not show insecurity. The 10 (20%) participants who showed insecurity in stage I, did not show it in stage V.

This situation could be explained by the fact that the pre-service EC teachers under the role of students were actively involved in the procedure, while under the role of teachers, they considered these stages of the IBSE but did not perform them.

CONCLUSIONS

The results obtained in this study show that the pre-service EC teachers' levels of insecurity in the two stages of the programme are not high and minor changes for the different stages of ISBE when they are involved in it as students or teachers.

However, these results point to the need to conceive IBSE not as a single thing but as a set of processes that may be emotionally very different for pre-service EC teachers when they have the role of students or teachers in the formative programmes.

In particular, it is striking that when they have to design an inquiry, they continue to express higher levels of insecurity in the phases of the problem setting, experience design and variable choice. It suggests that when these stages must be approached from designing activities for children in the EC educational levels, their tasks make them more insecure. Therefore, these phases should be given greater attention and educational support during pre-service EC teachers training programme.

We see this research as a starting point for investigating the relationship between insecurity and different aspects of the inquiry. In this sense, the results and conclusions must be considered provisional since they have been obtained from a single group of pre-service EC teachers in a particular formative context. It would be important to compare them with those obtained in other formative contexts where the participants' starting levels for IBSE are different, or other IBSE formative approaches are used.

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INTEGRATION OF CONTENT, PEDAGOGICAL AND TECHNOLOGICAL KNOWLEDGE OF SCIENCE TEACHERS IN THE DESIGN OF LEARNING ACTIVITIES

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The purpose of this study is to identify the content, pedagogical and technological knowledge of a science teacher and the integration that he makes of this knowledge (TPACK); through the design and reflection of a scientific activity mediated by digital technology. Qualitative analysis of the design and reflection of a high school physical science teacher's learning activity was carried out. The results indicated that the reasons for the type of integrated technology were fundamental, mainly in technological pedagogical and content knowledge (TPACK) and in technological pedagogical knowledge (TPK). In addition, problems of access to technology were found that influenced their choice and use of the technology proposed in the design of the activity. The findings have implications for teacher education programs and for researchers interested in evaluating science teachers' professional knowledge related to the use of technology.

Keywords: TPACK, Scientific education, Instructional design.

INTRODUCTION

In science education, reforms have advocated for more than two decades to develop a scientifically literate population through the integration of digital technologies in science teaching (National Research Council [NRC], 1996). In this way, students are encouraged to understand scientists' concepts and practices through the use of technology throughout their school life (NRC, 2012). Because teachers are considered one of the most influential factors in promoting student achievement (NRC, 2012), much of this understanding of science and the use of technology that students acquire is through instruction that these teachers offer in their classes.

Mishra and Koehler (2006) have described the knowledge required by teachers to effectively integrate technology into their instruction, calling it Technological, Pedagogical, and Content Knowledge (TPACK). TPACK refers to the dynamic interaction between the three knowledge (disciplinary, pedagogical, and technological) and their intersections in a specific context (Koehler et al., 2013)

The studies that have sought to develop and understand teachers' TPACK use different instruments due to the complex nature of the framework. According to Fisser et al. (2014), two main categories can be distinguished: self-assessment surveys and performance-based assessments that focus on lesson planning and teachers' performance in the classroom. However, it should be noted that the self-assessment surveys are not directly measuring knowledge or technological skills but rather the self-reported perceptions by teachers about their technological knowledge. For their part, performance-based evaluations allow investigating the logic behind teachers' thought processes (Mouza & Karchmer-Klein, 2013) and the implementation of said knowledge in the classroom context.

This study aims to identify the content, pedagogical, and technological knowledge of a science teacher and the integration that he makes of this knowledge (TPACK); through the design and reflection of a science activity mediated by digital technology. This objective is investigated from a qualitative approach where it is expected to deeply understand the decisions made by science teachers to generate learning opportunities mediated by technology.

THEORETICAL FRAMEWORK

Technological Pedagogical and Content Knowledge (TPACK)

The advent of technology made it clear that teachers require specific professional knowledge that enables them to effectively integrate technology into classrooms. Mishra and Koehler (2006) have described the knowledge required by teachers to effectively integrate technology into their instruction, calling it technological, pedagogical, and content knowledge (TPACK). TPACK is based on Shulman's (1986) taxonomy of teachers' knowledge, and especially pedagogical content knowledge (PCK) to include technology knowledge (TK). That is the knowledge required by teachers to integrate this knowledge into pedagogy knowledge (PK) and content (CK).

The TPACK is considered as a complex network of knowledge, where the three main knowledge is integrated: 1) TK, which refers to knowledge about technologies in a general context (technological knowledge); 2) PK that refers to the teaching and learning processes and methods shared by teachers in all areas (pedagogical knowledge); and 3) CK that refers to the understanding of the subject area (disciplinary knowledge). The interaction of these three generates four additional knowledge: 4) pedagogical content knowledge (PCK), which refers to knowledge of pedagogy that is applicable to the instruction of specific content; 5) content technology knowledge (TCK), which refers to the knowledge of how content can be transformed through the application of technology; 6) pedagogical technological knowledge (TPK) which refers to the knowledge of the use of technology to support teaching and learning approaches; and 7) TPACK, which refers to the knowledge necessary to teach content with technology.

TPACK framework in technology-mediated science education

The TPACK is a form of knowledge highly contextualized to specific topics of pedagogical lessons and activities (Cox & Graham, 2009). Therefore, it is expected that the knowledge required by a science teacher will be different from that required by a teacher of English, social studies, or another subject area. Based on this idea, Jimoyiannis (2010) proposed the Pedagogical Technological Knowledge and Science (TPASK) framework, where technology contrasts in science teaching and learning. Therefore, the TPASK, according to Jimoyiannis (2010), represents what science teachers need to know about technology in science education, for example, identifying technologies with the potential to represent and transform content so that it is more understandable to students, technologies that contribute to data collection, and technologies for analysis and communication of results. As a contribution to the identification and selection of technology by science teachers, McCrory (2008) in his study provides three classifications of technologies that can be used in the science classroom:

1. Technology that is unrelated to science but is used in the service of science (e.g., spreadsheets, graphics software)
2. Technology designed for teaching and learning science (e.g., simulations, animations)
3. Technology designed and used to do science (e.g., probes, digital microscopes)

Accordingly, the TPACK of science teachers is expected to help them select and evaluate technology resources in relation to content/science (science practices, cross-cutting concepts, and core ideas) and science-specific strategies. In line with Angeli et al. (2016), who hypothesize that some aspects of TPACK are domain-generic and others domain-specific, the latter being the focus of interest in this work.

METHODOLOGY

This study used a qualitative research approach involving a case study methodology. The participant was a serving high school physical science teacher. The data sources were a technology-mediated learning activity design template and a semi-structured post-design interview. The design task was to generate a technology-mediated science learning activity. The design was mainly composed of three parts.

Part 1: Identify types of technologies that integrate science teachers. An open question was formulated to determine the type of technological resource the teacher selects to reach the proposed learning goal.

Part 2: Determine the types of technology-mediated science activities that teachers design. Two open-ended questions were formulated to determine the type of activity or how science teachers integrate technology into their design.

Part 3: Determine evidence of pedagogical, technological, content, and TPACK knowledge in the justification for the choice of technology. An open question was formulated to determine the knowledge behind the reasons given by the teachers about their choice of technology.

The semi-structured interview enabled a deeper understanding of pedagogical, technological, and disciplinary knowledge. Also, to be able to identify how experience in teaching practice and technological experience influence the decisions made by the participant.

The data were analyzed deductively and inductively. The design and responses of the interviews were coded and classified into four categories: pedagogical knowledge, content knowledge, technological knowledge, and TPACK knowledge. Additionally, the type of technological resource integrated by the participant was investigated, for which a deductive analysis was followed based on the three categories of technologies for science education proposed by McCrory (2008). The categories are 1) technologies at the service of science, 2) technologies for teaching and learning science, and 3) technologies for doing science. Finally, to determine the type of activity designed by the participant, two categories were considered, namely, general teaching activities and content-specific activities (Graham et al., 2009). Finally, the type of designed activity was classified considering whether the technology was integrated to support general pedagogical teaching activities, according to the definition of technological pedagogical knowledge (TPK) or, if the technology was integrated to support content-specific teaching activities, according to the definition of pedagogical, technological, and content knowledge (TPACK).

RESULTS AND DISCUSSION

Type of integrated technology and technology-mediated activity that science teachers plan.

The analysis of the design activity developed by the participating teacher indicated that the technology integrated by the participant was a video. The video falls under the category of technologies designed for science teaching and learning (McCrory's #2). Furthermore, the type of teaching activity proposed was to use a video to support a content-specific teaching activity. The activity proposed by the teacher was to integrate technology to support non-experimental investigations of the whole class (Maeng et al., 2013). This finding is in line with previous studies (e.g., Blonder et al., 2013; Dwivedi et al., 2020) which videos are recognized as having great potential to support the pedagogical practices of science teachers, such as: visualizing an abstract concept, to show experiments that cannot be carried out in the classroom, to activate the consultation process of the students in the laboratory.

Knowledge in the justification of the choice of technology.

From the analysis of the interview, it was possible to determine that the main reason given by the participant regarding his choice to integrate a video was that it would help students to visualize abstract concepts, as shown in the following quote:

> The videos of the experiments can be repeated to analyze the immersed concepts without altering their variables by watching them over and over again. In addition, the video is short and concrete; it shows clear concepts between the tangential velocity and centripetal acceleration vectors and their relationship to each other.

This reason reflects a TPACK knowledge of the participant against identifying technologies with attributes such as visualization, interactivity, and simulation (videos, images, simulations, interactive whiteboard, among others) that contribute to the representation and understanding of abstract content typical of science (Brame, 2016; Chittleborough, 2014; Kadıoğlu-Akbulut et al., 2020). Additionally, the current COVID-19 pandemic caused the different educational systems to completely transform to evolve towards an online teaching-learning scenario (Mishra et al., 2020). Consequently, with little or no training, teachers worldwide have had to convert materials rapidly and adapt their teaching and assessment methods to a format suitable for online delivery (Dwivedi et al., 2020). This new scenario made teachers look for support in different open platforms to share and use educational resources. In this period, edutubers (creators of educational audiovisual content on YouTube) positioned themselves as references for both formal, non-formal and informal education (Pattier, 2021). Now, despite their many advantages, videos and animations (and other technological tools) are not inherently effective as an educational tool (Dorfman et al., 2019). Therefore, teachers must have a professional knowledge of technologies (TPACK) that allows them to make effective and productive use of digital videos in educational settings.

Another rationale for using digital video was to stimulate scientific interest and practice; how to pose questions or hypotheses (TPACK).

> I would play the first part of the video [students] without sound. The first part of the video is when the guy sets up the materials and starts spinning the hook... So, I would ask, what is the guy talking about? What does he mean he? What if the coin places it here? What if he turns it the other way? What happens if he turns it horizontally? So, he starts to investigate [student] what variables are there, what variables can I combine? Which ones can I relate to?

Therefore, digital videos, particularly in science education, can be used by teachers to elaborate or apply concepts discussed in class to new situations, to promote observation and inference in students (Dorfman et al., 2019).

Contextual and participant characteristics effects

On the other hand, the analysis of the answers given by the teacher during the interview made it possible to realize that the choice of technology that was integrated into the design of the learning activity could be influenced by the technological resources available in the school where he works. The teacher:

> The school has two computer rooms… the room is practically occupied all the time. In my living room, internet access is minimal… there is a television that works with a laptop to project a presentation or a video.

Therefore, due to connectivity and technological resource issues, teachers may be forced to select easily accessible and free resources, such as videos that can be downloaded and projected to the entire class in their classrooms without Internet access.

Finally, we proposed a class situation to identify if the participant recognized the limitations of the technological resource. It was found that the teacher failed to highlight the limitation of digital videos against the possibility that students manipulated experimental variables. This lack of knowledge may be related to science teachers' lack of education and training in content-specific digital technologies (TCK) since the teacher was asked about how he keeps up to date with technology and its educational uses for teaching science. The professor pointed out that the school provides technology training; however, the technologies he mentioned are not specific to science teaching and learning (McCrory's #2 and #3). Therefore, the lack of TCK can affect how teachers align technology with learning objectives and where it is appropriate to enrich the teaching process (Seery & McDonnell, 2013).

CONCLUSIONS

The purpose of the research was to identify the content, pedagogical, and technological knowledge of a science teacher and the integration that he makes of this knowledge (TPACK); through the design and reflection of a science activity mediated by digital technology. The results obtained reported that the type of integrated technology was mainly based on pedagogical content knowledge (PCK) and pedagogical technological knowledge (TPK). Besides, it can be determined that a possible cause is the teacher's lack of knowledge in the use of content-specific technologies (TCK) and contextual factors such as the lack of specific technological resources for science education.

This study provides an instrument to determine how and why teachers integrate technologies into their classroom designs. It also offers implications for the design of science teacher training and professional development programs for technology integration. One implication is that programs must ensure that they offer teachers experiences that enable them to learn and practice with more content-specific technologies—for example, knowing about technologies that transform the content of science for teaching and knowing about technologies that allow the active participation of students in scientific practices.

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Part 4 / Strand 4
Digital Resources for Science Teaching and Learning

Editors: *Jesper Bruun & Jesper Haglund*

Part 4. Digital Resources for Science Teaching and Learning

Design, evaluation and characterization of resources and environments for teaching/learning science: ICT and TEL in science education. Online learning environments, simulation and modelling tools, virtual laboratories. Self-regulation, reflection and collaboration in digital learning environments.

Part 4: Digital Resources for Science Teaching and Learning

Editors: *Jesper Bruun & Jesper Haglund*

Introduction

Strand four focuses on science learning in digitally enriched environments. Within this focus, many different perspectives and topics were presented as part of the ESERA 2021 strand, and this is reflected in the ten papers in this section of the electronic proceedings, represented by authors from Austria, Cyprus, Germany, Greece, and Italy.

The virtual format of the conference was due to the circumstances of the Covid-19 pandemic, as we could not meet physically. The change from in-class teaching to digital home-based teaching, partly because of the pandemic, was also a prominent theme in the presentations in the strand, including some of the papers in these proceedings. Lazos et al. present a study of how 13-year-old students used smartphone sensors in combination with phyphox to conduct free-fall experiments at home, whereas Velentzas and Theodonis, and Lefkos et al. present how students conducted virtual experiments in mechanics and thermal science, respectively.

The theme of inviting students to engage with virtual reality (VR), augmented reality (AR), and mixed reality (MR) environments is also represented in the strand. Within this theme, Tsivitanidou et al. have conducted a study on how students' attitudes toward science and digital technology related to their learning gain when using an immersive VR simulation on the special theory of relativity, while Lauer et al. present an AR toolkit for visualization of electrical circuits.

Four of the studies are dedicated to testing and assessing digital environments and resources for science education. Schmitt and Pietzner report on the development and evaluation of a digital learning environment on the differentiated atomic model in secondary chemistry teaching, whereas Küsel and Markic present a questionnaire study of pre-service science teachers' experience using LearningBits. Occhioni et al., in turn, invited science teachers to use and evaluate a virtual world on the topic of sustainability designed for secondary teaching, and Schindler and Pietzner report a positive effect on secondary students' cooperation and attention when introducing a response system in chemistry classrooms.

Finally, Harmer and Gross provide a methodological contribution in proposing a set of guidelines for analyzing video tutorials in chemistry education, comparing adherence to design principles to students' perceptions of tutorials.

We hope that strand four will continue to provide a forum for those interested in science teaching and learning in digitally enriched environments to share findings and exchange ideas to improve the future science education.

PHYSICS EXPERIMENTS AT HOME. A CASE STUDY IN THE ERA OF COVID-19 QUARANTINE

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The present paper presents an intervention which was designed and tested, during the COVID-19 quarantine period, in a first-grade class (13 years old students) of the secondary education in a Greek public school. It concerns the use of simple materials for setting up a free fall experiment at home, and the exploitation of the smartphones' microphone sensor in combination with the phyphox application for taking the needed measurements of time. The findings that emerged from the evaluation of the intervention and the difficulties observed and reported during its implementation are presented in the paper. The opinions and the stances of the students, about the intervention, as they were revealed through an online questionnaire are also discussed. The findings contribute to the conclusion that the described proposal is a good practice for individual experimentation of students and can be used not only in an environment of distance education but also as a model for assigning individual tasks to students during normal periods of teaching in the classroom.

Keywords: Laboratory Work in Science, Technology in Education and Training, Physics

INTRODUCTION

The development, in recent decades, of the new information and communication technologies has provided the background for the distance learning expansive growth. The necessity for this type of education became imperative during the quarantine period due to the COVID-19 pandemic (Tzifopoulos, 2020; O' Brien, 2021). Among the other questions that was raised in this period, was whether and to what extent this type of training could meet the requirements for the practice of students in the science course laboratory. One of the prospects that gathered wide interest was the development of educational proposals using solely Smart Mobile Phones (SMP) as the appropriate equipment. Indeed, nowadays SMPs have numerous sensors and with the proper applications (apps) can take measurements which can easily be processed, stored, and shared (Patrinopoulos & Kefalis, 2015; Kuhn et al., 2016; P'orn & Brasken, 2016; Vandermarliere, 2016; Pierratos & Polatoglou, 2018; Pili, 2018; Kateris et. al., 2020). Students could therefore, in an organized manner coordinated by their teacher, perform experiments at home with simple materials using their SMP's as "measuring devices". On this ground an intervention for student's experimentation was developed and conducted in the spring of 2020 during the first quarantine period in Greece. The aim of the study was to investigate whether pupils at the first year of secondary education could, following the instructions of a worksheet, perform an experiment at home, fill in the worksheet, and send their results to the teacher. Additionally, we have also tried to record after the completion of our intervention the difficulties encountered by the pupils as well as their views on the whole process.

METHODS

The intervention was conducted in a distance learning environment at the first-grade class of the secondary education, in a school of Athens, with the participation of 35 students. According to the Greek curriculum, the basic purpose of a physics course at this age is to familiarize students with experimental procedures. Consequently, the emphasis of the course is both on data collection (by directly measuring quantities such as length, time, mass, force, and temperature) and analysis mainly by constructing and interpreting diagrams. One of the major task students had already practiced on before the intervention described here, was that of taking measurements and drawing the corresponding diagram for the case of a spring obeying Hooke's law with the purpose of constructing a dynamometer.

For our intervention the activity "Measuring the time of free fall for a small sphere" was selected. This specific experiment was chosen on the ground that:

(i) it can be carried out using a common smart mobile phone since it demands the most usual of the sensors i.e., a microphone,

(ii) it requires a few simple everyday materials for its implementation,

(iii) and it can be carried out by a single person.

At the same time, the appropriate application for the smart mobile phone, that was going to be used by the students, in order to take the measurements and process them, had to be selected. Based on the fact that

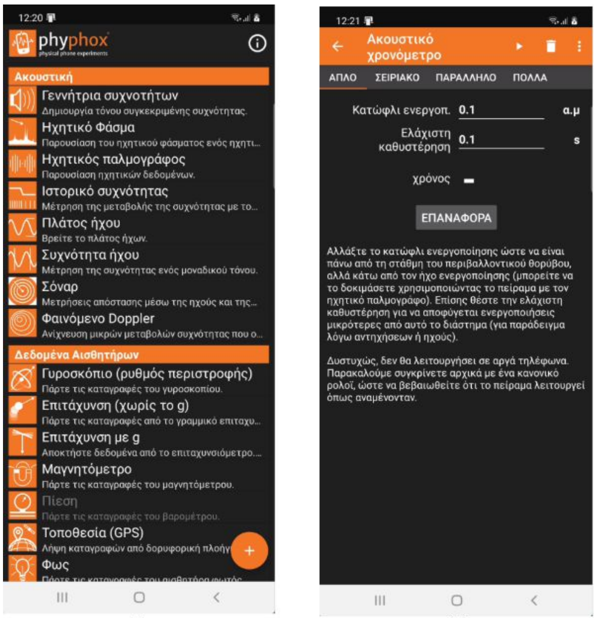
(i) it is available free of charge,

(ii) it enables full processing of the measurements directly on the smart mobile phone's screen, and

(iii) it is available for both of the dominant operating systems for SMPs (Android and iOS),

the phyphox application (see Figure 1(a)) was selected (Staacks et al., 2018; Carroll & Lincoln, 2020).

Students had, first of all, to set up the experiment by balancing a small sphere at the tip of a ruler that was protruding from the edge of a table, at a certain height from the ground (see Figure 2) that had to be measured with the help of a measuring tape or a ruler. Then, they had to abruptly hit the tip of the ruler in order to initiate the free fall of the sphere. Using the "Audio Timer" module (see Figure 1(b)), in the phyphox application, students had to measure the time of the sphere's free fall, i.e., the time from the first sound (produced by hitting the ruler) until the next one (produced by the impact of the sphere on the floor).



(a) (b)

Figure 1. (a) The first screen of the phyphox App (in Greek). (b) The "Audio Timer" module of the phyphox App that students instructed to use for the measurement of time (in Greek).

Then, students had to find a way to change the height of the free fall (by placing, for example, a stack of books on the table) and repeat the whole process in order to take 9 more measurements of time. Then, they were instructed to draw the graph of the time of free fall with the initial height. Finally, students, based on the already constructed graph, had to predict the time of fall of the sphere from a given height that was different from the measurements already gathered. It should be stressed, that students at this age had not been taught the laws of free fall and the investigation was, totally, experimental oriented.

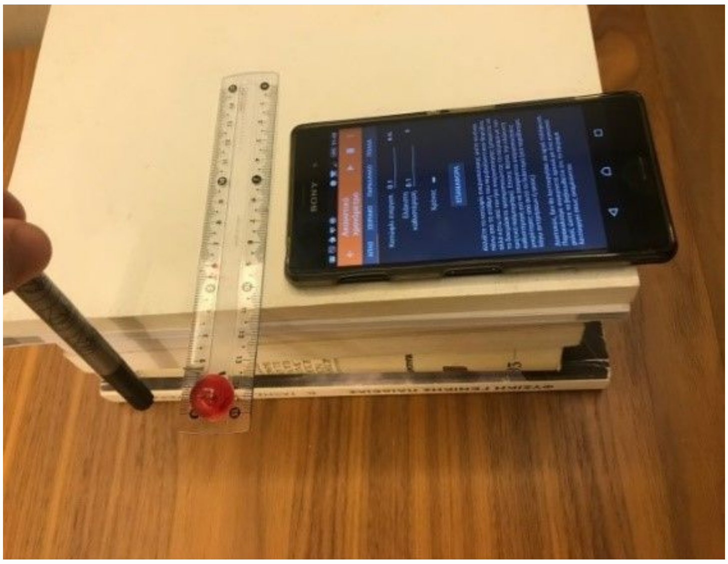


Figure 2. The setup of the free fall experiment.

Prior to the intervention, the teacher of the class placed the relevant educational material in the web site of the school (asynchronous mode). Then, in a 40-minute synchronous distance learning lesson the worksheet was presented to the students, and questions about experimentation were answered. After the presentation, students worked individually, and the teacher had only a supporting role in an asynchronous mode. The worksheet had the form of a text file, in this way students were able to add their answers on the electronic file that we had provided to them. Alternatively, they could print the worksheet, fill the answers in it, photograph it with their SMP's, create a pdf file, and finally upload it at the web site of the school.

Ten days after the completion of the intervention, students were asked to complete an online questionnaire (Google form) aimed at investigating the conditions for carrying out all the whole work, the possible difficulties that encountered, and the acceptance of the whole teaching intervention.

FINDINGS

The 35 completed worksheets submitted by the students, in combination with the online answered questionnaires, were the main tools for evaluating the intervention. The findings are summarized as follow.

The process of experimentation and the uploading of the completed worksheet files

The use of the synchronous and the asynchronous platform of distance learning did not pose any serious problems for students. 77% of them found the creation of the electronic pdf file and the uploading of this file to the web site of the school quite easy or just easy, and only 20% of them faced moderate difficulties. It is worth mentioning that finally, all students managed to successfully complete this part of the activity.

According to the online questionnaire 60% of the students spent about 2 hours to complete the whole process of experimentation, 29% 1 hour and 11% 3 hours.

The conduction of the experiment and the measurements

The experiment required careful manipulations and extreme care in order to measure the free fall time of the sphere from a small height. 45% of students described the experiment as quite easy or easy, 46% described it as of moderate difficulty and only 9% found it quite difficult (see Table 1). Also, 37% of the students, answered, in the online questionnaire, that they asked for help from relatives or friends.

The difficulties, encountered by students, seems to be related mainly with the execution of the experiment rather than finding the materials (86% said that they found the appropriate materials very easily or easily) or using the mobile phone or handling the phyphox application (66% of the students found the handling of the phyphox application quite easy or just easy, and 31% of moderate difficulty). In conclusion, given the unprecedented character of the whole process for students and the inherent difficulty of the experiment, we can argue that the results were encouraging.

The questions of the worksheet and its completion

It appears, even from a casual analysis of the completed worksheets, that the answers of the students can provide to the teacher valuable feedback on the crucial points that she/he should give emphasis during her/his teaching. This analysis showed that the students, while it was the first time that they had to draw a graph from experimental data in the form of a curve rather than a straight line, completed the task to an exceptionally large extent. In particular, about 15% of the students drew a straight line, while the rest realized that their experimental points were not complying with a straight line. 52% of students drew the parabola correctly (see Figure 3), while 33% of the students connected the experimental points.

86% of the students (see Table 1) found the questions of the worksheet understandable and 89% had not any serious difficulty answering these questions.

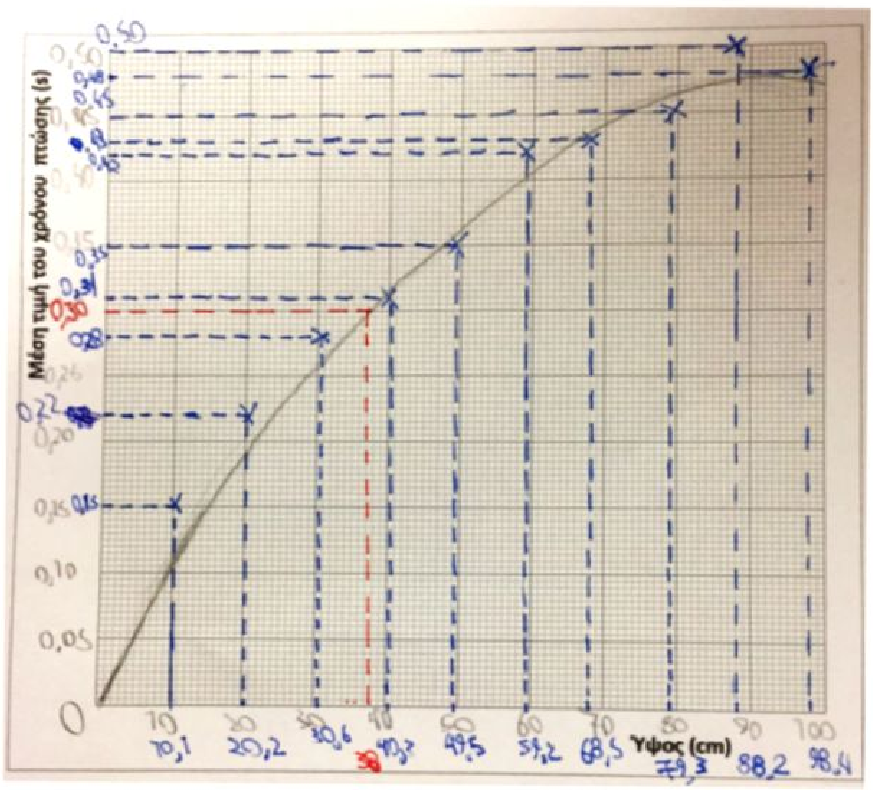


Figure 3. The correct parabola graph, along with the experimental data points, for the free fall experiment presented in a student's paper. The horizontal axis is height (in cm), and the vertical one is time (in seconds).

Students' opinion about the intervention

The majority of students (80%) (see Table 1) replied, in the questionnaire, that the whole process was interesting or very interesting and 60% of them found that it was also pleasant or very enjoyable. It is worth noting that 31% of the students did not find the experimentation neither pleasant nor unpleasant, choosing a neutral stance (see Table 1). This attitude maybe connected with the quite demanding process of experimentation.

Table 1. Some of the questions of the online questionnaire with the percentage of the answers.

	Quite Easy (1)	(2)	(3)	(4)	Quite Difficult (5)
How would you characterize the difficulty of the experiment?	11%	34%	46%	9%	0%
	Clear (1)	(2)	(3)	(4)	Hard to understand (5)
How would you characterize the worksheet's questions?	43%	43%	9%	6%	0%
	Very Interesting (1)	(2)	(3)	(4)	Uninteresting (5)
How would you characterize the whole process?	37%	43%	11%	3%	6%
	Very enjoyable (1)	(2)	(3)	(4)	Not at all enjoyable (5)
How enjoyable was the experimentation process?	34%	26%	31%	6%	3%

CONCLUSIONS AND IMPLICATIONS

The present paper is a case study concerning experimentation in a distance learning environment. More specifically, students performed a free fall experiment at their home using simple materials, such as a ruler, a sphere etc., and their mobile phone as a measuring device. This process was unprecedented for students, but they found the activity interesting and, to a certain degree, enjoyable.

As findings showed, the main objective of the intervention i.e., the experimentation of students at their homes in a period with no access at the school lab, has been achieved. The students, despite the difficulties, carried out the proposed experimental activity, took the measurements, drew the graph based on the data gathered and filled in the answers to the worksheet's questions. The whole process offers to the teacher the opportunity to evaluate the course of his teaching and to identify the shortcomings of the students.

This proposal, for the performance of experiments by students at their home, may have a broader perspective than applying it only in an environment of distance learning. It can be applied even in normal periods when students are in school and have access to the physics lab and experimental activities like this can be assigned as individual work. A prerequisite for such an assignment is for the teacher to select the appropriate experiments on the basis of the criteria mentioned in this paper.

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SUPPORTING LABORATORY WORK WITH VIRTUAL EXPERIMENTS: A CASE STUDY DURING THE COVID-19 QUARANTINE

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This paper presents an educational proposal for distance learning physics labs. It was designed for first-year undergraduate students, and it was implemented during COVID-19 quarantine conditions. At the beginning of the lab course, teachers presented the real experiments to the students, by using videos and photos of the corresponding devices. Then students were given specially prepared videos of virtual experiments, that were based on models of the corresponding real devices, and were asked to take measurements. Finally, students had to complete corresponding worksheets to process their measurements, and present their experimental findings. This proposal for distance learning physics labs is cost-effective, platform and device-independent, and it can be realized quite effortlessly. Both students and teachers found this approach very helpful during quarantine and think that it has a high potential of use even after quarantine conditions end. It is suggested that virtual experiments are used in parallel with corresponding real experiments so that students will understand the role of models, have additional exercises for practice and better assessment, become familiar with the lab devices used in the corresponding real experiment, and be introduced to the measurement process, error analysis and data presentation of the physics lab.

Keywords: Laboratory Work, Simulations, Teaching Practices

INTRODUCTION

The development of new information and communication technologies in the past decade has provided valuable tools for distance education, which recently became compulsory during the COVID-19 pandemic quarantine period (O'Brien, 2021). However, it is unclear whether and to what extent, distance education could meet the need for students' physics laboratory practice (Pols, 2020). Various proposals have been made to satisfy this need, such as take-home experiment kits and remote control of real experimental devices (Turner & Parisi. 2008; Gröber, et al., 2008), which in most cases can be costly and hard to implement or can take a long time to implement. Another direction for distance learning, is the utilization of virtual laboratories, the advantages and disadvantages of which have been extensively researched (e.g., Hamed, & Aljanazrah, 2020; Daineko, et al. 2017; Zacharia & Olympiou, 2011). Some of the advantages of virtual experiments are:

- The virtual experiments do not require complicated and expensive equipment and devices.

- Virtual experiments can model objects, processes, and phenomena that are often not perceived in the real educational laboratory, such as objects of the microcosm.

- Within virtual experiments, it is possible for students to easily change experimental setups by changing specific model parameters, something that in the real lab is usually hard or even impossible to do. For example, in a virtual optics experiment, one can make consecutive small changes in the refractive index of a glass prism.

- Virtual experiments are safe and it is not possible to destroy devices due to clumsy handling.

- In virtual experiments, it's possible to visualize in real-time, graphs of physical quantities, vectors, and fields.

But next to the advantages, there are also some disadvantages and limitations of the virtual experiments. More specific when using only virtual experiments:

- Students will never realize that in real experiments there can be unexpected events that can occur and lead to wrong measurements that have to be excluded.

- Students do not develop practical experiential skills to get a sense of scale and size, such as using their hands to intercept the dimensions and the weight of an object.

Research has shown that the combination of experimentation in real and virtual laboratories "help students to learn better than doing either a physical or virtual experiment alone" (Sullivan, et al., 2017).

The present work suggests a new approach to laboratory practice, which was designed and implemented during the period of quarantine, at the Physics Department of the School of Applied Sciences and Mathematics of the National Technical University of Athens in the first-year general physics (mechanics) course. This educational proposal was created out of the need to remotely cover the course's laboratory teaching during the quarantine period.

The proposal was structured based on the following requirements and constraints:

- It shouldn't require a long development time.

- It shouldn't be expensive.

- It shouldn't require special equipment.

- It should cover as many real experiments' educational goals as possible.

- The virtual experiments should be simulations that are based on models of the real experiments. This was necessary so that the experimental work could be continued in the real lab if the quarantine conditions were stopped. In addition to that, the virtual experiments should be designed so that they can be used after the end of the quarantine conditions as an auxiliary tool for the students' preparation for the real labs.

Details of the approach are presented below, in the Methods section. The effectiveness of this educational proposal, as well as various difficulties encountered in addition to the students' and lab teachers' opinions regarding this approach, are fully described in the Findings and Conclusion sections. In short, our findings show that this distance learning proposal could be beneficial for students both during and after quarantine.

METHODS

The first-year undergraduate physics course requires students to attend a three-hour introductory lecture regarding the analysis and presentation of experimental results, after which they perform four laboratory experiments. During each experiment, they take measurements in the lab for two hours, and then they process the data at home and prepare their assignments individually. However, in the first semester of 2020-2021, there were quarantine conditions in effect due to COVID-19, making it impossible for students to access the laboratory. Therefore, it was imperative for the nine teachers responsible for the course to provide a means for their 82 students to complete the required laboratory experiments.

The aforementioned introductory lecture was done remotely using Cisco Webex Meetings (CWM), and after the lecture the students were given tables with measurement data that they had to analyze and present as homework. Then, students were introduced remotely through CWM, to the real laboratory experiments of the course. Each lab teacher presented the theoretical background of her experiment, including videos and photos of the real experimental devices and setups. In addition to the presentations, the real experiments (including some minor variations) were modeled using Interactive Physics software (IP). The simulated virtual experiments were recorded and exported in video format, and a corresponding worksheet was designed (Figure 1).

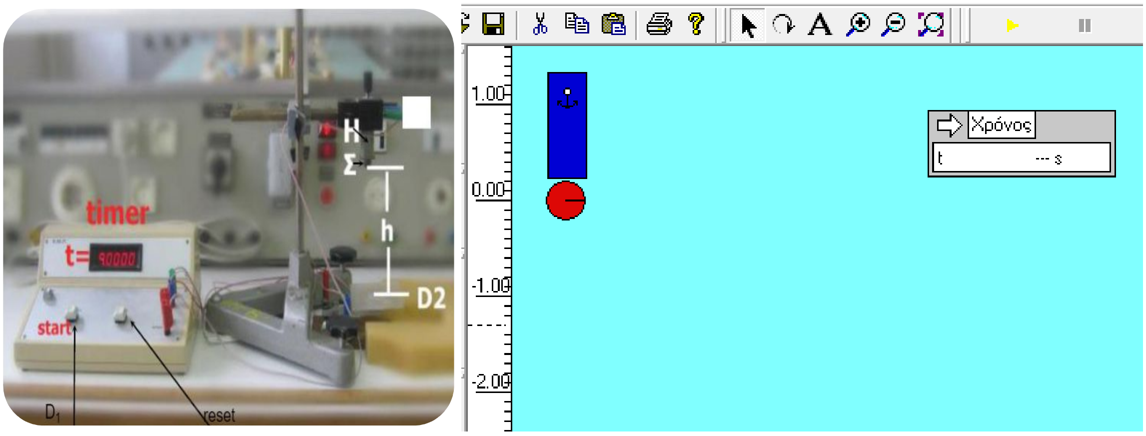

Figure 1. The real experimental device (on the left) and the corresponding virtual experiment (on the right) for the measurement of gravitational acceleration, g, by studing the free-fall motion of a body.

More specifically, the following seven experiments were modeled.

1. Experimental measurement of gravitational acceleration, *g,* by studying the free-fall motion of a body.
2. Experimental study of energy conservation during the free-fall motion of a body.
3. Experimental measurement of gravitational acceleration, *g,* by studying the oscillations of natural pendulums.
4. Experimental measurement of gravitational acceleration, *g,* by studying the oscillations of simple pendulums.
5. Experimental study of Newton's laws of motion.
6. Experimental study of the direct collision of two spheres.
7. Experimental measurement of the tensile strength of a wire.

The videos and the worksheets were posted on the asynchronous distance learning platform of our institution. For any questions regarding the virtual experiments, students contacted teachers via email. At the beginning of each virtual experiment, students had to operate a video of the virtual experimental procedure. To take measurements, students had to pause the video several times at different time frames. For example, in the free-fall experiment, students should pause the video of the motion of the free-falling body at different times, and measure, with the help of an included ruler, the distance from the dropping point and the time. Then they process these measurements in the given worksheet and answer the corresponding questions (Figure 2). Finally, students posted their completed worksheets electronically on the platform for evaluation. It should be noted that when structuring the virtual experiments, most goals that are set for students' work which is usually done in the real laboratory (i.e., table of values, significant digits, errors, graphs, conclusions, etc.) were taken into consideration. At the end of the process, students and teachers completed a questionnaire to express their views on it as well as the perspective(s) it had provided.

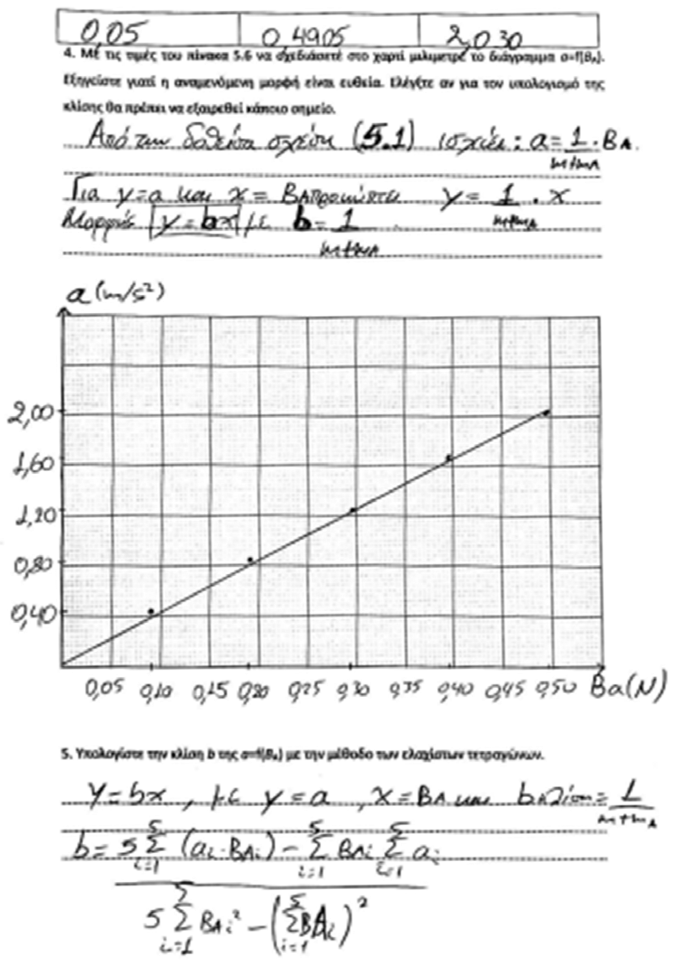

Figure 2. A random page of a given worksheet, completed with student's answers.

Depending on the needs of each virtual experiment, one or more videos were prepared. For example, in the case of the pendulum, we prepared a video containing several pendulums of different lengths oscillating. Students had to watch the same video several times, concentrating each time on the oscillation of a single pendulum of a specific length. During each view, they had to pause the video at the appropriate moments to record the time of 10 oscillations, just as in the real laboratory. We chose to record the simulations as videos and refer to them when we built the worksheets that students had to work with, instead of asking students to use the IP software, for the following reasons:

(i) Not all students may be able to install the IP software on their devices. For example, it is impossible to install IP software on mobile devices. Unfortunately, this is not just a feature of the IP software only, but it’s more general.

(ii) In the prepared videos, only the absolutely necessary measuring instruments were displayed, rather than all the tools and graphs contained in the IP software, so that students can perform their measurements with corresponding errors. For example, in one of the videos where a body free falls only a ruler parallel to its trajectory and a digital timer, are shown. No other digital measuring instruments or variable graphs are presented (e.g., for the position, speed, acceleration, etc.). Therefore, students, by stopping the video at appropriate time frames, had to measure the position of the body on the ruler, instead of taking their digital values from the IP software directly, and they had to think how to write their measurements with the correct significant digits, as they would do with a ruler in the real lab.

(iii) When preparing the video of a simulated experiment, it is possible to program some systematic errors into the experiment, that students should discover through the analysis of the data. The origin of these systematic errors can be hidden by carefully selecting the capturing area when recording the video. If students use IP software directly though, the origin of the systematic errors can’t be hidden so no analysis would be needed to discover them.

(iv) By using videos of the simulations, problems that may arise from possible changes or discontinuations of the simulation software are avoided. Nowadays for example it’s a pity that so many beautiful simulations that were made using FLASH software, are no longer supported by web browsers and have become useless. On the other hand, it’s safe to say that videos will always be supported on any device making them a good choice if you want to make your virtual experiments platform and device-independent.

(v) It is easy to mix and match in the prepared video parts from various simulations available on the internet (e.g., PhET, GeoGebra, etc).

FINDINGS

The performance of the virtual experiments and the data analysis

The present study is based and focuses on the use of virtual experiments’ videos. The main difference between virtual experiments and real experiments is the measurement procedure. The analysis and presentation of the measured data and the corresponding questions are almost the same, either the data comes from a virtual or from a real experiment. Thus, our study did not focus on the analysis of the data by the students but emphasis was given on the measurement procedure.

The teachers though evaluated students' worksheets, both for their measurements and for the analysis of the data (figure 3). Consistently data analysis was harder than measument procedure for all experiments. This is common in physical experiments too.

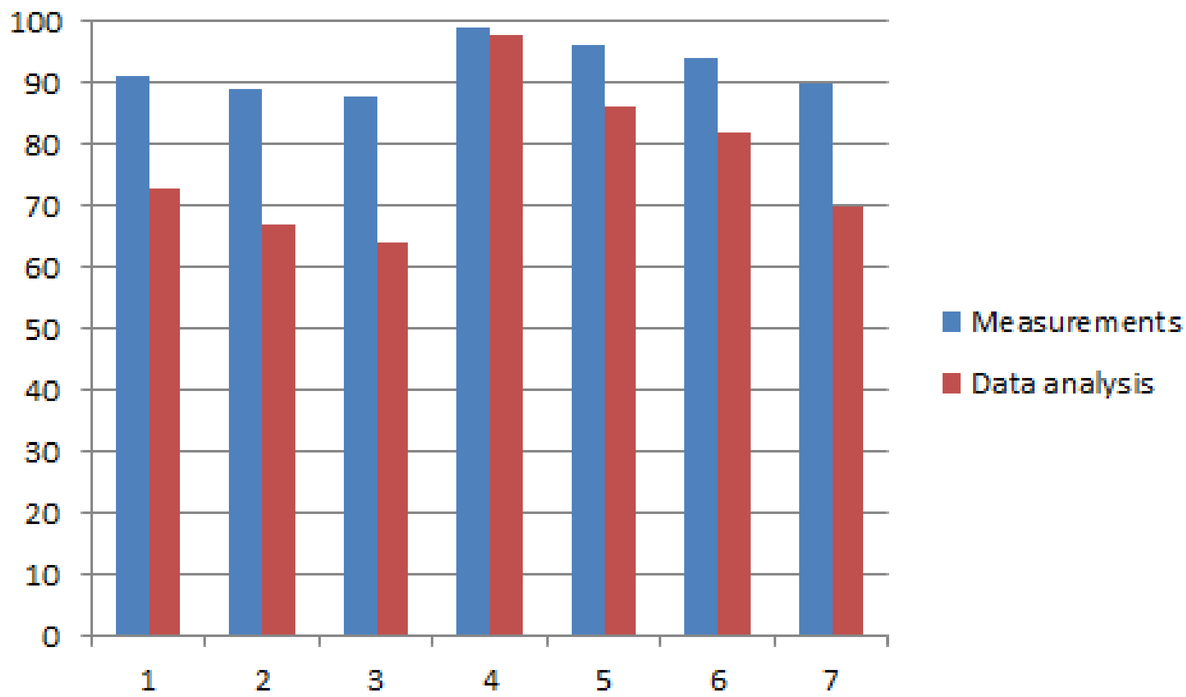

Figure 3. The average score per experiment number, for measurements(blue) and data analysis (red).

Most of the 82 students (89%) took measurements for the first time using a virtual experiment. However, most of them (52.1% to 73.4%, depending on the experiment) said that taking the measurements seemed an easy process. The evaluation of the students' worksheets by the teachers showed that the average score for taking correct measurements ranged from 88% to 99%, depending on the experiment. This leads to the conclusion that students took relatively good measurements from the videos.

In order to identify the difficulties student faced in taking measurements during the virtual experiments, we analyzed students' worksheets, who scored grades that were lower than the average. We present below possible difficulties in taking measurements from virtual experiments that were highlighted by analyzing students' worksheets, in addition to an analysis of their views on this laboratory teaching approach.

From the analysis of the worksheets of students who had a low grade, it appeared that the difficulties in taking measurement may be due to two main reasons:

(i) They were not able to write the measurement with the correct significant digits, which is a difficulty that students encounter in the real lab too, and

(ii) they did not use some simple auxiliary tools at home (e.g., a rectangular ruler to more accurately determine the position of the center of mass of a free-falling body on a parallel ruler shown on the computer screen during the video).

Analyzing the data and answering the worksheets' questions was not an easy process for the students. Specifically, only 18.4% to 48.9% (depending on the experiment) stated they did not have any difficulty. However, as already mentioned, the difficulty in answering questions and process data would be the same as the one they would also face in the real laboratory since almost the same questions were asked. The average score for data processing ranged from 64%

to 98%, depending on the experiment. Figure 3 shows the average score per experiment in terms of measurements and data processing.

Students' views

The analysis of the virtual experiments' evaluations by the students, showed that they found the process useful to a significant degree. Specifically,

- about half (46.4%) said that they were significantly helped to become familiar with the lab practice,
- 28% that they were probably helped, and
- 25.6% that they did not think they were helped.

Also, 63.5% considered that the performance of virtual experiments is much more effective for their learning than the analysis of ready-made measurements.

Teachers' views

Generally, teachers found the proposed process educationally useful. They expressed the view that it helped them identify the difficulties that students have in laboratory practice and more specific in data analysis. However, apart from the catch that students don't have experiential contact with the real world when they conduct virtual experiments (e.g., they do not physically feel how heavy a body is, or they do not have to level a track), teachers found another disadvantage. Contrary to real experiments, in virtual experiments, there are no unforeseen or accidental events that can happen and result in wrong measurements. For example, from the analysis of the worksheets, it was found that with the virtual experiments, it was almost impossible to find an experimental point in a diagram, which was significantly differentiated from all the others, and thus had to be checked for exclusion, while this is a common case in many real experiments.

All teachers (9/9) considered that the use of virtual experiments helped to familiarize students with the laboratory practice significantly more than the process of sending students ready-made tables of measurements for processing. They also stated (8/9) that the proposed procedure could help students practice laboratory skills even when quarantine conditions end. They suggested that the virtual experiments should be used:

(i) In parallel with the real experiment, so that students understand the role of models.

(ii) As additional exercises for better practice and assessment of students.

(iii) For familiarizing students with the experimental setup and method during their preparation before the corresponding real experiment, and

(iv) In the introductory lectures on measurement and error analysis and processing and presenting laboratory data.

CONCLUSIONS AND IMPLICATIONS

This paper presents an educational proposal for distance learning physics labs. It was designed for first-year undergraduate students, and it was implemented during COVID-19 quarantine conditions. Students are informed with videos and photos about the real lab devices, and then they perform tasks using videos of virtual experiments, which include models of the corresponding real devices.

The proposal does not require any financial expense or special resources, and it can be realized relatively easily and quickly. Also, the idea of using virtual experiments videos, makes the process independent of installation problems, change or discontinuation of the simulation software that was used to prepare the videos.

Our findings show that the proposed process helped students' lab practice and that teachers found it useful during quarantine. In addition, teachers think that the process can be potentially useful even after quarantine conditions end. The fact that the educational value of supplementation of physical experiments with pre-lab practice sessions with virtual experiments shows promise is in agreement with other relevant works (Chaturvedi, & Dharwadkar, 2011).

In conclusion, we can say that the use of virtual experiments, as proposed in the present work, can partially cover the goals of first-year physics (mechanics) laboratory courses, in cases of the absence of the physical laboratory. When real experimentation is possible, virtual experiments can be an important auxiliary tool for the preparation of the students. as they provide the experimenting possibilities that go beyond the practical and time constraints of the real laboratory. The preparation of virtual experiments' videos guarantees their device-independent usage.

The project was initially limited to the mechanics' chapter of the physics course and IP software but has the potential to be improved and extended to other physics chapters, using other software or ready-made simulations for modeling. Such an extension of the proposal along with in-depth research can further pinpoint in detail its advantages, disadvantages, and perspectives.

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LINKING THEORY TO PRACTICE IN INQUIRY-BASED VIRTUAL LABORATORY ACTIVITIES

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This study deals with secondary school students working with “ThermoLab”, a simulated virtual laboratory environment. The students were engaged in a number of inquiry activities, both “closed” and “open” type. Our interest lies in evaluating the effectiveness of labwork, by measuring students linking theory to practice during lab activities. Students worked in pairs, and data were collected after analyzing and coding students’ conversations from video and audio recordings, in five different laboratory sessions. We have applied the Category Based Analysis of Videotapes (CBAV) method, according to which, the density of students’ knowledge verbalization is related to specific labwork contexts, and which can be used as a measure for their linking theory to practice during labwork. Our findings showed that while working in a virtual laboratory environment, students were able to create links between theory and practice, but these were more likely to occur while working in “open” inquiry type activities, rather than “closed” type ones. Moreover, these links presented variations between different student pairs.

Keywords: Physics verbalization, Video Analysis, ICT Enhanced Teaching and Learning

INTRODUCTION

Laboratory work is considered of paramount importance in Science Education, for various reasons like: students linking theory & practice, developing experimental skills and getting to know the methods of scientific thinking (Millar et al., 2006). During labwork students get involved in the world of ideas, while representing the world of objects, they observe and interact, while manipulating either specially constructed equipment or common life objects (Psillos & Niedderer, 2006). However, the effectiveness of labwork in achieving these goals is not that straightforward (Hofstein & Lunetta, 2004), and learning is not automatically acquired as in one hand students have their own perceptions and aims – probably different from the ones set by the designers of the activities (Psillos & Niedderer, 2006), and on the other hand learning is affected by a number of factors, such as time consuming procedures and technical details (Séré, 2002). Technology-based laboratory implementations, like simulations/virtual laboratories, have been reported to deliver better or - at least - the same learning outcomes as traditional labwork (Smetana & Bell, 2012), by overcoming some of the above-mentioned weaknesses.

Inquiry-based approaches provide an excellent opportunity for students to express their views and be engaged in discussions about the phenomena and concepts under study and laboratory work is right in the heart of inquiry. According to Lemke (1990), verbal communication in laboratory work is very important, since talking science equals doing science through the medium of language. This topic is still under investigation (Hennessy et al., 2020) in science education and has been used by a number of researchers as a means to assess labwork’s efficiency (e.g. Schreiber et al., 2016) or students linking theory to practice (e.g. Kluge, 2019; Skoumios & Passalis, 2013).

Additionally, although a sizeable amount of empirical research has been focusing in comparing inquiry-based with more traditional approaches (Blanchard et al., 2010), the specific types of inquiry-based activities that are more likely to promote the establishment of this link have not yet being definitely identified (Von Aufschnaiter & Von Aufschnaiter, 2007), but evidence seems to point in the direction of openness (Bunterm et al., 2014).

The aim of the present study is to assess students' learning during labwork, where students are engaged in inquiry-based activities. Accepting a model proposed by Psillos & Niedderer (2006), this type of assessment of learning happening during labwork is called effectiveness-1. Specifically, we are investigating whether students create links between theory and practice when working in ThermoLab (Hatzikraniotis et al., 2001), a simulated virtual laboratory environment for thermal phenomena, and furthermore if the number of links created is related to the kind of activity, they are engaged in.

Our research question is: How do the different types of activities affect the amount of science talk, which eventually reflects students' linking theory to practice, and how does the amount of verbal interactions varies between different student pairs?

METHODOLOGY

Context and sample

The work presented here, is part of a wider study of an inquiry-based and ICT enriched Teaching Learning Sequence (TLS) (Méheut & Psillos, 2004) with a laboratory orientation, applied by the 1st author in a secondary school Physics class in Greece, comprising 14 students (13-14 yr.). Students were working in pairs (7 pairs), each pair having their own computer and worksheets, and their conversations were video and audio recorded. Physics is included in the compulsory curriculum, and the TLS covered topics concerning Thermal Phenomena using ICT tools like ThermoLab (Lefkos et al., 2005).

ThermoLab (Figure 1) is an open virtual laboratory environment, with no pre-defined experiment setup, where students can conduct their investigations, by setting up and executing their own experiments, using virtual materials and instruments (water, oil, metallic cubes, heaters, thermometers, beakers, etc.). By following specially structured worksheets, students were not only being introduced to the phenomena under study, but were also being engaged to inquiry in meaningful way, starting from more "closed" and gradually moving towards more "open" activities.

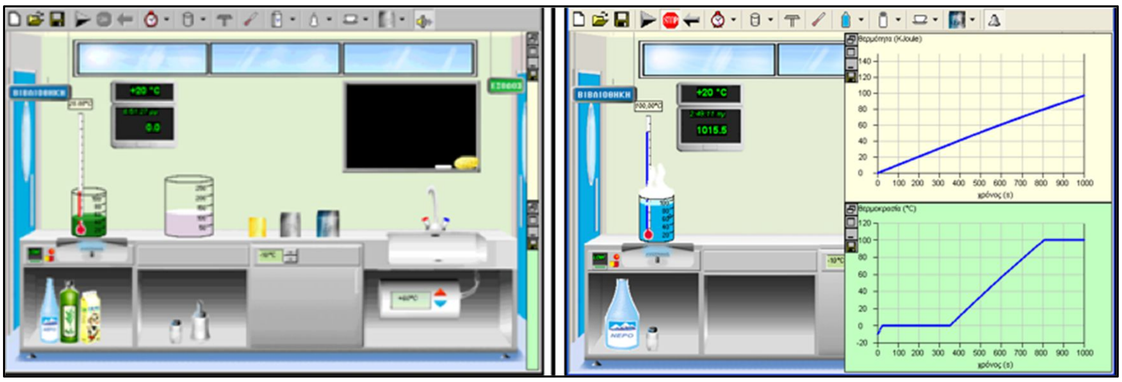

Figure 13. Sample screenshots from the virtual laboratory ThermoLab..

In this study we focus on results that were collected from two student pairs working with ThermoLab on 5 different laboratory activities (Table 1), one teaching hour each. The in-group co-operation was much smoother in pair A, than in the other pair (pair B).

These activities were selected from the teaching sequence and represented either the “closed” or “open” type of inquiry. Several authors have tried to classify inquiry from closed to open, depending on the amount of guidance provided. Bell et al., (2005) assigned 4 levels (confirmation, structured, guided, open inquiry), based on three parameters, who gives the question, the methods, and the conclusion. Hegarty-Hazel (1986) split the methods into “equipment” and “procedure” and the “guided inquiry” into two levels (guiged-1 & guided-2). According to Du et al., (2005), inquiry-based activities can be identified in six levels, ranging from Lecture/Demo (level 1) to Student-Designed Inquiry (level 6), depending on who is responsible (teacher/students) for specifying the topic or pose the questions to be investigated, define the experiment’s setup, the methodology, or the method to be used for analyzing the results and drawing conclusions. In our case, we have opted variations in the setup and methodology of the experiments in order to provide the testing ground for the research question. One activity was more “closed” type or “structured lab” with a teacher-defined setup and procedure (level 3), while the other activities were more “open” type, i.e., either “challenge-Lab” with a teacher-defined procedure and student-selected setup (level 4) or “student directed inquiry” without a given experimental setup or procedure (level 5). In all types, the topic and questions to be investigated were provided by the teacher.

Table 10. The selected activities, corresponding topic and type

Activity Name	Topic	Type of Inquiry
Radiation-1	Thermal radiation – bodies of different color	Closed (structured or structured-Lab)
Radiation-2	Thermal radiation – bodies of different surface area	Open (guided-2 or student-defined)
Calorimetry-1	Calorimetry – thermal interaction between 2 different liquid substances	Open (guided-1 or challenge-Lab)
Calorimetry-2	Calorimetry – thermal interaction between a solid and a liquid substance	Open (guided-2 or student-defined)
Phase Change	Phase changes – thermal interaction between water and ice	Open (guided-2 or student-defined)

Category Based Analysis of Videotapes

One common method of collecting data during laboratory activities, is by means of video recordings, that can be studied and analyzed afterwards, by using coding schemes. The videotape itself is not data, but it is a resource for data construction, a source out of which actual data must be defined and searched for (Erickson, 2006). One of the methods of video analysis is called Category Based Analysis of Videotapes (CBAV), proposed by Niedderer et al., in 2002, but still in use by other researchers (e.g., Coppens, Van Den Bossche, & De Cock, 2016).

Hence, following the CBAV method, one can measure how often and in which contexts students talk about physics (i.e., use physics concepts related to the activity) during laboratory work, thus, converting verbal communication to data by calculating the Density of verbal expressions concerning a number of predefined categories in a given laboratory context.

$$Density(KP / X) = 100 \cdot \frac{\sum Timeunits\_KP\_in\_X}{\sum all\_Timeunits\_X}$$

Figure 14: Calculating the Density of Verbalization of the KP category during the X laboratory work context.

For example, in order to calculate the density of Physics Knowledge (KP) in a given laboratory context, e.g., using the simulation (X), one has to count all time units with verbalization of physics knowledge (KP) and then divide it with the total number of time units where students work in context X (Figure 2). Time unit is user (researcher) defined, which in the present case is set to 30 sec., as this is considered adequate for a student to express a verbal statement, and this can be coded in the respective verbalization category. The total time units were allocated individually for each pair and activity.

In our work the laboratory context under study is ThermoLab and the categories measured for the purpose of this research are: (a) Verbalization about Physics concepts concerning Virtual objects (VP), e.g., students deciding about the experimental setup and initial conditions, and (b) Verbalization about Physics Theory or students' perceptions (PT), e.g., students comparing results to their perceptions. The sum of VP and PT density is also calculated, representing the total Physics Knowledge verbalization density.

Table 11: Physics Knowledge (VP+PT) Density, per activity (type) and per student pair. The first two highlighted cases are discussed in more detail.

		Student Pair A Density (%)			Student Pair B Density (%)		
Activity Name	**Openness of Inquiry**	**VP**	**PT**	**VP+PT**	**VP**	**PT**	**VP+PT**
Radiation-1	Closed	19.4	16.7	**36.1**	27.5	17.2	**44.7**
Radiation-2	Open	50.0	12.5	**62.5**	44.2	13.5	**57.7**
Calorimetry-1	Open	46.4	28.6	**75.0**	55.3	10.5	**65.8**
Calorimetry-2	Open	63.0	10.9	**73.9**	50.0	22.7	**72.7**
Phase Change	Open	53.9	26.9	**80.8**	36.7	20.0	**56.7**

RESULTS

Table 2 summarizes the results of the application of the CBAV method described above, as applied on the videotapes of two pairs of students, pair A and pair B, while working in ThermoLab. It shows the measurements for the verbalization density (%) of VP, of PT, and the total density of Physics Knowledge (VP+PT), for a set of 5 laboratory activities as described above. Moreover, Figure 3 presents these results graphically, concerning students pair A and students pair B respectively.

In the following lines, we will present the findings in detail using Radiation-2 and Radiation-1 as an example to demonstrate the differences between an "open" and a "closed" type activity, respectively, since they share the same conceptual content (Thermal Radiation). As shown in Table 2, the total Physics Knowledge (VP+PT) Density for both pairs of students is greater for the "open" type activity in comparison to the "closed". More specifically, in the former, Student Pairs A and B had 62.5% and 57.7%, respectively, whereas in the latter, Pair A had 36.1% and B had 44.7%. This finding indicates that the students were stimulated to verbalize physics knowledge more often during "open" type activities.

Furthermore, the contribution of Physics concepts concerning Virtual objects (VP) for both pairs of students was also greater for the "open" activity (Radiation-2) in contrast to the "closed" (Radiation-1), where student pair A had 50% and 19.4%, respectively, while student pair B had 44.2% and 27.5%, respectively.

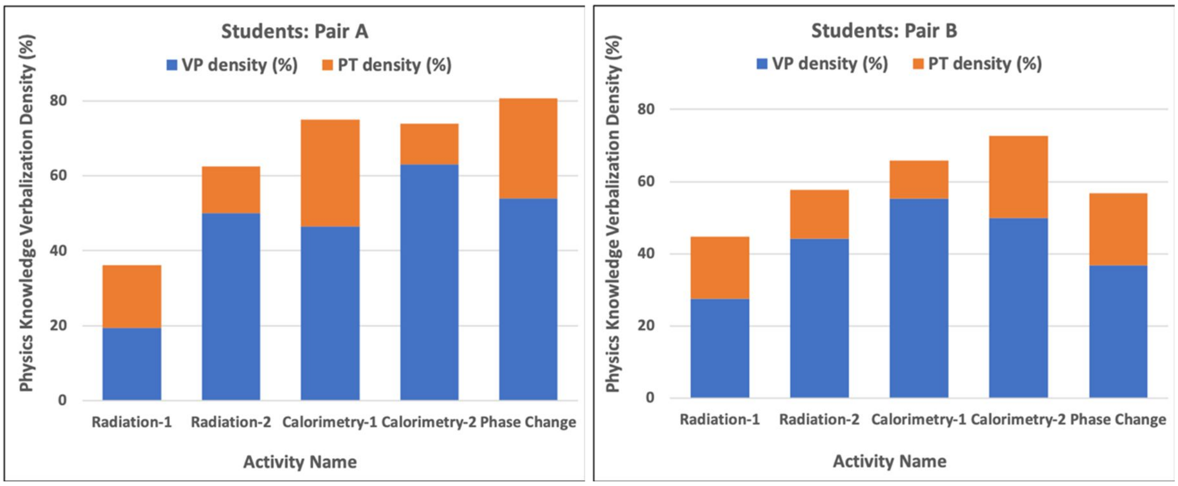

Figure 15. Density of verbalization (%) of the two student pairs (A and B), about Physics concepts concerning Virtual objects (VP) and Physics Theory (PT).

In fact, this VP verbalization category, presents greater differences between "open" and "closed" activities, than PT category. This is an important finding, as it means that while manipulating the virtual objects (e.g., setting up the experiment, taking decisions about the variables), students are triggered to think (and speak) about physics.

An overall view of the Table shows that these findings are also valid for all the other "open" type activities, where student pair A had percentages ranging from 62.5% – 80.8% (in comparison to 36.1% for the closed), and student pair B ranged from 56.7% – 72.7% (as against 44.7% for the closed-type).

Differences observed in verbalization density between the student pairs A and B, are mainly attributed to their different personalities and the resulting group dynamics. This was evident when watching the videotapes and listening to the verbal interactions of the students, since students of pair A seemed to cooperate more smoothly than students in pair B, who were frequently arguing about minor details, mostly irrelevant to the lesson.

A further analysis of variance using One-Way ANOVA, showed that the effect of the type of activity on the total Physics Knowledge (VP+PT) Density of student pair A was significant, $F(1,3) = 18.629$, $p = .023$. On the other hand, concerning student pair B, the effect of the type of activity on the total Physics Knowledge (VP+PT) Density was not significant, $F(1,3) = 4.859$, $p = .115$.

Certainly, this has to be considered as one of the limitations of our study, but might also be attributed to the above mentioned comment about the difference in group dynamics. A future comparison of more activities and more student pairs, will probably provide us with a more robust picture on this issue.

DISCUSSION

Our data presented earlier (Table 2, Figure 3,4) can give an insight about the effect of the type of activity in the total Density of Physics knowledge verbalization (VP+PT), since there seems to be a clear indication that the "open" type activities result in a greater density of Physics knowledge verbalization, as compared to the "closed" type ones.

Furthermore, following the theoretical background of the CBAV model, this means that students are creating more links between theory and practice, during an "open" type labwork activity.

In a more detailed observation of our data, we can also comment the following:

- The density of verbalization about the physical properties of the virtual objects (VP), is very high in all the cases of the "open" type activities and rather low in the case of the "closed" one. In our view, this is an indication that virtual objects are perceived by the students as having physical properties like the real ones. In other words, manipulating virtual objects is being conceptualized like the manipulation of the real ones. We could claim that, even though the physicality of the interaction is different, the conceptual interaction is similar (Lefkos et al., 2011).
- The Density of verbalization concerning physics theory (PT) was quite similar in all of activities, either "open" or "closed" type. We believe that this is quite an interesting aspect about the use of the virtual laboratory, since it provides evidence about students' creating links to Physics Theory, which means that a level of abstract thinking is also fostered while working in a virtual environment like 'ThermoLab'. The effectiveness of virtual labs in supporting the construction of concepts, was also found by Gnesdilow & Puntambekar (2021), who analyzed students' written explanations.
- The Density of verbalization of student group A, is greater to the one of group B, in all activities. This is an indication that verbalization might also be affected by factors not related to the structure of the activities, like the quality of interactions between students. Similar findings are reported concerning small group interactions while working in open type investigative activities, where some groups outperform others in their learning effectiveness depending on their mutual respect (Brookes et al., 2021).

Finally, we have to give the credit of acquiring the above observations, to the specific characteristics of ThermoLab, since being an open learning environment, allowed us to design a TLS with different types of activities, in order to conduct this investigation or other ones related to the ability of students to design their own experiments (Lefkos et al., 2011). This could not have been accomplished in other types of virtual laboratories with pre-selected experiment setups.

These comments should, nevertheless, be considered under the previously mentioned limitations of our study.

CONCLUSIONS

The objective of this study was to evaluate students' learning while they were engaged in inquiry-based activities, using ThermoLab, a virtual laboratory environment, and in particular to investigate the amount of verbalization about science, taking place in two different types of activities.

Our study findings suggest that Physics Knowledge verbalization is affected by the type of activity students are engaged in. Students are likely to express more verbalizations about Physics knowledge in "open" inquiry type activities. This finding also indicates that students tend to create more links between theory & practice, in this activity-type, in accordance with similar studies reporting that a more open form of inquiry is more beneficial to students (Bunterm et al., 2014). Additional factors related to the variation of group dynamics, might also need to be taken into account.

Moreover, the virtual lab "ThermoLab" seems to provide a fruitful learning environment for students to verbalize their physics knowledge, hence further contributing to linking theory to practice.

Despite the recognized advantages of inquiry-based approaches (Sokołowska, 2018), teachers seem to be reluctant to adopt it (Melville et al., 2013). Having flexible tools and open learning environments like virtual laboratories, for designing teaching interventions and easily implementing inquiry-based approaches can be a critical factor for having their mind changed. Additional findings from empirical research, like this one, reporting about the type of inquiry activities that are most fruitful for learning, could also provide useful information. Further investigation on this topic is required, involving a larger number of activities and students, so that supplementary and more noteworthy results can be obtained.

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ENABLING CONCEPTUAL UNDERSTANDING IN PHYSICS VIA IMMERSIVE VIRTUAL REALITY

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The integration of immersive Virtual Reality (VR) in authentic science classrooms can result in a totally new learning experience for the students. However, the effect of the integration of immersive VR on conceptual learning gains and the learning experience itself, considering students' pre-existing science- and digital technologies-related attitudinal profiles, has not been explored to date. In this study we have enacted a 90-minute intervention with high-school students (n=107), learning about the Special Theory of Relativity in their Physics course through an immersive VR simulation. We aimed to examine students' conceptual learning gains and differences in their perceptions of the learning experience, considering their attitudinal profiles. Clustering analysis has revealed two attitudinal profiles: the low attitudes profile (n=48) included students with low science- and digital technologies-related attitudes, and the opposite for the high attitudes profile (n=59). Results from a 2x2 RM ANOVA revealed a statistically significant interaction between learning and attitudinal profiles. In addition, a one-way MANOVA test showed statistically significant differences between the two profiles in relation to students' perceptions of the learning experience, with high-attitudes students outperforming their counterparts. Findings and implications of students' individual differences in learning and attitudes linked to the integration of immersive VR in the science classrooms will be discussed.

Keywords: ICT Enhanced Teaching and Learning, Inquiry-oriented learning, Physics

INTRODUCTION

Emerging technologies have the potential to support educational reforms and to enhance teaching and learning practices, including teaching, and learning in science. Especially in the science and physics education field, emerging technologies, such as immersive Virtual Reality (VR) simulations, may facilitate the teaching and learning of physical concepts and phenomena (Barab et al., 2000), which cannot directly be observed through daily experiences (e.g., the Special Theory of Relativity – STR) (Arriassecq & Greca, 2012). In efforts to integrate immersive VR simulations in schools, it is imperative to take into consideration the fusion of technology and pedagogy, aiming to result in learning experiences that can leverage the affordances of VR within K-12 education (Georgiou, Tsivitanidou, Eckhardt, & Ioannou, 2020; Jowallah, Bennett, & Bastedoet, 2018). Yet, previous work in this direction has systematically neglected students' perceptions of the learning experience and personal attributes (e.g., attitudes), which might have a significant effect of the successful integration of novel technologies in the classroom. On one hand, the evaluation of students' perceptions of the learning experience structured around the integration of emerging technologies in the classroom is deemed crucial, as students' voices could shed light on the learning experience itself (Chang et al., 2015). On the other hand, it is also critical to delve into factors related to students' personal attributes (e.g., attitudes), as those may have a significant effect on how the integration of novel technologies in the classroom is perceived as well as on subsequent conceptual learning. This research gap becomes even more crucial in efforts that aim to situate immersive VR simulations in the context of student-centred pedagogies, e.g., inquiry learning, rather than being used as a stand-alone format (Georgiou, et al., 2020). Attitudes have long been recognized as important predictors of individual differences in many educational endeavours.

In this study, we focus on the adoption of scientific attitudes by students (Osborne et al., 2003), which reflect open-mindedness and willingness to revise opinions based on experimentation and empirical data (Fraser, 1978), and on digital technology-related attitudes (i.e., perceived ease of use, affect towards digital technologies and perceived usefulness). Specifically, we sought to investigate the potential effect that the integration of an immersive VR simulation in inquiry-based Physics lessons may have on students' conceptual learning gains and perceptions of the learning experience, considering students' attitudinal profiles as these derive from their scientific- and technology-related attitudes. Even though attitudinal profiles deriving from public attitudes towards science and technology have been already explored (Pullman et al., 2019), to the extent of our knowledge, no previous research has explored pre-existing students' attitudinal profiles, deriving from their scientific- and digital technologies-related attitudes. Moreover, potential differences in students' conceptual learning gains, as well as potential differences in students' perceptions of a learning experience that entails an immersive VR in the classroom, taking their attitudinal profiles into account have not yet been examined.

RESEARCH QUESTIONS

The present study was guided by three main research questions (RQ) as follows: (1) Are there pre-existing attitudinal profiles grounded on high-school students' science- and digital technologies-related attitudes? (2) Are there any differences in students' conceptual learning gains across time, taking their attitudinal profiles into account? (3) Are there any differences in students' perceptions of the learning experience, taking their attitudinal profiles into account?

METHOD

Participants

The sample consisted of 107 high-school students (10th-12th graders) of which, 50 were girls (47%) and 57 were boys (53%), with a mean age of 15.78 years old (SD=0.65). The students were guaranteed anonymity and consent forms were obtained from their legal guardians regarding the data collection, prior to the start of the intervention. Students worked in groups of 3-4 members throughout the whole intervention, studying a learning material following the inquiry-based pedagogy on the Special Theory of Relativity (STR). However, students completed individually all the tests and the questionnaires, which were administered for data collection purposes. At the outset of the implementation, students were also warned about possible side effects (i.e., motion sickness, nausea, dizziness) and were asked to report immediately any of these effects to the researchers (however, we have not observed these side effects in our study). Last, the students were informed that they were not obliged to engage with immersive VR if they did not wish to do so; in this case, the students could watch the simulation from the external projection and not be immersed (however, all students who participated in this study selected to be engaged and work with the immersive VR).

Learning material

The intervention aimed at promoting students' understanding of the STR implications (i.e., time dilation, length contraction), building on the STR axioms. Specific tasks from the learning material developed by Dimitriadi and Halkia (2012) were adopted with necessary adaptions applied. The conceptual path chosen is the one that was found to follow most of the scientific books, that is a qualitative approach to the first axiom of the STR, a reference to problems arising at the speed of light which links to the second axiom, followed by an introduction and elaboration of the consequences of the STR accounting the two axioms. No complicated terminology or mathematical formalism was used, except for just one simple application of the Pythagorean Theorem with which all the students were already familiar as this had been already taught, as part of the national curriculum.

The inquiry-based approach was embraced for promoting social construction of knowledge through the enactment of learning activities that involve the development of hypotheses, a data collection and analysis process, followed by data interpretation and debate with peers using evidence and representations towards the formation of coherent and evidence-based arguments (Constantinou, Tsivitanidou, & Rybska, 2018; Chinn & Malhotra, 2002). The material was organized into inquiry phases as proposed by Pedaste et al. (2015), including an orientation phase, followed by conceptualization, investigation, conclusions, and discussion (Pedaste et al., 2015).

The study of the learning material was organized in five learning stations, which served as data-collection points during the inquiry learning process. The students were asked to complete a given mission in a 90-minute session. Two of the stations utilized an immersive VR simulation, a third station included video material and the rest two stations provided textual information.

Procedure

At the beginning of the intervention, all students completed a pre-survey and a pre-conceptual test, during a time slot of 20 minutes. Then, a 60-minute preparatory session took place, in which the students were introduced to the given mission and the two axioms of STR through simple examples and thought experiments. The preparatory session was followed by a 90-minute intervention during which, the students started studying the learning material within their groups for completing the mission. Specifically, the students were split into five groups, and, through rotation, each group was given 15 minutes to implement a given task per learning station. Students' transition from station to station was enacted by a bell ringed. In this way, every group could experience all five stations (see Figure 1).

The learning stations were conceptually connected, as the inquiry-based activities built on each other to promote learning. At the same time, each station could operate independently, as there was not any required sequential order to be followed by the students. In all the stations, students were asked to analyse, interpret, and synthesize the pieces of information collected, to explore consequences of the STR (i.e., time dilation, length contraction, simultaneity). In this context, the completion of worksheets was also part of the intervention, to support students in reporting, synthesizing, and reflecting on the data collected from the learning stations. In particular, each group was provided with a single worksheet, containing the tasks of the five learning stations.

The students in each group were requested to collaborate and work together in completing the worksheet, upon interpreting together the gathered data in each learning station and reaching consensus on their conclusions. In each station, one student per group was assigned as the leader, being responsible to coordinate the group discussions and report the group's conclusions in the given worksheet. The group leader role was reassigned to another student from one station to the next, securing in this manner that all students in a group would enact the role of the leader at least once during the whole intervention.

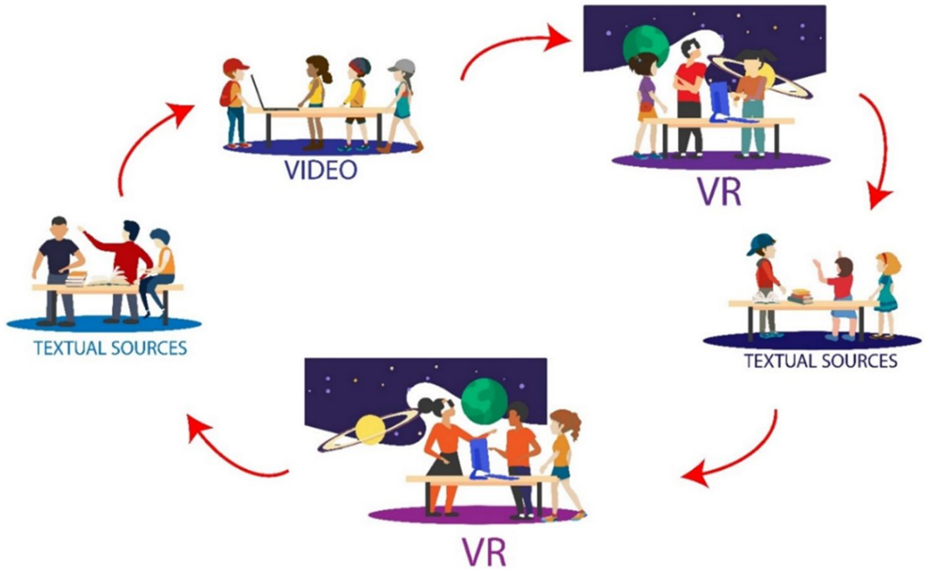

Figure 1. Classroom setup in learning stations. Reproduced with permission from Tsivitanidou et al. (2021).

As soon as the students had passed through all the stations, they were given 15 minutes to take an evidence-based position as a group to the driving question of this inquiry and discuss their conclusion on the plenary. The intervention was supported by the two first authors with prior extensive science teaching experience and who attended preparatory meetings before each classroom session. Aligned with the inquiry-based approach, the role of the two teachers shifted from the 'dispensers of knowledge' to becoming facilitators for supporting students' learning throughout the process (Anderson, 2002). Towards this direction, the learning material included one checkpoint at the end of each task, in which students were prompted to briefly discuss with the teacher(s) their outcomes and resolve any potential difficulties. Finally, at the end of the intervention, the students were asked to complete a post-conceptual test, as well as a post-activity questionnaire on their perceptions of the learning experience, during a time slot of 20 minutes.

Apparatus

The immersive VR simulation that was used in this study aimed at supporting students' understanding of time dilation and length contraction, as the main STR implications. While using the VR simulation, the students were asked to control a spaceship to travel inside and outside our solar system. The spaceship cockpit was comprised of several panels, which provided valuable information, including the distance to a selected destination measured in light-years (ly), the traveller's speed as a factor percentage of the speed of light, the elapsed time in the spaceship, and the elapsed time on Earth, from the perspective of an inertial observer. The location of the spaceship was presented by a map displayed on the left, while a set of autopilot controls appeared on the right side of the screen allowing the students to travel to any of the provided destinations (i.e., the sun, all solar planets, outermost bounds). Alternatively, the students could navigate manually by using the WASD keys on the keyboard (W=accelerate, S=Stop, A/D=Rotate left/right). Figure 2 illustrates the main screen of the immersive VR simulation with its main characteristics, as presented above.

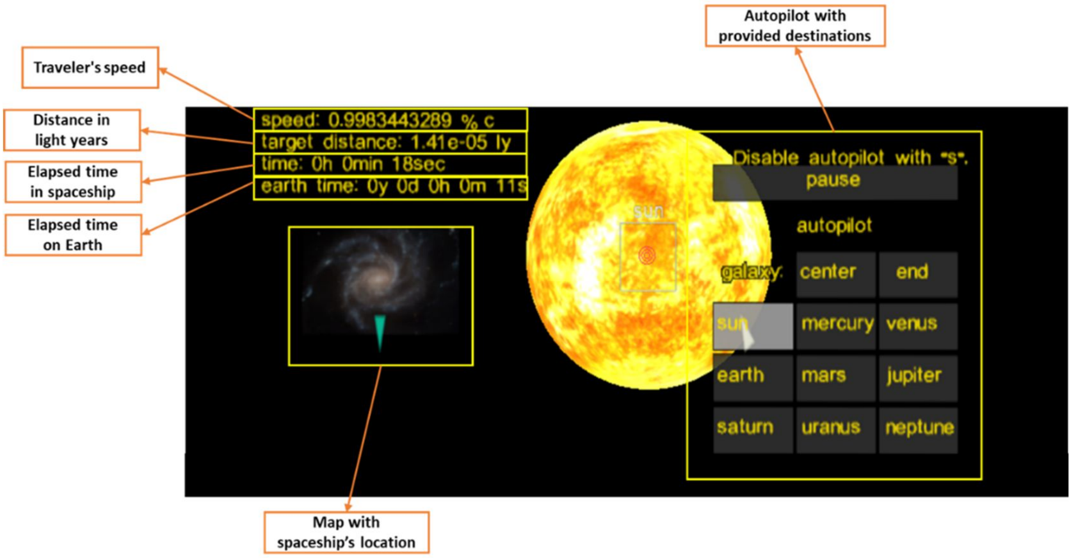

Figure 2. Main screen of the immersive VR simulation with its main characteristics. Reproduced with permission from Tsivitanidou et al. (2021).

The particular VR simulation was created by Chu et al. (2019) and was based on a running model developed in C++, while OpenGL was chosen for the graphics programming and OpenVR to access the HMDs. The physical magnitudes were properly simulated with the aid of a self-written graphic engine specifically designed for displaying objects with massive size differences. The deployment of the immersive VR simulation was enacted with the use of Oculus Rift HMD tethered to personal computers (four sets in total) and equipped with sensors to track the position of the user. This setting allowed a better processing of graphics for real-time tracking and interactions and secured a high-quality learning experience for the students.

Data collection

This study followed a quantitative approach. Data were collected through (i) a pre-survey measuring demographics, scientific attitudes (TOSRA, see: Fraser, 1978) with a Cronbach's alpha calculated to 0.78 for all translated items, and attitudes towards digital technologies (CAMYS, see: Teo & Noyes, 2008) with Cronbach's alpha calculated to be 0.86 for "Perceived ease of use", to 0.89 for "Affect" and 0.78 for "Perceived usefulness", which are considered as satisfactory; (ii) a pre-post conceptual test (three open-ended questions assessing students' conceptual learning on the STR) for which inter-rater reliability values (Cohen's Kappa), for all coding processes were found to exceed 0.85 in every case, and (iii) a post-activity questionnaire on students' perceptions of the learning experience (CMLES, see: Maor & Fraser, 2005); Cronbach's alpha coefficients for each subscale of CMLES were calculated accordingly to α=0.59 (relevance), α=0.81 (complexity), α=0.77 (challenge), α=0.73 (negotiation), α=0.75 (inquiry learning), and α=0.82 (reflective thinking). Students completed all the surveys on an individual basis. A quantitative approach towards analysing data was followed.

ANALYSIS AND RESULTS

Pre-existing high-school students' attitudinal profiles (RQ1)

A K-means clustering analysis was conducted, setting as attributes students' science- and digital technologies-related attitudes. The K-means classification analysis provided two clusters, which have statistically significant differences in relation to science-related attitudes (F=69.059, p< 0.001) and attitudes towards digital technologies (F=101.448, p< 0.001). The first cluster included students (n=48) with low science-related (m=3.62, SD=0.53) and digital technologies-related (m=3.86, SD=0.51) attitudes, thereby named as 'Low-attitudes' profile, whereas the second cluster included students (n=59) with high attitudes in both variables (science-related: m=4.37, SD=0.39; digital technologies-related: m=4.65, SD=0.28) (see Table 1), thereby named as 'High-attitudes' profile.

Table 1. Results of the K-means Clustering of the Students Based on their Attitudes.

Variables	Low attitudes profile (n = 48)		High attitudes profile (n = 59)		F
	Mean value	SD	Mean value	SD	
Science-related attitudes	3.62	0.53	4.37	0.39	69.059 ***
Digital technologies-related attitudes	3.86	0.51	4.65	0.28	101.448 ***

ns = non-significant; * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

Differences in students' conceptual learning gains across time, taking their attitudinal profiles into account (RQ2)

A 2x2 Repeated Measures Analysis of Variance (RM ANOVA) was conducted to address RQ2. For the testing: (a) the dependent variable was "conceptual learning" as a within-subjects factor with two levels –pre-test and post-test scores and (b) attitudinal profiles was a between-subjects factor with two levels (low-attitudes profile vs. high-attitudes profile). The findings revealed a statistically significant interaction (learning x attitudes profile) (Wilks' Lambda = 0.901, $F_{(1,105)}$ = 11.572, p = .001), with a large effect size ($\boldsymbol{n_G^2}$ =0.120), indicating that the students' conceptual learning gains were different for students allocated in the high vs low attitudinal profiles accordingly (Table 2). Specifically, students assigned in the 'High-attitudes' profile (m=15.50, SD=6.60) experienced larger gains in the conceptual understanding of STR compared to students allocated in the 'Low-attitudes' profile (m=10.62, SD=5.23) (see Figure 3).

Table 2. Results of the Repeated Measures ANOVA

Variables	Low-attitudes cluster (n = 48)		High-attitudes cluster (n = 59)		F	η_G^2
	Mean value	SD	Mean value	SD		
Pre-test	7.66	3.63	8.96	3.76	11.572***	0.12
Post-test	10.63	5.23	15.51	6.61		

ns = non-significant; * $p < 0,05$; ** $p < 0,01$; *** $p < 0,001$.

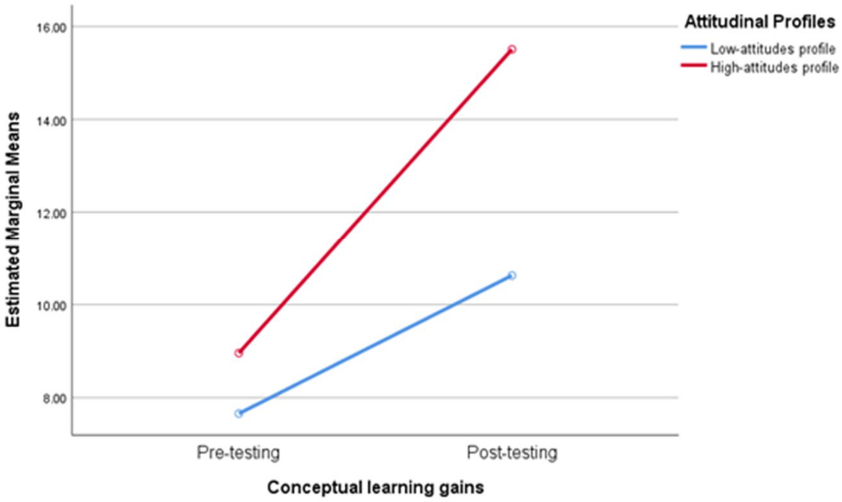

Figure 3. Statistically significant interaction: conceptual learning x attitudinal profile. Reproduced with permission from Tsivitanidou et al. (2021).

Differences in students' perceptions of the learning experience, taking their attitudinal profiles into account (RQ3)

A one-way multivariate analysis of variance (MANOVA) was performed for RQ3. As part of this statistical test, we treated students' perceptions as the dependent variable, including all the scales of the CMLES instrument (i.e., challenge, complexity, relevance, reflective thinking, inquiry learning, and negotiation), and attitudinal profiles as the categorical independent variable (i.e., low- attitudes profile vs. second- attitudes profile). The criterion of homogeneity of variations was not violated as demonstrated by the F value ($F_{(21, 37087)} = 0.798$, p=0.725). The MANOVA results provided that the value 0.83 of Wilk's Λ is statistically significant, $F_{(6,100)} = 3.145$, $p < 0.01$, partial $\eta^2 = 0.170$, and therefore there were differences in students' perceptions of the learning experience, taking their attitudinal profiles into account. Further, statistically significant differences have been detected for all dependent variables, after Bonferroni adjustment, setting the p-value for each test at .083 (p=.05/6). In particular, "High-attitudes" students outperformed "Low- attitudes" students on Inquiry learning $F_{(1,105)} = 16.570$, $p < 0.001$ with a large effect size (partial $\eta^2 = 0.136$), and Complexity F (1,105) = 9.963, p =0.002, Relevance $F_{(1,105)} = 4.152$, p =0.044, Reflective thinking $F_{(1,105)} = 5.500$, p =0.021, Challenge $F_{(1,105)} = 6.664$, p =0.011, and Negotiation $F_{(1,105)} = 4.198$, p =0.043, with medium effect sizes (see Table 3).

Table 3. Results of the one-way MANOVA test on the CMLES Scales.

Variables	Low-attitudes profile (*n* = 48)		High-attitudes profile (*n* = 59)		*F*	*partial η²*
	Mean value	SD	Mean value	SD		
Challenge	4.221	0.068	4.458	0.061	6.664*	*0.060*
Complexity	4.288	0.072	4.593	0.065	9.963**	*0.087*
Relevance	4.100	0.065	4.278	0.059	4.152*	*0.038*
Reflective Thinking	4.092	0.079	4.342	0.072	5.500*	*0.050*
Inquiry Learning	4.217	0.064	4.566	0.057	16.570***	*0.136*
Negotiation	4.438	0.064	4.614	0.058	4.198*	*0.038*

ns = non-significant; * $p < 0{,}05$; ** $p < 0{,}01$; *** $p < 0{,}001$.

DISCUSSION

First, the findings revealed that the high-school students who participated in this study, were clustered in two different attitudinal profiles: the low attitudes profile included students with low science- and digital technologies-related attitudes, and the opposite for the high attitudes profile. Attitudinal profiles have been already studied distinguishably for science-related and digital technologies-related attitudes, as well as their association and/or the effect of those on students' performance (Lee, 2004; Shim et al., 2003), and perceptions of particular learning environments (Kavanagh et al., 2017; Lee, 2004). However, attitudinal profiles emerging from both digital technologies-related attitudes and students' adoption of scientific attitudes, have not yet been reported in the literature. Their identification and further examination in relation to students' learning experience encompassing novel technology integration in the science classrooms is of paramount importance for research and practice. Second, the 2×2 RM ANOVA results demonstrate a within-subjects effect of the enacted intervention, for students' pre-test and post-test scores on their conceptual understanding of the STR, and statistically significant between-subject effects on students' conceptual learning gains. Students assigned to 'High-attitudes' profile, seem to benefit more in terms of their conceptual learning on the SRT topic, in the context of the intervention that encompassed an immersive VR simulation, compared to the 'Low-attitude' students. The findings of this study are in alignment with previously reported research findings, according to which positive associations between science-related (e.g., Lee, 2004) and digital technologies-related attitudes and in particular attitudes towards VR environments (e.g., Huang, Rauch, & Liaw, 2010) have been found with students' conceptual learning gains. However, the significance of examining a combination of attitudinal traits in current efforts of meaningfully integrating immersive VR simulations in the classroom has been highlighted (Jowallah et al., 2018) and our study contributes to this direction. Last, our findings have demonstrated an effect that students' attitudes may have on their perceptions of the learning experience. High-attitude students seem to perceive more positively the learning experience, in terms of the immersive VR simulation that was used (i.e., challenge, complexity, and relevance), and in terms of the inquiry-based constructivist learning process that was endorsed, in relation to their counterparts. Students' positive attitudes towards educational VR technology (Mikropoulos, Chalkidis, Katsikis, & Emvalotis, 1998; Mikropoulos & Natsis, 2011) and positive perceptions of VR in education (Kavanagh et al., 2017) have already been reported. However, our findings further add to the existing body of knowledge, by demonstrating an effect that students' attitudes may have on their perceptions of the learning experience.

Our findings again bring implications for instructional design and practice, when efforts for integrating immersive VR simulations in instruction are made. As already argued by Huang et al. (2010), crucial factors to be considered during the VR integration in instruction is the appropriateness of such simulations for average learners, as well as the appropriateness of instructional set ups (Burdea & Coiffet, 2003). At the same time, our findings suggest that students' attitudinal profiles should be encountered in efforts of integrating novel technologies into instruction, in addition to the appropriate pedagogy and instructional set up framing such interventions. Educators should encounter the potential diversity of student attitudes during the integration of immersive VR simulations in their classrooms for physics learning. Adaptation and personalization to the different needs of students should be catered, as well as the provision of introductory sessions for familiarization with the technology and pedagogy employed in such interventions. Further to that, in this study students' conceptual learning gains and their perceptions of the learning experience were affected by the particular instructional design and the overall learning experience itself. In addition, our findings have implications for teacher training, during which teachers may be guided and supported adequately on how to use immersive VR simulations effectively for teaching and learning in the classroom. We suggest the conduction of further research on novel technologies integration in the classroom, that are grounded on other pedagogies and instructional principles, and on different physics and science concepts, as well the further examination of additional attitudinal traits and their potential effects on students' perceived learning experience and conceptual learning gains.

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AUGMENTED REALITY-TOOLKIT FOR REAL-TIME VISUALIZATION OF ELECTRICAL CIRCUIT SCHEMATICS

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The contribution is centred around the presentation of the didactical concept and the technical implementation of a toolkit for real-time visualizations of electrical circuit schematics with Augmented Reality (AR) for physics education. After an introduction to the state of research on learning with AR in physics education, the didactical curriculum and the specific learning difficulties of electrical circuit schematics from introductory to higher level physics education are expounded. Subsequently, the technical features of the toolkit are explained. The major technical feature of the toolkit is the dynamic real-time visualization of electrical circuit symbolics: electrical circuit symbols of components and electrical circuit schematics of (parts of) electrical circuits can be perceived in real-time during the circuit assembly. Lastly, pending technical improvements are discussed and an outlook concerning the practical implementation of the toolkit is given. Overall, this contribution provides insights into current didactical design potentials and prevailing challenges concerning the use of AR-technology in physics education.

Keywords: Dynamic visualization tools, Educational Technology, Physics

THEORETICAL BACKGROUND

Augmented reality in physics education

Augmented Reality (AR) allows for simultaneous perception of real and digitally generated information (Azuma, 2001). It can be understood as a concept for computer-generated environments (Silva et al., 2003), where the real environment as the initial channel of perception is enriched with spatially and/ or semantically connected virtual information (Milgram & Kishino, 1994) to provide supplementary information in real-time (Liu et al., 2006). The most used AR-technology in educational contexts is display-based AR, where a handheld device (e.g., smartphone or tablet) is used to present AR, whereas head-mounted display-AR devices (hereafter referred to as HMD devices) are still little used (Akçayır & Akçayır, 2017). The HMD devices allow for the perception of virtual objects in the direct field of view and leave the hands free for other activities (e.g., the conduction of scientific experiments). AR has emerged as a technology in teaching and learning during the past years and has so far shown potential for applicability in different educational and pedagogical contexts: AR can promote the acquisition of knowledge and skills (Arici et al., 2019; Garzón & Acevedo, 2019), and it can have a positive influence on motivation and engagement (Zhang et al., 2020). However, the use of AR can entail technical difficulties and may result in a prolonged instruction time for both teachers and students (Munoz-Cristobal et al., 2015). Results by Wu et al. (2013) on the implementation of AR in education suggest that overall, not the implementation of AR itself, but the didactical embedment of AR determines the success of learning. The use of didactically substantiated AR technology for physics education, especially AR-supported physics experiments, reduced cognitive load by integrating real and digital information in the learner's field of view (Thees et al., 2020) and resulted in a higher learning gain compared to a non-AR-setting (Altmeyer et al., 2020). An AR-tool for laboratory experimentation on magnetism by Adusselam & Karal (2020) increased students' academic achievements and facilitated learning. The authors further suggest using AR as a supplemental tool for real-world activities rather than a standalone AR-environment. Permana et al. (2019) published a learning book on electricity that is enriched with animations, sounds and videos by the help of AR. Weatherby et al. (2020) described the concept of an AR-application for real-time visualization of the electrical potential modelled as a height profile alongside the physical circuit. The described real-time integration of spatially and semantically connected information in the field of view by means of AR holds potential to be transferred to other fields of physics education, as shown below.

Difficulties of learning circuit schematics

Although electrical circuit schematics provide a simple, structured symbolic representation of electrical circuits, the understanding and usage of electrical circuit schematics from introductory physics education up to early secondary level physics education can be impaired by various causes: Apart from matching the physical components with the corresponding symbolics, a crucial difficulty lies in the discrepancy between the (rather functional) spatial arrangement of the tools and the clear, often simplified structure of the corresponding circuit schematic (Wilhelm & Hopf, 2018). On the one hand, multiple possible circuit schematics can be drawn based on a single given serial circuit (see Figure 1a). On the other hand, multiple spatial arrangements within a parallel circuit can correspond to the same given circuit schematic (see Figure 1b).

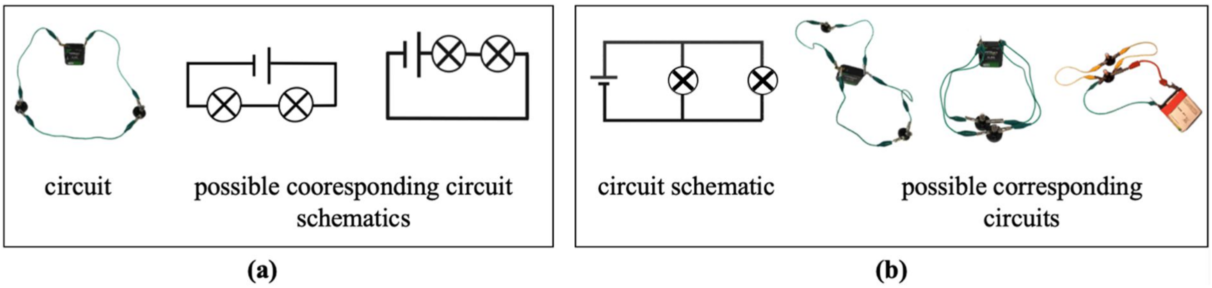


Figure 1. Examples for discrepancies between circuit and corresponding circuit schematics: (a) starting from a given circuit, (b) starting from a given circuit schematic.

The described discrepancies between the spatial arrangement of the tools and the simplified structure of the circuit schematic may obstruct the formation of cognitive connections between the circuit components/ the circuits and their symbolic representations. However, the establishment of representational competencies concerning the shift between physical and symbolic representations of electrical circuits is essential for a beneficial use of circuit schematics. As physics experimentation skills in secondary education can be positively influenced by early-age acquisition of knowledge on physics experimentation (Stern et al., 2015), those competencies should be fostered from an early age on. In higher physics education, however, electrical circuit schematics serve more as a structural aid for the use of complex electrical circuits.

AR-TOOLKIT DEMONSTRATION

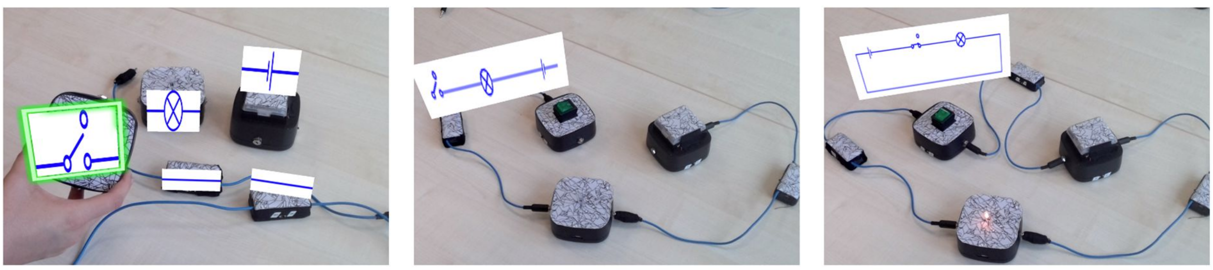
Technical Features

To facilitate the learning of electrical circuit schematics and to ease the prevailing learning difficulties, an AR-toolkit to provide real-time visualization of electrical circuit symbols and circuit schematics was designed (Lauer et al., 2020). The components of the toolkit are specially designed boxes with plugs on the sides for establishing cable connections (see Figure 2). Currently available components are lightbulbs, batteries, cables and switches. All components are covered with visual markers as explained later.

(a) (b) (c) (d)

Figure 2. Components of the AR-toolkit: (a) lightbulb, (b) switch, (c) battery, (d) cable.

The toolkit allows for real-time visualization of single component symbols and circuit schematics of unfinished and full electrical circuits (see Figure 3). A visual touch-highlight (see Figure 3a) emphasizes the connection between component and symbol and offers visual orientation when handling many components at a time. The structure of the circuit schematic displays the physical connection of the tools rather than their spatial arrangement in order to always present the semantically correct, but structurally most simplified circuit schematic.



(a) (b) (c)

Figure 3. Real-time visualization of symbolics for electrical circuits: (a) visualization of symbols for single components with green touch-highlight, (b) visualization of the schematic for unfinished circuits, (c) visualization of the schematic for full circuits.

The real-time visualization is enabled via wireless communication between the boxes, a server and the mobile AR-device (see Figure 4). The component boxes are distinctively designed so that they can be identified, and their physical connection can be determined at any time during circuit assembly. The information concerning the physical connection of the components is passed on via the wireless network to an application on a computer which calculates the appearance of the corresponding symbols and/ or schematics that are to be displayed. The formerly mentioned visual markers are uniquely assigned to the components and thus serve as the spatial positioning anchor for the corresponding symbols and schematics. In this way, the symbols and schematics can be perceived as virtual objects in spatial proximity to the real components or circuits and their appearance adapts in real-time when the physical components are moved or when their connection is modified.

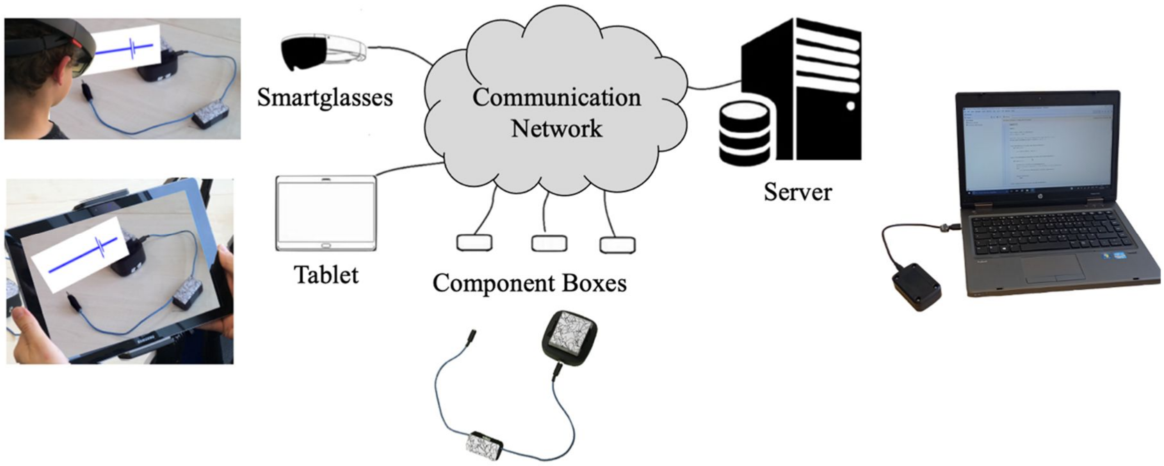


Figure 4. Schematic depiction of the wireless communication network for the real-time visualization of the symbolics via AR.

The toolkit is compatible with both handheld tablet-devices and HMD devices. In the case of handheld tablet-devices, the AR is created by integrating the virtual symbolics and schematics into the camera view of the device. The tablet must be either mounted on a stand (which reduces the mobility) or it must be held in the hand (which impairs the simultaneously ongoing circuit assembly process). As the HMD-devices are mounted on the user's head, they leave the hands free for the physical circuit assembly and create an AR-experience where the symbols and schematics are seemingly integrated into the direct field of view. However, this technology is not yet widely used in education, not least because of the high cost.

Fields of application

The presented AR-toolkit aims at encountering the described difficulties of understanding electrical circuit schematics in introductory physics education. It is suitable for introducing students to the schematic symbols and for step-by-step explanation of the circuit semantics regarding the process of abstraction from the electrical circuit to the simplified circuit schematic in primary school or early secondary school physics education. A major pending development is the detection and visualization of parallel circuits. The aim is to enable the toolkit to distinguish serial from parallel circuits and to adapt the display of the circuit schematics accordingly. The toolkit could then be used in early secondary physics education to support the differentiation between serial and parallel circuits. In higher physics education, the use of the toolkit shifts from a teaching-function to an assistive function. It could be used to keep track of complex connections between components.

Summary and Outlook

Overall, the use of didactically substantiated AR-technology in physics education holds potential to facilitate the acquisition of (representational) competencies by connecting objects of the real world with additional virtual information in real-time. The presented AR-toolkit for real-time visualization of electrical circuit schematics represents a first-stage prototype of such a use case. However, further technical optimization is required to enable its use in everyday scholar education and training. Therefore, the following technical improvements are planned or are being carried out: the underlying software will be optimized to handle a larger number of active components at a time. This is necessary as regarding the current version, the reaction time of the display of AR-schematics and symbols increases significantly with the number of active components. For the practical use in everyday educational situations, a reduction of the box size and an assimilation to the appearance of common electrical tools in education should be taken into consideration.

ACKNOWLEGMENTS

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EXPERIMENTAL CASE STUDY ABOUT USABILITY AND EFFECTS OF A DIGITAL LEARNING ENVIRONMENT

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In recent years, digitization has become increasingly prevalent in the classroom. In chemistry, there are a wide variety of opportunities for using digital media and materials in the classroom; this includes digital learning environments. These must be developed with care and on the basis of curricular guidelines and be tested in practice. Topics that are more suitable for digital media seem to be abstract, less descriptive ones, where a multimedia approach is used to support students in the learning process. In the context of this work, an introductory digital unit on the differentiated atomic model was developed. It is publicly available on the University of Oldenburg website. The unit was used and evaluated in an explorative quasi-experimental study in chemistry classes in two ninth grade classes of a secondary school in Lower Saxony. To assess the quality of the digital learning environment, perceived usability and opinions regarding the instruction were measured quantitatively. There were significant differences between male and female students.

Keywords: Secondary School, Computer Based Learning, Distance Learning

INTRODUCTION

In recent decades, technological progress has led to major changes in the social relevance of media, particularly digital media. It is no longer possible to imagine most professions without it, much less everyday life. The way it is used has influenced communication, culture, and other social fields besides. This includes school life. In March 2020, distance learning through digital media became almost immediately necessary because of the COVID-19 pandemic: digital teaching became the ‘new normal’. The Standing Conference of the Ministers of Education and Cultural Affairs of the Länder in the Federal Republic of Germany (KMK) has focused on the digitization of schools, teaching, and teacher training in its guidelines and recommendations since the 1990s (Kultusministerkonferenz [KMK], 1998, 2012, 2017). It addresses the transformation of teaching and learning processes in its 2017 strategy paper, ‘Education in the Digital World’: it states that processes are to be redesigned and made more diverse. Particularly in the light of digitization, this involves a change in teaching concepts. Learners should become more independent within the learning process, with a view to further education. The role of teachers also needs to change in this process to one that accompanies learning. The strategy paper explicitly calls for the systematic use of digital learning environments based on curricular requirements; it also states that learning situations can and should be created independently of physical presence (KMK, 2017, pp. 12–14).

STATE OF RESEARCH

The KMK’s objectives can only be achieved at schools in Germany if the equipment of digital devices for teachers and pupils, the use of digital teaching and learning materials, and the technical infrastructure are realised in accordance with the strategy formulated in 2017. As such, the following section provides a brief overview of current survey results on this topic. The use and development of curriculum-based digital learning environments also needs to draw on already established research findings and principles of media design and use in schools, which will be discussed in the second part of this section.

Current Situation at German Schools

The second international comparative study ICILS (International Computer and Information Literacy Study) conducted in 2018 showed that although German schools have improved compared to 2013, they are still below average in many fields in comparison to international and European counterparts (Eickelmann, Gerick, Labusch, & Vennemann, 2019, p. 138). For example, only 39% of German schools had access to digital devices in most classrooms, and about half had transportable classroom sets. The availability of school intranet with applications and workstations was better: 72.6% of schools have intranets for teachers and students. However, only about a quarter of schools reported providing Wi-Fi access for teachers and students, and only 30.1% of teachers are satisfied with access to digital learning materials in their school (Eickelmann et al., 2019, pp. 151–161). The proportion of teachers who use digital media in the classroom every day has more than doubled in comparison to 2013, but it is still significantly lower in Germany (23.2%) than the international average (47.9%) and the EU comparison group (47.6%). The same applies to non-daily but at least once-weekly usage (Drossel, Eickelmann, Schaumburg, & Labusch, 2019, pp. 215–216). Concerning computer and information-related competencies, the study indicates that female students have a significantly higher level of competence than male students (Gerick, Massek, Eickelmann, & Labusch, 2019, p. 279). The use of digital media by male and female students, on the other hand, takes place with different emphases. For example, males use digital media at school significantly more often for school-related purposes than females. The latter, on the other hand, do so outside of school (Gerick et al., 2019, p. 296).

Several studies conducted during the COVID-19 pandemic in early and late 2020 and a study from early 2021 have shown that German schools were largely not well prepared for distance and digital learning (Forsa Gesellschaft für Sozialforschung und statistische Analysen mbH [forsa], 2020a, 2020b; Gewerkschaft Erziehung und Wissenschaft [GEW], 2021). The forsa study was conducted with 1,031 teachers in April 2020, in the first period of school closures. About a quarter of teachers (28%) cited the lack of digital equipment for students as the biggest challenge in distance learning. One fifth (21%) cited the creation or provision of appropriate digital learning content (forsa, 2020a, p. 3). Only 45% used a digital learning or work platform for communication (forsa, 2020a, p. 9), whereas 41% of all teachers also used these platforms to communicate tasks (forsa, 2020a, p. 15). It is particularly striking that only 3% of the teachers used digital learning platforms or learning software as an assignment or teaching format (forsa, 2020a, p. 17). The GEW study from early 2021 describes that the use of digital media is now part of everyday practice at most German schools (90%). As a result, the demands on teachers have increased due to digitization. Additional workload arose primarily from distance and hybrid teaching as well as from adapting and transferring analogue to digital materials. Most teaching materials are shared through school networks or cloud services. Digital textbooks are hardly used at all. (GEW, 2021).

From the objectives of the KMK, the recent study results, and due to the COVID-19 pandemic, the need for the development of practical digital learning materials or learning environments can be observed. Therefore, the following section will briefly describe some relevant aspects and possibilities of learning with digital media.

Learning with Digital Media

The review of study results shows that the effects of digital media and digital learning cannot be clearly determined. This is mainly due to the fact that studies in this field always look at specific media, content, and methods in a wide variety of situations, and that these conditions naturally have an influence on the effects measured. The Visible Learning research program, started by John Hattie with a summary of about 800 meta-analyses, identifies factors and classifies them according to their effect on learning performance. According to this, the effect sizes of the influence of digital or new media in schools are between small and medium (Hattie, 2009, p. 221). It is uncontroversial that computer usage in school is more effective when it is implemented as a supplement or support and not as a substitute for classical instruction (Hattie, 2009, p. 222). The advantage of the didactic integration of digital media is also acknowledged by several other authors (e.g., Bayraktar, 2001; Tamim, Bernard, Borokhovski, Abrami, & Schmid, 2011). The positive effects of digital media can be enhanced when students learn independently and are self-controlled, when they work and learn cooperatively, and when they have the opportunity to receive assistance from the teacher or classmates (Hattie, 2009, pp. 225–226; Hillmayr, Ziernwald, Reinhold, Hofer, & Reiss, 2020). If gender-specific differences are considered, Whitley's meta-analysis of computer-related attitudes and behaviour found statistically significant but small differences (Whitley, 1997). According to Cooper (2006), females are disadvantaged compared to males when it comes to learning with digital media, regardless of age or background; this is referred to as 'the digital divide'. Hattie (2009, p. 222) reports lower effect sizes for female students than for male students with regard to the impact of computer-based teaching.

Digital media offers a wide range of possible applications, especially in science lessons. The first simple digital learning environments appeared as early as the 1980s in the form of software with question-answer schemes for knowledge retrieval. These have evolved enormously in recent decades with the emergence of graphical user interfaces and HTML-based development (Eilks, Flintjer, Krilla, Möllencamp, & Wagner, 2004). These digital learning environments or even special learning programs have the disadvantage that they are tailored to specific target groups with specific prerequisites and cannot usually be used by teachers without further adjustment, since the teaching process depends on the students' level of development and prior knowledge. They must, therefore, be developed individually and be as broadly usable as possible to fulfil their potential in chemistry lessons. Nowadays, Open Educational Resources enable the provision, use, modification, and sharing of digital learning materials for free. Nevertheless, programs such as PowerPoint and PREZI allow teachers to develop their own simple learning environments on their own, without great technical skills (e.g., Banerji, 2017; Wlotzka, 2020).

Digital learning is not unequivocally superior to traditional teaching, but the use of digital media can still be seen as positive overall, especially in the context of the increasing digitization of our society. Female and male students differ in their use of digital media for school, with males apparently benefiting more from digitally supported instruction. Nevertheless, the wide range of possible applications offers teachers and students opportunities to acquire further competencies in different learning situations. Especially in chemistry lessons, there are many potential fields of application, which have increased in recent years due to new technologies and simpler application opportunities.

THE DIGITAL LEARNING ENVIRONMENT

The aim of our project was the development of a digital learning environment (DLE) for the introduction of Bohr's atomic model. This topic is an extremely crucial part of the chemistry curriculum in all schools. The structure of matter is one of the recurring topics in chemistry and science classes at German schools and it is taught in a spiral curriculum. The topic is a major theme in chemistry, so is a relevant aspect of science literacy and important to further understanding chemistry and science-related content (Jong & Talanquer, 2015). The contents of the DLE were chosen in accordance with the chemistry curriculum in Lower Saxony, Germany, where the topic is taught in the ninth and tenth grades as the introduction of the differentiated atomic model (Achtermann, Hildebrandt, Rebentisch, & Witte-Ebel, 2015). The DLE was developed in discursive exchange with teachers and educational researchers. Based on Dalton's atomic model, students are led to the necessity to change the model they know by the existence of charged particles, namely electrons, through the examination of electrostatic phenomena. They are already familiar with them from physics classes, but the phenomena are explicitly related to the explanatory power of the atomic model at this point. Rutherford's scattering experiment is then reviewed through a digression about radioactive radiation types, thus introducing the nuclear-shell model. The structure of the nuclei of protons and neutrons, and the existence of isotopes, form the next building blocks of the DLE before the structure of the electron shell in energy levels is worked out based on emission spectra or the ionization energies. Lastly, students work out the structure of the periodic table of elements, in which they can link and apply the knowledge they have acquired. As such, the DLE follows a classical progression for the introduction of the differentiated atomic model, which has already been part of several studies (e.g., Eilks, 2005, 2013).

The DLE includes texts, graphics, animations, videos, and tasks so that students can also work on the learning unit independently. It has been implemented on the website of the Chemistry Education Research Group of the University of Oldenburg and the content is freely usable through the Creative Commons license Attribution-NonCommercial 4.0 International (CC BY-NC 4.0).

In order to evaluate the DLE and its implementation in the lessons, we focus on the following research questions:

1. How do students rate the perceived usability of the developed DLE?
2. How do students rate the integration of the DLE in the lessons?
3. What differences regarding gender exist for the two factors under consideration?
4. Is there a correlation between the two factors under consideration?

METHOD AND SAMPLE

The developed DLE was used in an explorative quasi-experimental field study in two different ninth grade classes of a Lower Saxony high school and, due to the COVID-19 pandemic, in two different teaching scenarios. In the autumn of 2020, the DLE was implemented in classroom teaching where the students worked with tablets in groups of two. In the spring of 2021, the students had to use the DLE in distance learning. Each scenario was taught by the same teacher. To answer the research questions presented, the students were asked to rate the perceived usability of the DLE with the system usability scale developed by Brooke (1996) in a post-questionnaire. The scale has been well-tested in different scenarios and provides a suitable possibility to measure the perceived usability of a system. The integration of the DLE into the lessons, which is, as pointed out, a factor for the efficacy of digital media use, has been measured with the 11-item five-point Likert scale questionnaire ‘Opinion on learning’, developed by Schindler (2020).

Twenty-eight students (15 male and 13 female) participated in the classroom teaching scenario. In the distance learning scenario, the sample consisted of 26 students (11 male, 14 female, one not specified).

RESULTS

In order to assess the usability of the website of the DLE, the System Usability Scale (SUS) was used in the post-test questionnaire. From the ratings of the 10 items, the SUS score was calculated for each student and used for the following results. Table 1 gives the descriptive statistics segregated for the two teaching scenarios, and two possible interpretations: a grade according to Lewis (2018) and the adjective rating by Bangor, Kortum, and Miller (2009).

Table 12. Descriptive statistics and interpretations of the SUS score for the two teaching scenarios.

	N	Mean Score	SD	Grade	Adjective rating
Classroom teaching	27	71.76	19.00	C+	Good
Distance learning	23	68.04	21.81	C	Fair

In order to compare the perceived usability in both scenarios, a Mann-Whitney U test in SPSS was used. The results showed no significant difference ($U = 281.500$, $Z = -.566$, $p = .572$). However, when comparing the scores for the two teaching scenarios by gender, a high significant difference with a strong effect can be found for the male students ($U = 25.000$, $Z = -2{,}543$, $p = .010$, $r = .52$). They have a significantly higher score in classroom teaching (mean = 75.50) than in distance learning (mean = 56.67), and therefore have a higher perceived usability in this scenario. Table 2 summarizes the results of this test. No such effect can be found for the female students ($U = 53.500$, $Z = -1.340$, $p = .186$). A significant difference with a strong effect can also be found when comparing the scores of female and male students. The results are shown in Table 3. In distance learning, the female students rated the perceived usability significantly higher (mean = 78.27) than the male students (mean = 56.67) ($U = 21.500$, $Z = -2{,}483$, $p = .011$, $r = .53$).

Table 13. Results of the Mann-Whitney U test for comparison of classroom teaching and distance learning usability scores by gender.

	Middle rank		U	Z	p	r
Female	Classroom teaching	10.96	53.500	-1.340	.186	
	Distance learning	14.88				
Male	**Classroom teaching**	**15.33**	**25.000**	**-2.543**	**.010**	**.52**
	Distance learning	7.78				

Table 14. Results of the Mann-Whitney U test for comparison of female and male students' usability scores by teaching scenario.

	Middle rank		U	Z	p	r
Classroom teaching	Female	12.21	68.500	-1.052	.300	
	Male	15.43				
Distance learning	**Female**	**14.35**	**21.500**	**-2.483**	**.011**	**.53**
	Male	7.39				

The scale 'Opinion on learning' has been used to give an insight into the integration of the DLE into the lessons. This can be interpreted as a factor for the efficacy of the implementation. In Table 4, the descriptive statistics segregated for classroom teaching and distance learning are shown. The mean values of the scale are 3.18 for the classroom teaching scenario and, with 3.27, relatively higher for the distance learning scenario. These values present an overall positive opinion on learning with the DLE.

Table 15. Descriptive statistics for the opinion on learning for the two teaching scenarios.

	N	Mean	SD
Classroom teaching	27	3.18	.92
Distance learning	24	3.27	.66

As aforementioned for the usability scores, a Mann-Whitney U test was conducted to compare classroom teaching and distance learning. No significant difference for the opinion on learning could be found (U = 297.500, Z = -.500, p = .617). The same applies when comparing the two teaching scenarios by gender. The results are shown in Table 5. Nonetheless, a significant difference with a medium effect can be found when comparing female and male students in the two teaching scenarios (U = 27.000, Z = -2,272, p = .023, r = .47). In distance learning, the female students (mean = 3.59) have significantly better opinions about learning with the DLE than male students (mean = 2.91). The results of the Mann-Whitney U test are shown in Table 6.

Table 16. Results of the Mann-Whitney U test for comparison of classroom teaching and distance learning opinion by gender.

	Middle rank		U	Z	p
Female	Classroom teaching	10.92	53.000	-1.596	.118
	Distance learning	15.71			
Male	Classroom teaching	13.63	50.500	-1.015	.318
	Distance learning	10.61			

Table 17. Results of the Mann-Whitney U test for comparison of female and male students' opinion by teaching scenario.

	Middle rank		U	Z	p	r
Classroom teaching	Female	12.29	69.500	-1.002	.323	
	Male	15.37				
Distance learning	**Female**	**14.57**	**27.000**	**-2.272**	**.023**	**.47**
	Male	8.00				

Finally, to investigate whether there is a correlation between the perceived system usability and the opinion on learning with the DLE, Spearman's rank correlation coefficient has been calculated regarding the gender for both teaching scenarios. As shown in Table 7, the usability correlates significantly with the opinions on learning in both teaching scenarios for female students, but not for male students.

Table 18. Results of Spearman's rank correlation between usability score and opinion on learning for the two teaching scenarios regarding gender.

		r_s	p
Classroom teaching	**Female**	**.901****	**< .001**
	Male	.446	.095
Distance learning	**Female**	**.724****	**.005**
	Male	.289	.451

DISCUSSION AND CONCLUSION

The results of this study show that the students evaluate the developed DLE and its usability appropriately and that the opinion on learning with it is overall positive. However, there are clear differences in the ratings between male and female students. Accordingly, the quantitative data collected indicate that the female students following distance learning were significantly more comfortable with the DLE than the male students. The latter seem to accept the special teaching-learning situation less well than the female students in both distance learning and classroom teaching. Similar results regarding gender differences can be found in other study contexts on the use of digital media in higher education (e.g., Dousay & Trujillo, 2019; Niemeyer & Zewail-Foote, 2018; Pölloth, Schwarzer, & Zipse, 2020). These studies found similar indications of a reverse digital divide in different scenarios. A qualitative research approach would be worthwhile to gain insight into the causes of this gender discrepancy.

It is crucial for the education sector to examine the consequences of digital teaching and learning for students more closely in order to be able to take appropriate steps to prevent disadvantages. After all, distance learning may become a legitimate alternative or a supplement to traditional classroom teaching in the future.

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DEVELOPMENT OF INTERACTIVE LEARNING MEDIA FOR PRE-SERVICE SCIENCE TEACHERS IN HIGHER EDUCATION

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The success of the usage of digital technology in higher education is based on learning concepts, which are built on modern educational theories and didactical concepts. In addition, in order to be effective, these learning concepts need new and suitable learning media based on digital technology. Therefore, interactive digital learning media, so-called LearningBits, were developed. The LearningBits are used for reflection, sensitisation, repetition, practice, and content consolidation. They are learner-centred, interactive, adaptive, and oriented towards game-based learning. Using the Participatory Action Research approach for university teaching, the LearningBits are designed, implemented, and evaluated in the context of pre-service science teacher education. In the present study, a mixed-methods design is used to assess the potential for support of LearningBits in pre-service teachers' learning and learning activities. 149 pre-service science teachers participated in the study. Overall, the results show that the LearningBits support pre-service teachers' learning in higher education. Based on the results, university teaching with interactive digital media can be promising.

Keywords: ICT Enhanced Teaching and Learning, Higher Education, Technology in Education and Training

THEORETICAL BACKGROUND

As digitisation continues in the world we live and work in, politicians, parents, learners, teachers, and researchers see great potential and demand learning with digital media in higher education. However, for the further development of higher education with digital media, new teaching concepts are needed. There is a wide range of software, apps, and tools, but few didactically proven concepts (Otterborn, Schönborm, & Hultén, 2018) for science education (Bastian & Riplinger, 2016). One of the most used and evaluated concepts to reach the goal of digital learning in higher education is the blended learning approach focusing on the flipped classroom.

However, for such teaching concepts to succeed, didactically appropriate digital learning media are needed based on pedagogical theories and concepts. They must fit with the didactic concept, i.e., the learning objectives and methods (Herzig, 2014), consider the learning prerequisites of the students, and support them in their self-responsible learning process (Kerres, 2013; Otterborn et al., 2018). According to Kerres (1998) and Bremer (2004), the following tasks can be distinguished for media in university teaching in the context of a course: Knowledge (re)presentation, knowledge transfer, knowledge application, knowledge construction, and knowledge communication. Herzig (2017) describes the use of digital learning media in teaching as a source of information, as a learning aid, as a tool for solving tasks, as a subject of analysis, as a planning tool, for exchange, for storing information, and for the students' presentation of results and information.

The development of digital learning media is thus relevant for the success of the further digital development of tertiary education. Therefore, it is also supported by the European Commission

(European Commission, 2020) in its Digital Education Action Plan 2021-2027. Furthermore, interactive digital learning media is assigned great importance, as it promises individualised, motivating, and multimedia learning (Niegemann & Heidig, 2019). A medium can achieve individualised learning if it enables the selection and presentation of content that optimally fits the learner. Therefore, interactive digital learning media promise to support individual learning processes (Petko & Reusser, 2005; Sosa, Berger, Saw, & Mary, 2011). The motivating character of interactivity is explained by the inclusion of the learner in the learning process (Haack, 2002; Niegemann, 2019). This is the case since content presentation in interactive scenarios is an effective way for learners to become active recipients (Reinmann, 2011). Successful interactivity can create curiosity (Schelhowe, 2007), has positive effects on learning success in small groups (Nussbaum, Alcoholado, & Büchi, 2015) and blended learning scenarios (Castaño-Muñoz, Duart, & Sancho-Vinuesa, 2014). In addition to improving knowledge retention through repetitive elements, deeper content processing can be promoted in interactions where the learner is productively engaged (Haack, 2002). Learning knowledge can apply to new situations through multimedia content such as interactive visualisations or simulations (Haack, 2002; Plass & Schwartz, 2014). Studies show that a high degree of interactivity in digital learning media could lead to higher performance outcomes (Proske, Narciss, & Körndle, 2007; Sosa et al., 2011).

LEARNINGBITS

To fulfil this demand and develop authors' teaching, so-called LearningBits were designed, implemented, and evaluated in various learning activities in the science teacher university education program. LearningBits are newly designed digital learning media created by the authors for a variety of pre-service science teacher education courses. The LearningBits are interactive, adaptive, and oriented towards game-based learning and story-based learning (see figure 1). The learner-centred media can be used in multiple learning situations, e.g., before and after the lecture, synchronously and asynchronously, at home and the university, and are independent of a single course. Furthermore, the LearningBits are browser-based, making them easy to use, share, and integrate into courses. Integrated into a learning management system, lecturers can see how far individual students are with the respective LearningBit and can be responded directly to difficulties. LearningBits have already been created to reflect on pre-service science teachers' ideas about good teaching, raise awareness of future students' misconceptions, repeating and practising content, e.g., on the basics of constructivism or levels of inquiry-based learning, and cooperative learning (overview (in German): www.visio6.de/LearningBits).

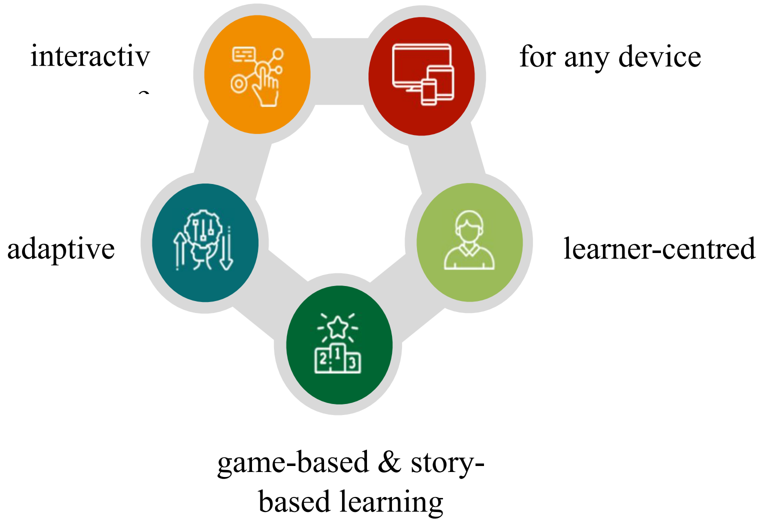

Figure 1. Characteristics of LearningBits.

The LearningBits were developed according to the model of Participatory Action Research for higher education (Tolsdorf & Markic, 2018). In this cooperative development, chemistry education lecturers from different universities, students, a chemistry teacher, and a German education lecturer worked together in an interdisciplinary team. The LearningBits were thus developed and tested step by step in a communicative, cyclical process.

RESEARCH QUESTION

The following research questions (RQ) guided the evaluation of the pre-service science teachers' view of the LearningBits:

RQ1 How do pre-service science teachers evaluate the learning with the LearningBits?

RQ2 To what extent do LearningBits support pre-service science teachers in learning activities?

RQ3 How do pre-service science teachers rate the usability of the LearningBits?

METHOD AND SAMPLE

To answer the named research questions, a mixed-methods design was chosen. Regarding RQ1, research data were gathered by a self-developed quantitative questionnaire in 7 items (see Figure 2, Likert 1-5). Additionally, pre-service science teachers in this study were asked to explain their learning experience and benefits of learning with LearningBits within an open questions tool.

Based on the categorisation of learning activities (see table 1) by Aebli (2011) and Reusser (2014), a quantitative questionnaire with 10 items (Likert 1-5) was developed and used to answer RQ2.

Finally, with the quantitative *System Usability Scale* (Brooke, 2016; translated, Likert 1-5), RQ3 is addressed with 10 items. The term *usability* briefly describes the user-friendliness and fit of software for the users and the respective context.

Table 1. Learning activities by Aebli (2011) and Reusser (2014).

learning activities	description
make contact	experience problems and get involved; confrontation with content
build up	link new knowledge to prior knowledge, understand, formulate insights, restructure
flexibilise	deepen, work through, recognise connections, change perspective, gain insights
consolidate	practice, consolidate, repeat
apply	transfer, application, recognise strategies, reflect

149 pre-service science teachers participated in the study. They are on average 22.9 years old and were in the third or fourth semester of their bachelor studies. In addition, 83.4 % of the participants are female, typical for the authors' university. The survey period was in the winter semester 2019/20 (WS; $N = 74$) and summer semester 2020 (SS; $N = 75$). The two groups differ from the digitally conducted teaching in the summer semester 2020 caused by the COVID-19 pandemic.

RESULTS

RQ1: How do pre-service science teachers evaluate the learning with the LearningBits?

In the qualitative study, pre-service science teachers expressed that LearningBits facilitate the introduction to lessons through problematising and sensitising content. The LearningBits enable independent repetition and reflection, as well as the illustration and deepening of content. According to the participants, the LearningBits present the contact well and are suitable for individual learning. The usage of different elements (e.g., individual tasks) supports this. The participants describe LearningBits as entertaining, playful, easy to use, fun, and having a good design. Figure 2 shows the quantitative study results, which confirm the qualitative statements of the pre-service science teachers. Both groups rate the LearningBits very similarly in the qualitative part of the study. However, the quantitative data shows that the pre-service teachers in the summer semester 2020 rate the LearningBits higher regarding their learning ($M_{WS} = 3.67$; $M_{SS} = 4.06$; $\Delta M = 0.39$; $p < 0.001$; $d = 0.61$).

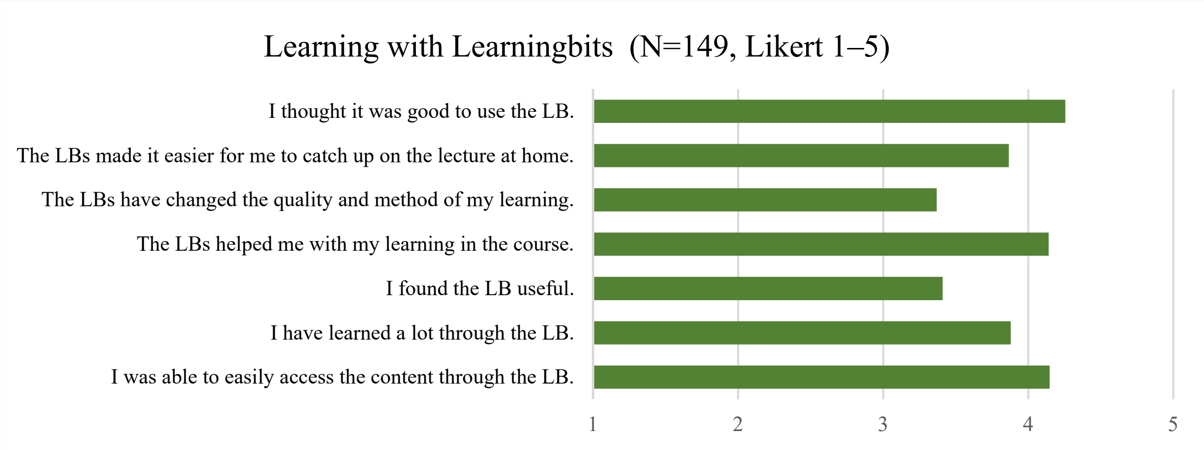

Figure 2. Evaluation of learning with LearningBits.

RQ2: To what extent do the LearningBits support pre-service science teachers in learning activities?

The quantitative data collected (see Figure 3) show that with approval ratings well above 3.70, LearningBits helped pre-service science teachers in all five learning activities (see Table 1). The highest ratings are for the learning activities 'build up'(linking knowledge, understanding, structuring; $M = 4.15$) and 'consolidate' (repeating, practising; $M = 3.94$). Pre-service science teachers participating in the lecture during the summer semester 2020 rate the LearningBits as more supportive as the participants of the winter semester 2019/20 ($M_{WS} = 3.71$; $M_{SS} = 4.09$; $\Delta M = 0.38$; $p < .001$; $d = 0.60$).

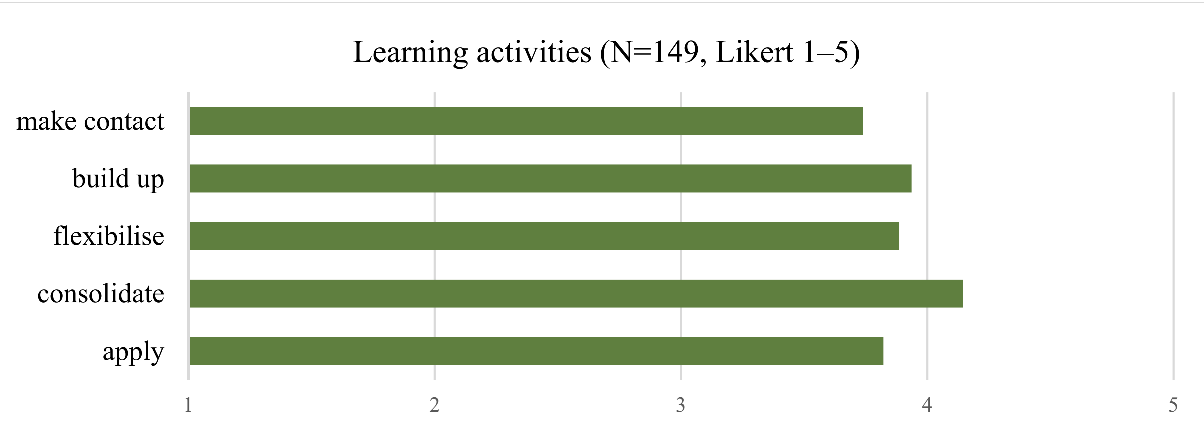

Figure 3. Evaluation of LearningBits in learning activities.

RQ3: How do pre-service science teachers rate the usability of the LearningBits?

For the *System Usability Scale* (Brooke, 2016), which has a Likert scale of 1-5, pre-service science teachers rate the LearningBits with a high value of 4.18. They, thus, evaluate the usability and ease of use as very suitable for themselves and their learning context. The pre-service science teachers in the summer semester 2020 rate the usability significantly higher than pre-service teachers of the winter semester 2019/20 ($M_{WS} = 4.01$; $M_{SS} = 4.34$; $\Delta M = 0.33$; $p < .001$; $d = 0.52$). For the pre-service teachers in the summer semester, LearningBits was more suitable and usable in their learning context.

DISCUSSION

The results show that the LearningBits support pre-service science teachers in their learning and contribute to a successful digital teaching concept in higher education. As stated by the study participants, the LearningBits can be used in all learning activities and show a high usability. Especially in the learning activity 'consolidate', i.e., practising and repeating, the usefulness, learning effectiveness, and attractiveness of the LearningBits was emphasised. Regarding the limitations, only pre-service science teachers from one university and one lecture participated in the study. The evaluation of the LearningBits as learning media is, of course, strongly dependent on the teaching concepts of the lectures.

The pre-service teachers' better evaluation of the LearningBits in the summer semester of 2020 can be explained by the pandemic-related online teaching. The courses took place synchronously online. It is to assume that those pre-service teachers were more intensively and possibly more seriously engaged in the work with LearningBits, and thus, see the values and usage due to the online learning. This could be the explanation for the higher rating. Furthermore, the contact to the lecturers was limited so that the LearningBits possibly became direct 'contact persons. Pre-service science teachers could rate the LearningBits higher since they seemed to be more relevant as a learning medium, e.g., for the exam, due to the omission of other social contacts with fellow pre-service science teachers. Overall, and this was mentioned by individual participants in indirect feedback, the entire learning concept in which the learning media were used plays a role in the evaluation. We assume that pre-service teachers honoured that the lecture used various digital and student-oriented concepts right at the beginning of the online semester. In the qualitative data of the summer semester, the varied design through activities and the creative tools were particularly praised by numerous pre-service science teachers. These aspects could be interesting for designing digital, possibly asynchronous learning opportunities for universities after the COVID-19 pandemic.

Based on the presented results, digital university teaching with interactive digital media can be promising. Therefore, further development, testing, and evaluation of interactive digital media should be implemented by university educators. Authoring software like h5p.com or learningapps.org can be easy first points of contact that can be used creating interactive learning media by lecturers. With learning management systems such as Moodle or more complex authoring tools such as eXeLearning, complex interactive learning media can be made, e.g., with learner tracking or diagnostics. In this process, university teachers should assist each other and be supported by digitisation or e-learning departments and colleagues. Templates could also be developed together with publishers in the education sector. However, it is essential to focus on individual learning and independent reflection and sensitisation, especially for pre-service teachers.

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TEACHING SUSTAINABILITY TOPICS IN VIRTUAL WORLDS. A PRELIMINARY STUDY

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Education for Sustainability may contribute to the real change of mind among students who could become action-makers towards a social transformation. Virtual worlds can help learning offering a rich learning environment to explore, collaborate, interact or to use a gamification approach. This paper presents a preliminary study using an Opensimulator platform, to experiment how virtual words can help middle school students (K6-K8 grade) to achieve a global point of view about Sustainability. The experimentation was carried out with the collaboration of a group composed of 21 teachers. They explored the educational paths, interacting with objects, reading in-world and web-resources, playing online games and running quizzes. Results show that teachers found the Sustainability Hub, created for this activity, an involving, interesting and well-organized educational tool to approach Sustainability topics.

Keywords: Computer Supported Learning Environments, Teaching Innovations, Science

INTRODUCTION

The multi-dimensional approach of Agenda 2030 Goals for Sustainable Development (SDGs) towards eradicating poverty and reaching peace is the greatest global challenge of our time (UN, 2017). In fact, SDGs give a new impetus to our collective development aspirations, covering a wide range of issues such as poverty, hunger, health, education, sustainable energy and cities, sustainable consumption and production, climate change, forests, oceans, and peace. The Target 4.7 (*By 2030, ensure that all learners acquire the knowledge and skills needed to promote sustainable development, including, among others, through education for sustainable development and sustainable lifestyles, human rights, gender equality, promotion of a culture of peace and non-violence, global citizenship and appreciation of cultural diversity and of culture's contribution to sustainable development*) gives education a key-role to promote a sustainable development and lifestyles (UN,2015; Ferreira et al., 2007). As the links between humans and nature relate to the health of our planet, education for Sustainable Development becomes necessary in all school curricula and allows pupils to enhance their knowledge, skills, and abilities to behave in a more sustainable manner (Merritt et al., 2019). Therefore, education for Sustainability may contribute to the real change in the minds of students, through well-planned didactic activities, facilitating the societal transformation process the Agenda 2030 requires. UNESCO has been promoting Education for Sustainable Development (ESD) since 1992, recommending to plan and run ESD projects in schools and Universities to help students to became sustainability change-makers (UNESCO, 2017). In this framework, ICT (Information and Communication Technologies) can accelerate and improve the approach to the SDGs through formal, non-formal and informal learning, promoting low-cost e-learning activities; allowing people to collaborate at a distance an facilitating the knowledge transmission. In fact, ESD highlights the key role of the "Basic skills and competencies needed in the 21st century" necessary to support sustainability, encompassing the ICT literacy (Dede, 2009). Virtual worlds, as ICT tools, offer a great potential as effective platforms to foster learning, allowing in the same virtual environment, a variety of activities aimed to improve technical and digital skills beside the learning of sustainability topics.

Learning Sustainability in virtual words

Virtual worlds are "shared, simulated spaced which are inhabited and shaped by their inhabitants" who are represented as avatars. These avatars mediate our experience of this space as we move, interact with objects and interact with others, with whom we construct a shared understanding of the world at that time" (Girvan, 2018). Nowadays there is a growing interest in the use of virtual reality environments because "through immersive education participants can be offered a feeling of 'being there', through a synchronous connection that allows them to communicate with a sense of presence" (Contreras-Mendieta et al., 2018). Among virtual worlds, OpenSimulator, aka Opensim, is a highly customizable open-source platform, used also for educational purposes for collaboration, simulation, gamification approaches and experimentation (Gregory et al., 2016), with demonstrated applicability also for studies in Geoscience education (Boniello et al, 2016, Paris et al, 2020).

In general, there are two non-mutually exclusive approaches to a virtual world: a) teachers let students develop a specific topic in the world from scratch using creativity and problem-solving abilities, b) teachers build a specific educational path to be explored by students in a self-pace way. In this work the latter approach was used, in conjunction with a gamification approach, including game elements like challenges and acquisition of badges (Deterding, 2011). Game elements created for this project were implemented in the Sustainability Hub, taking advantage of a special editor embedded in the viewer (http://wiki.secondlife.com/wiki/LSL_Portal) which allows to give "behaviours" to the objects. So, 3D items in the world, if properly triggered, can move, change size and colour, give interactive menus with multiple choices, start games or award students with badges or link to external web resources and activities.

METHODS

This project is part of broader activities to support schools in their Environmental and Civic Education curricula, in the framework of a PhD research at the University of Camerino.

A section dedicated to the environmental Sustainability and the United Nation Agenda 2030 has been created in a virtual world called Techland, made by the Opensimulator 3D server application (www.opensimulator.org). Techland is managed by one of the authors (Occhioni, 2017) since 2010, to engage K6-K8 degree students in STEM activities (Science, Technology, Engineering, Mathematics). This environmental section, added in 2019, is made up of a group of islands each one deals with a different aspect of Sustainability (i.e., Agenda 2030 and Sustainability goals, waste management, energy, urban sustainability, water management) (Occhioni, 2021). The Sustainability Hub Island (fig. 1.) is the "landing point" of the Techland's environmental section.

The Sustainability Hub is a sort of welcome area for teachers and 11-13 years old students, where they can first approach environmental Sustainability topics and retrace the path that led to the definition of the SDGs. Sustainability Hub is also the "hub" for reaching the other islands of the project. In each section of the island, it is possible to find engagement questions for pupils, interactive objects, multimedia presentations, links to external resources, online games, practical activities for pupils. At the end of each section, it is possible to play interactive quizzes that provide a badge to verify pupils' new competences.

Figure 1. "Sustainability Hub" island.

Sustainability Hub

In the "Sustainability Hub" island six sections can be recognized.

In the "Welcome area" (section 1) the instructions relative to each kind of learning object in the various sections are described. In this area a map of the island and the teleport panel to transfer to the other islands in the "Sustainability" section are shown. In the "Sandbox" students can experiment with building activities.

In the "Current world scenario" (section 2), students may approach topics like population growth, hunger and poverty, over-exploitation of resources, increase in greenhouse gases in the atmosphere, loss of biodiversity.

In the section "Georesources and circular economy" (section 3) the concept of resource is emphasized, highlighting how waste can also become a resource for the production of secondary materials. The role of the circular economy in production processes is introduced.

The "Sustainability Indicators" section (section 4) shows the concepts and definitions of "Water Footprint", "Carbon Footprint", "Ecological Footprint" and "Ecological Backpack" through interactive examples, practical activities, internal and external resources. In this section pupils can also calculate the various indicators related to their daily actions such as washing, drinking, eating or using the smartphone.

The "Agenda 2030" section (section 5) focuses on the most important international events and agreements leading to the 2030 Agenda in 2015. All the 17 SDGs and 169 targets are described, defining the three dimensions of Sustainability (economic, environmental and social) and the "5 P" pillars: Planet, People, Prosperity, Peace, Partnership. In this section the state of the art in the reaching every goal is highlighted.

The "Sustainable City Game" (section 6) is an interactive game similar to the "Game of the Goose". Each avatar becomes the pawn and the supporter of an SDG. Dices have 16 faces and represent 16 objectives of the "Agenda 2030". The interactive game boxes to move on represent an ideal route from a conventional city to a sustainable city. To reach this target, players must face different tasks: individual multiple choice disciplinary tests, online games, digital draws, multiplayer challenges (Beccaceci et al, 2021).

The experimentation

This research focuses on testing the effectiveness of the "Sustainability Hub" island as an engaging tool to teach Sustainability. This first step of the project is aimed to a preliminary study involving a group of 21 teachers (in different sessions), experimenting and testing the island before involving students. Table 1 summarizes some teachers' information.

Table 1. Teachers' information.

School degree	Subject	Years of teaching	Age	Gender
K6-K8 degree 85.7%	Math and science = 61.1% Technology = 22.2% Humanistic = 16.7%	< 5 = 14.3% 6÷10 = 9.5% 11÷15 = 47.6% 16÷20 = 14.3% 21÷25 = 9.5% > 25 = 4.8%	< 30 = 0.0% 30÷39 = 4.8% 40÷49 = 61.9% 50÷59 = 28.6% >59 = 4.8%	Male 26.8% Female 73.2%
K9-K12 degree 14.3%	Natural Science/Physics 100%			

Teachers logged in the world from their home, using a graphical user interface called viewer (the one proposed was Firestorm - firestormviewer.org). After an initial training (1 h) to master how to move and interact in the world, they were free to explore the educational paths for 2 hours, interacting with objects, reading internal and external resources, playing online games and running quizzes (Fig. 2).

Figure 2. Teachers during a session of experimentation.

RESULTS

At the end of the activity satisfaction questionnaires were proposed, composed both by a series of statements to rank with a Likert scale (1: strongly disagree, to 5: strongly agree) and by open-answer questions. The questions concerned the consistency of the educational path with the sustainability topics, clarity and completeness of in-world and web-resources, quality of learning scenario, and the effectiveness of practical activities. Most teachers' answers (more than 70%) are encompassed in the range of 4-5 Likert scale (Tab. 2). The open-answer questions allow the authors to collect suggestions for improving some areas of the island (such as: *extend the area reserved to georesources and circular economy with more contents about materials and green economy, improve the "road sign" of the island*).

Regarding the students' target, from a multichoice question emerge that teachers believe that the island is suitable especially for K6-K8 students (90.5%) or K9-K10 students (52,4%). The 42.8% stated that the island can be experiment by primary school students with simplification of content and only the 23.8% of the teachers think that it is suitable for K11-K12 students.

Table 2. Teachers' satisfaction questionnaire answers.

Questions	**Likert scale**		
According to Likert scale (1: strongly disagree, to 5: strongly agree).	**% 1-2**	**% 3**	**% 4-5**
The educational pathway is consistent with the sustainability topics	0.0	23.8	76.2
The multimedia presentations and info-panels are clear and explanatory	0.0	28.6	71.4
Web resources and on-line games are suitable for learning	0.0	28.6	71.4
The learning scenario is engaging	0.0	23.8	76.2
The number of practical activities is enough to foster learning	19,0	0.0	81,0
Practical activities are well-structured	0.0	42,9	57,1
Moving through the different part of the island is easy	9.5	38.1	52.4

From a technical point of view, 23.8% of the teachers experimented some difficult in the use of the graphical user interface (viewer Firestorm) and another 23.8 % had a lot of difficult with it. This issues in managing the various functions of the viewer and a certain difficulty in moving across the virtual island emerged by teachers' answers. Therefore, for the following experimentations the time allotted for teachers' training will be extended. In addition, some teachers (19%) stated that practical activities were not enough to foster learning. One hypothesis regarding this problem is that the time session was too short for them, so they didn't notice their presence or they did not have the possibility to explore them all. Anyway, we decided to increase the number of activities to be performed by students, adding new online or interactive games (fig. 3), thinking also that students are accustomed to play online games and they will possibly move much faster and more confidently than adults in the virtual worlds.

DISCUSSION AND CONCLUSION

Some points of interest were observed during the experimentation and others were evidenced thanks to the data evaluation. Based on teachers' opinion, Sustainability Hub is an educational tool well-organised and effective to approach Sustainability topics with attention to ICT.

Figure 3. Practical activities in the section "Sustainable indicators".

The didactic activities, the in-word and online educational resources are involving and consistent with the aims stressed in Goal 4.7 of Agenda 2030: "*by 2030, ensure that all learners acquire the knowledge and skills needed to promote sustainable development*" (UN, 2015). Furthermore, the use of Geosciences topics like water, carbon and ecological footprint and overexploitation of geomaterials allows students to acquire new knowledge and competences about Geosciences and Sustainability, with many interdisciplinary connections. Sustainability Hub offers also the possibility to reflect about simple but effective actions to take in everyday life at home and at school to increase sustainable awareness, to promote pupils become active change-makers and promoters of a new environmentally-friendly culture.

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EFFECTS OF USING A STUDENT RESPONSE SYSTEM IN CHEMISTRY CLASSES

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In the natural sciences, the use of student response systems in higher education has a long tradition (MacArthur & Jones, 2008) and is also becoming increasingly popular in university teaching in Germany. Many studies show that students rate the use of student response systems positively and that it has a positive effect on attention or cooperation. Due to the increasingly better technical equipment of schools with WLAN or tablets, the use of digital media has also increased in German schools in recent years (Eickelmann et al., 2019). There has not yet been widespread dissemination and use of student response systems in science, as is the case at American high schools, for example. In addition, there is a lack of studies investigating the acceptance and effects of the use of student response systems in science teaching (Hunsu et al., 2016). In the context of the intervention study carried out, the ARSnova student response system was used in 6th grade chemistry lessons at a grammar school in Lower Saxony, taking into account the "Question Cyle" developed by Dufresne et al. (1996). The study shows, besides other findings, that the chosen use of the Student Response System has a positive effect on the cooperation and concentration of the students and therefore confirms the already existing positive findings of its use in higher education.

Keywords: Student Response System, K-12, chemistry

INTRODUCTION

Student response systems, for which the names audience response (cf. Kay & Knaack, 2009; Kibler, 2015), classroom response system (cf. Fies & Marshall, 2006; Kundisch, 2013), personal response system (cf. Woelk, 2008) or electronic voting system (cf. Simpson & Oliver, 2007) are also frequently used in the literature, are feedback and voting systems that enable the participation of students in a simple way. Since the introduction of student response systems in higher education in the 1960s, the form, availability and functionality of these systems have changed considerably (Hunsu et al., 2016). Initially, these were stationary systems, firmly anchored in the rows of seats, with very complex technical equipment (Quibeldey-Cirkel, 2018). The first reliable system was used at Cristopher Newport University in 1985 under the name Classtalk I (Kay & LeSage, 2009). Students were able to answer simple multiple-choice questions via wired input devices (clickers) connected to a central computer (Kundisch, 2013). The answers were then transmitted to a computer and collected.

In the 1990s, wireless input devices were increasingly developed. These were handed out to the students at the beginning of a course and were connected to the software on the teacher's computer via radio or infrared transmission using a receiver device. The collected responses were evaluated directly and presented via a histogram using an LCD projector (Burnstein & Lederman, 2001). These hardware-based student-response systems, collectively known in the literature as clickers, have been increasingly used in US high schools, colleges, and universities since the turn of the millennium (Quibeldey-Cirkel, 2018).

In addition to hardware-based systems, software-based response systems have also become established due to the widespread use of internet technology and WLAN in lecture halls and the now widespread use of mobile, internet-enabled devices (smartphones, tablets, etc.). These can either be obtained as an app via the popular app stores from Apple or Google or can be called up as web-based browser apps directly via the internet browser (Software as a Service, SaaS). (Kundisch, 2013). Many of the software-based solutions offered are free in-house developments by universities, some of which are even offered under an open-source licence (Schwartz et. al., 2014).

Use of a student response system

The use of student response systems has increased since the 1990s, partly due to the technical advancement of the available systems and the less complex implementation through software-based systems. By 2004, more than one million clickers were already being used in classrooms in the USA (MacArthur & Jones, 2008). Student response systems can be used in a variety of ways. They are used to increase student interaction, collaboration, and attention during lessons, to promote discussion among students and to provide feedback on performance to both students and teachers through formative assessment. (Kay & LeSage, 2009; MacArthur & Jones, 2008). Through the immediate feedback of the assessment results, students have the opportunity to directly monitor their own learning progress in the sense of self-monitoring and to carry out a self-assessment (Quibeldey-Cirkel, 2018). Learning checks as part of feedback help participants to realistically assess and reflect on their own learning progress. They increase motivation, as students can actively shape and control their own learning process (Erlemann et al., 2014). In addition, obtaining feedback through the student response system can also be used to provide the teacher with useful information about possible misconceptions or difficulties in understanding and to adapt the course of the lesson accordingly.

Students can either submit their answers anonymously (Banks, 2006) or the input device is personalised by an assigned number and the answers given during the lecture are used to assess performance or check attendance (Burnstein & Lederman, 2001; Vital, 2012).

Effects of the use of a Student Response System

Many studies at universities show positive effects of this use on students' attention (cf. Russell et al., 2011; Hoekstra, 2008), cooperation (cf. Landrum, 2013) or learning performance (cf. Mayer et al., 2009).

The impact of the use of student response systems has been described in detail in several review articles (e.g., Caldwell, 2007; Fies & Marshall, 2006; Simpson & Oliver, 2007; Kay & LeSage, 2009; MacArthur, 2008). Overall, it appears that student response to the use of the student response system in lectures is often positive (Kay & LeSage, 2009; Caldwell, 2007; Fies & Marshall, 2006; Simpson & Oliver, 2007). This positive attitude towards the use of student response systems is also evident in the few existing studies conducted in schools (Kay & Knaack, 2009; Kay, 2019; Vital, 2012). Overall, the number of studies examining the use and impact of student response systems in schools is very small compared to studies conducted in higher education institutions (Liu et al., 2017). Specifically Scientific studies on the use and effects of student response systems in schools from Germany, however, are not very widespread (Hunsu et al., 2016; Chien et al., 2016).

In a study, the use of the student response system ARSnova was therefore investigated in the chemistry lessons of a 6th grade at a grammar school in Lower Saxony, Germany. The study examined, among other things, the usability of the student response system ARSnova, the students' attitudes towards the lessons with ARSnova and the effects on attention, cooperation, and concentration.

METHOD

The use of the ARSnova student response system in chemistry lessons took the form of an intervention study over a period of six double lessons with the help of the Question Cycle developed by Dufresne et al. (1996). It was conducted in four classes of a 6th grade of a grammar school in Lower Saxony. The existing class structures were not changed. Within each grade, two classes function as treatment and two classes as control group. The treatment group used ARSnova during chemistry lessons and the control group is taught conventionally. The study is designed in such a way that one teacher always teaches both, a control group, and a treatment group. A total of 114 students participated in the study, 59 students in the intervention group and 55 students in the control group.

The chosen pre/post design ensures that any effects that occur result from the intervention and are not caused by differences in the groups that already existed before the study. The System Usability Scale (SUS) was used to assess the usability of the ARSnova student response system (Brooke, 1996). For rating the ten items, a five-point Likert scale was used. To evaluate the scale, the negatively formulated items are recoded, the corresponding numerical values of the evaluation of the statements are then added and multiplied by a factor of 2.5 (Brooke, 1996). The resulting value ("System Usability Score") lies between 0 and 100.

The questionnaire for assessing attention, concentration, and cooperation consisted of 14 items and the questionnaire for assessing attitudes towards teaching with ARSnova consisted of 11 items, which were also rated with a five-point Likert scale.

RESULTS

Assessment of the usability of ARSnova

The usability of the student response system ARSnova is rated as very good by the students of the 6th grade. According to Bangor et. al (2008), products with a system usability score of 85 are excellent products, and this value is even exceeded with a score of 88.23. If the Sauro & Lewis (2012) "curved grading scale" is used for evaluation, the value of 88.21 corresponds to an A+ rank.

Table 19. Results System Usability Score.

	n	Minimum	Maximum	Mean	Standarddeviation
System Usability Score	49	27,50	100	88,2143	15,95893

Assessment of the attitude to teaching with ARSnova

The calculated mean value for the overall scale of 3.0017 shows that the 6th grade students have an overall positive attitude towards teaching with ARSnova. They enjoy using the student response system, which is reflected in the high agreement of the corresponding item. In addition, using the ARSnova student response system, the students perceive the lessons as more varied. The students are of the opinion that the use of ARSnova should also be extended to other subjects and that the use of ARSnova has had a positive effect on their learning success. The corresponding mean values of the items concerned are consistently above the mean value of the overall scale. Overall, 86.5% of the Year 6 students score a mean greater than 2 in the overall test and therefore rate the teaching with the student response system ARSnova moderately positive to positive.

Table 20. Results Assessment of attitude to teaching with ARSnova.

	n	Minimum	Maximum	Mean	Standarddeviation
Attitude to teaching with ARSnova	52	0,55	4,00	3,0017	0,87262

Table 21. Frequency distribution – attitude to teaching with ARSnova

Mean	n	Cumulated percent
0	0	0 %
≤ 1	4	7,7 %
≤ 2	7	13,5 %
≤ 3	21	40,4 %
≤ 4	52	100 %

Pretest – Assessment of attention, concentration, and cooperation

The mean ranks of the intervention group are higher than those of the control group in the subscales attention and cooperation. This means that the students in the intervention group rate their attention and cooperation during chemistry lessons slightly higher than the students in the control group. In the area of concentration, the mean rank of the control group is higher. Accordingly, the students of this group rate their concentration during chemistry lessons slightly higher than the students of the intervention group. The differences between the two groups are not significant in the subscale attention with an asymptotic significance of $p = 0.199$, in the subscale cooperation with an asymptotic significance of $p = 0.171$ and in the subscale concentration with an asymptotic significance of $p = 0.440$ and can therefore only be assumed. Both groups are presuppositional equal regarding the assessment of cooperation, concentration, and attention during chemistry lessons.

Table 22. Assessment of the attention, cooperation, concentration (pretest)

	Group	n	Middle rank	U	Z	p
Attention	Control group	55	52,95	1372,000	-1,286	0,199
	Intervention group	58	60,84			
Cooperation	Control group	53	52,10	1330,500	-1,368	0,171
	Intervention group	59	60,45			
concentration	Kontrollgruppe	54	57,84	1385,500	-0,772	0,440
	Intervention group	56	53,24			

Posttest - Assessment of attention, concentration, and cooperation

After the implementation of the intervention, the Mann-Whitney-U-Test provides a different picture. There are significant differences between the control group and the intervention group in all three subscales. In the area of attention assessment, the comparison of the mean ranks in the posttest shows that the intervention group agrees more with the items on attention than the control group. The mean rank of the control group drops from 52.95 to 47.61 compared to the pretest, while the value for the intervention group remains almost constant at 60.27 compared to the value of the pretest at 60.84. Overall, an asymptomatic comparison of the mean rank of the intervention group and the control group shows that the intervention group agrees more with the items on attention than the control group. Overall, with an asymptotic significance of $p = 0.034$, there is a significant difference between the control and intervention groups with regard to the assessment of attention during chemistry lessons.

In the subscale on the assessment of cooperation during chemistry lessons, the intervention group also achieves a significantly higher mean rank than the control group. The difference between the two groups is significant with an asymptotic significance of $p = 0.003$. The students in the intervention group thus rate their cooperation during chemistry lessons significantly higher overall than the students in the control group after the conducted lesson with ARSnova.

Table 23. Assessment of the attention, cooperation, concentration (posttest)

	Group	n	Middle rank	U	Z	p
Attention	Control group	54	47,61	1092,500	-2,119	0,034
	Intervention group	53	60,27			
Cooperation	Control group	55	45,15	943,000	-2,927	0,003
	Intervention group	51	62,51			
Concentration	Control group	55	47,56	1076,000	-2,641	0,008
	Intervention group	55	63,44			

In the subscale for assessing concentration during chemistry lessons, the mean rank of the control group decreases from 57.84 to 47.56 compared to the pretest and the mean rank of the intervention group increases from 53.24 to 63.44. The difference regarding the assessment of concentration is significant with an asymptotic significance of p = 0.003. Overall, the students in the intervention group thus rate their attention, cooperation and concentration significantly higher than the students in the control group.

If one also examines by means of Wilcoxon tests whether there are significant changes in the assessment of attention, concentration, and cooperation within the intervention group or the control group between the pretest and the posttest, significant changes in the response behaviour between the pretest and the posttest can be determined in the subscale for the assessment of concentration and cooperation in chemistry lessons.The students in the intervention group rate their concentration during chemistry lessons higher in the posttest than in the pretest. The assessment of concentration in the control group developed in exactly the opposite way.

Table 24. Results Wilcoxon Test attention, concentration, and cooperation

		ConcentrationPost - ConcentrationPre	CooperationPost – CooperationPre	AttentionPost - AttentionPre
Intervention group	Z	-2,123[a]	-0,763[a]	-0,261[a]
	p	0,034	0,445	0,794
Control group	Z	-3,710[b]	-2,314[b]	-0,229[b]
	p	<0,001	0,021	0,819

a: based on negative ranks; b: based on positive ranks

Tabel 6 shows that the control group assesses its concentration during chemistry lessons significantly worse in the posttest compared to the pretest. Within the intervention group, there is a positive change in the assessment of concentration between the response behaviour in the pretest and in the posttest.

In the area of the assessment of cooperation, there are no significant differences in the response behaviour between the pretest and the posttest in the intervention group. In the control group, however, the picture is different. The high number of negative ranks or the high mean rank of the negative ranks indicates a lower agreement with the items of the subscale for the assessment of cooperation in chemistry lessons in the posttest compared to the pretest. The calculated asymptotic significance of p = 0.021 shows that the control group assessed their cooperation significantly worse in the posttest than in the pretest.

In the area of the assessment of attention during chemistry lessons, there are no significant changes in the response behaviour between the pretest and the posttest in either the control or the intervention group.

The statistical investigations show that after the conducted lesson, the students who were taught with the student response system ARSnova estimate their attention, cooperation and concentration significantly higher than the students in the control group. The control group assesses their concentration and cooperation significantly worse after the lesson than before the lesson.

CONCLUSIONS

The results of the study show that the students of the 6th grade are able to use the selected student response system ARSnova very well and that the students evaluate the lessons positively because of the inclusion of questions and tasks via the student response system using the "Question Cycle" developed by Dufresne et al. (1996).

The very high value for the "System Usability Score" of 88.23 in the 6th grade shows that the usability of ARSnova is rated as very good by the students of the 6th grades. According to Bangor et. al (2008), products with a system usability score of 85 are excellent products, and this value is even exceeded. If the Sauro & Lewis "curved grading scale" is used for evaluation, the value of 88.23 corresponds to an A+ rank. The usability of ARSnova is thus rated as excellent by the students of the 6th grades.

These results show that the students already work well with the ARSnova student response system after a short familiarisation period and generally have few problems with the operation of the programme. These results are in line with the study conducted by Gröblinger et al. (2016) on the use of ARSnova at the University of Innsbruck.

Many studies (cf. Wit, 2003; Caldwell, 2007) on the use of student response systems at university show that students have a positive attitude towards its use. This positive attitude towards the use of the student response system ARSnova can also be observed among the students of the 6th grade. Within the framework of the study, the attitude towards teaching with ARSnova was determined by means of an eleven-item questionnaire with subsequent averaging. This predominantly positive assessment of the use of student response systems is in line with the results from studies at the university (cf. Wit, 2003; Draper & Brown, 2004) and the few existing studies at the school (cf. Kay, 2019; Kay & Knaack, 2009, Vital, 2012).

The present results show that by using the student response system ARSnova, students also rate their own cooperation, attention, and concentration significantly higher than students in the control group.

It is striking that after lessons with the student response system ARSnova, students in year 6 rate their own attention, cooperation, and concentration significantly higher than students in the control group. The regular inclusion of questions and activities in the lesson according to the "Question Cycle" developed by Dufresne et al. (1996) using ARSnova leads to a measurable increase in the assessment of their own concentration during chemistry lessons. In contrast, the students who are taught conventionally rate their own concentration worse after the lesson. This is not surprising, since the content of the lesson with its references is significantly more difficult and abstract than the lesson content discussed in the run-up to the study. This leads to a significantly poorer assessment of the students' own cooperation during the lesson unit. This is ultimately also reflected in an unfocused approach to work.

Through the ARSnova student response system and the inclusion of questions, the students are more involved in the lesson. On the one hand, through the processing of work assignments by means of digital terminals and the ARSnova programme, and on the other hand, through the work phases that follow this processing. Therefore, in the classes that worked with the ARSnova student response system, this significant deterioration in the assessment of their own participation from pretest to posttest is not measurable. This positive effect of using the Student Response System on participation is consistent with numerous studies (Kay and LeSage, 2009; Vital, 2012; Landrum, 2013). Although the use of ARSnova does not lead to a measurable significant increase in the 6th graders' assessment of their own attention during chemistry lessons compared to the conventional lessons conducted before the study, the students who worked with ARSnova during the lessons assess their attention in the past lessons significantly higher after the lesson than the students in the control group. This positive assessment of the effect of the student response system on attention has also been demonstrated in studies in the higher education context (Landrum, 2013; Russell et al., 2011; Kay and LeSage, 2009) and to a lesser extent in the school context (Kay & Knaack, 2009).

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DEVELOPING AND EVAULATING GUIDELINES FOR ANALYSING VIDEO TUTORIALS FOR THE CHMISTRY CLASSROOM

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Video tutorials have become an integral part of the life of teenagers: not only are they watched for amusement, but are also regarded as a valuable, low-threshold source of information. Although video tutorials offer various opportunities for learning and teaching chemistry, there are also limitations as far as effectiveness for learning is concerned, as correctness of content and chemical language, depth of learning and pedagogic content knowledge cannot be automatically presumed. Therefore, the preliminary study within this qualitative project aimed at developing and evaluating guidelines for analysing chemical video tutorials, as these video tutorials do not undergo superordinate quality control. The guidelines have been developed based on in-depth literature study and cover media pedagogic aspects as well as chemistry-specific content aspects and pedagogic (content) knowledge related aspects. As the preliminary study has shown that the guidelines work, the first videos have been analysed in depth with the developed category system in the first main study. In order to find out whether the scientific findings correspond to students' needs and perceptions, the analysis of the video tutorials is accompanied by a survey of students' perceptions. This survey shows that video tutorials can provide information in a way that appeals to students due to simplicity and clarity, but without further embedding, the perceived information only remains on a purely reproductive level without fostering deeper understanding.

Keywords: Video Analysis, ICT Enhanced Teaching and Learning, Secondary School

INTRODUCTION

The EU Kids Online Study (2020) showed that almost two thirds of the kids questioned use the internet regularly to do work for school. It displayed that YouTube video tutorials play a major role for 12 to 19-year-olds when it comes to acquiring knowledge. This is not only true for getting information on leisure time interests, but also for preparing and post-processing content dealt with at school, in order to prepare for tests or presentations, to revise aspects that have not been fully comprehended or to acquire deeper insights into certain topics of interest.

As video tutorials, unlike schoolbooks, do not undergo superordinate quality control, correctness of content and chemical technical language cannot be taken for granted. Therefore, the underlying qualitative research project aims at developing and evaluating guidelines for analysing chemical video tutorials in order to be able to integrate them into the chemistry classroom in a way beneficial for learning.

Before going into more detail about the potentials and limitations of video tutorials, the term video tutorial has to be briefly defined. As there is no consistent use of the terms 'video tutorial' in general and 'experimentation video' and 'explanatory video' in particular, the authors defined the term 'video tutorial' for the underlying research project as any short sequence of moving audio-visual input from the internet that has been produced to convey information by either professionals or private persons taking about 3 to10 minutes to watch.

For chemistry teaching, the term 'video tutorial' has to be further differentiated into 'experimentation' and 'explanatory video'. An 'experimentation video' focuses on doing, describing and explaining experiments (a.o. Huwer & Seibert, 2017; Cresswell et al., 2019) whereas an 'explanatory video' focuses on explaining complex conceptional topics and problems, such as chemical bonding or atomic models (a.o. Christensson & Sjöström, 2014; Wijnker et al. 2019). Within this project, only explanation videos that are not built around an experiment shall be considered.

POTENTIALS AND LIMITATIONS OF CHEMICAL VIDEO TUTORIALS

Before going into detail on the development and evaluation of the category system, the question why YouTube video tutorials should be integrated into the chemistry classroom at all has to be addressed. As low-threshold educational resources, videos provided on YouTube, which are available free of cost at any time, offer great potential for learners as well as teachers in the process of teaching science in general, and chemistry in particular. These videos communicate content through several sensory channels simultaneously by displaying pictures on screen accompanied by auditory input in order to provide information. This multimodal presentation of content in videos allows learners to exploit information in various different ways (Mayer, 2014).

Nonetheless, video tutorials as effective tools for content-based learning are not undisputed. They may convey an inadequate impression of the extent and depth of learning, as the concise presentation of content tempts learners to believe to have mastered new content easily and comprehensively, neglecting the fact that a several-minute video can only present a fragment of a wider topic (Salomon, 1984). Furthermore, chemical video tutorials tend to switch inconsistently between the levels of the Johnstone triplet, which may lead to the development of scientifically inadequate conceptions of the subject matter. (Johnstone, 2000; Harmer & Groß, 2020). At the same time simplification and attempted humour may possibly lead to inadequate chemical technical language and consequently to the development of scientific misconceptions (Nakheleh, 1992; Rees, 2018; Markic & Childs, 2016).

Despite these limitations, video tutorials bear great potential for chemistry teaching. Videos in general offer various opportunities for media-supported differentiated teaching and individualized learning in the chemistry classroom (a.o. Groß, 2017; Tomlinson, 2014). Being able to pause and repeat certain sections, video tutorials allow students to learn at their own pace. Hence, learners are forced to take responsibility for their own learning processes within a safe self-determined learning environment, which leads to decreasing concerns about potential failure (Wells, Barry & Spence, 2012).

Studies show that the effectiveness of learning with video tutorials is strongly dependent on the design of the respective video (Kulgemeyer, 2018). Therefore, it can be assumed that a good video tutorial must not only focus on content but also on aspects of pedagogic content knowledge and media pedagogic content knowledge. Based on these theoretical findings it can be assumed that the use of video tutorials as a tool for media-supported differentiated learning within the chemistry classroom is only reasonable, if these videos suffice certain quality criteria.

OVERVIEW OF THE UNDERLYING RESEARCH PROJECT

Based on these theoretical findings the underlying qualitative research project aims at gaining insights into how video tutorials can be implemented into the secondary school chemistry classroom as a tool for media-supported differentiated teaching and learning. Particular objectives of any classroom implementation have to be supporting students' content learning, fostering the acquisition of chemical technical language and enhancing media literacy including critical reflection of media content.

The project is divided into three parts. The initial preliminary study served to develop and evaluate a device for analysing chemical video tutorials based on categories deductively derived from in depth literature study. This tool also serves as coding manual for the qualitative pedagogic content analysis (Mayring, 2015) of selected chemical video tutorials in the first part of the main study that aims at answering the research question, what challenges and opportunities occur when using video tutorials in the chemistry classroom. In order to find out whether the results of the scientific analyses correlate with students' perceptions, a students' perceptions survey is carried out using a semi-structured questionnaire. This survey aims at finding out what students take away from chemical video tutorials and how they perceive them on a meta-level.

Based on the results a booklet for teachers with guiding principles on what to consider when employing video tutorials in the chemistry classroom shall be created in the long run. Additionally, in the second part of the main study, tasks supporting the acquisition of content knowledge, chemical language and media literacy shall be developed and evaluated based on the results of the video analyses.

THE LITERATE-BASED CATEGORY SYSTEM

As videos may take the role of a tutor in the process of knowledge transfer, the particular objectives of any classroom implementation have to be supporting students' content learning, fostering the acquisition of chemical technical language and enhancing media literacy including critical reflection skills of media content. Consequently, criteria for the video analysis have to explore chemical content, pedagogical realization and pedagogical content knowledge including adequate chemical language, in order to be able to gain insights into how video tutorials can contribute to students' understanding of abstract conceptual topics. Based on these considerations a three-tier category system has been developed (see Table 1), which is also used as the coding manual for the qualitative content analysis (Mayring, 2015) of selected video tutorials in the main study.

Therefore, categories have been derived deductively from in-depth study of relevant literature, resulting in the three main categories: K1 *Content*, K2 *Pedagogic content knowledge principles* and K3 *Media pedagogic principles* and respective subcategories, as illustrated in Table 1. Each category requires a separate coding cycle.

Table 25. Overview of the 3-tier literature-based category system.

K1 **Content** (a.o. Fleischer, 2017; Kniffka & Roelke, 2001; Schröter-Bauss et al., 2018; Johnstone, 2000)	1. correctness of content: fully correct, partially correct, incorrect 1.1 fully correct 1.1.1 terminology is explained systematically 1.1.1.1 new terminology is explained systematically 1.1.1.2 homonyms are explained systematically 1.1.2 meaningful transition between the levels of Johnstone triplet 1.1.3 use of similes to foster understanding 1.2 partially correct 1.2.1 inaccuracy resulting from inaccurate subject matter 1.2.2 inaccuracy resulting from inaccurate chemical technical language 1.2.2.1 intermixture of chemical technical language and everyday language 1.2.2.2 intermixture of the levels of the Johnstone triplet 1.2.2.3 use of anthropomorphisms 1.3 incorrect no further steps taken
K2 **PCK principles** (a.o. Kulgemeyer, 2018; Markic & Childs, 2016; Barke, 2006;)	1. structure & sequencing 1.1 topic of the video tutorial is stated 1.2 information is sequenced into smaller units of meaning 1.3 principle of coherence 1.3.1 synonyms are used 1.3.2 avoiding the use of pronouns 1.3.3 title fits content 2. consideration of prior knowledge 2.1 reference to students' prior knowledge 2.2 embedding students' prior knowledge using models and analogies 3. use of examples: to connect to everyday life, to raise interest, to illustrate explanations
K3 **Media pedagogic principles** (a.o. Mayer, 2014; Moreno & Mayer, 2000; Astleitner et al., 2006)	1. disobedience of multimedia principle 2. disobedience of modality principle (including redundancy and split attention) 3. disobedience of principle minimal explanations 4. explanations are not clarified using illustrations 5. direct address of target group

METHODOLOGY

In order to find out about the challenges when using video tutorials for teaching and learning conceptional topics in the chemistry classroom, a corpus of video tutorials has been analysed using qualitative content analysis according to Mayring (2015). Therefore, the deductively derived category system from the preliminary study has been employed as a coding manual and categories were inductively adapted. The sample are video tutorials explaining abstract, conceptional topics. The analysis followed the given procedure: first, the video was transcribed including transcription of spoken language and the corresponding picture. Then the semantic structures were attributed to the respective categories in three runs, one run for each category. In case the categories were adapted the material was recoded.

In order to ensure reliability and objectivity, coding was done by 3 intercoders and the results were discussed in a coding conference (Mayring, 2015) in the sense of consensual coding

(Kuckartz, 2018). As semantic validity is of increased importance when dealing with video tutorials aiming at explaining certain sets of information to learners, expert opinions have been employed to reconstruct meaning of text passages that have been attributed certain meaning in the process of coding. Therefore, pre-service teachers functioned as experts.

SELECTED RESULTS OF THE IN-DEPTH VIDEO ANALYSIS

The following section shall show selected results from the in-depth analysis of a video tutorial on metal bonding from the YouTube channel *Chemie-simpleclub*. The aim of the qualitative content analysis of this video tutorial was to discover strengths and weaknesses in the presentation of metal bonding in this particular video. Table 2 shows a representative excerpt from the video tutorial on metal bonding (Chemie-simpleclub, 2015) explaining, why metal atoms stick together. The video was analysed in regard to the research question: What challenges occur when using video tutorials for teaching and learning abstract conceptional topics (here metal bonding)?

Table 26. Excerpt from the *Chemie-simpleclub* video tutorial on metal bonding; auditory input translated by the authors.

Visual input	Auditory input
	*The valence electrons can be imagined as an electron gas cloud.*
	The bond is caused by attractive forces between positively charged metal nuclei and negatively charged electrons.
	To say it clearly in German, the metal nuclei and the free electrons, that are buzzing around, attract each other, therefore the metal sticks together.
	Due to this structure a lot of properties of metals can be explained.

The first line of Table 2 has been coded fully correct. Simpleclub uses a simile in order to help the recipients understand the concept of the freely moveable electrons here They do neither explain the term electron gas cloud in further detail though, nor the term valence electron. The concept of the bond being caused by attractive forces is also coded fully correct. The term metal nuclei has been explained earlier in the video and a short definition is also provided in white lettering on the screen, saying "Atomrumpf = Metallatom ohne Außenelektron*"* (translated: metal nuclei = metal atoms without their valence electrons). This can be regarded acceptable as this definition is an abridged version of the phrase "metal nuclei are metal atoms without their valence electrons and are therefore positively charged", which is given earlier in the video, when the illustration is verbally explained step by step but in obedience of the principle of modality (including redundancy) abridged here.

The utterance "to say it clearly in German the metal nuclei and the free electrons, that are buzzing around, attract each other, therefore the metal sticks together" was categorized partially correct as “buzzing around” is clearly not suitable chemical technical language, as the term “buzz around” is incorrect lexis borrowed from everyday language. Additionally, the visual input makes it a typical anthropomorphism as the phrases in the speech bubbles (Relax!, Stay!, Shut up! etc.) allocate feelings and attitudes and therefore human qualities to the electrons. This may potentially lead to non-scientific misconceptions about electrons in metal atoms.

The last utterance “Due to this structure a lot of properties of metals can be explained.” however is a good example of a meaningful transition between the levels of the Johnstone triplet, as it is clearly stated that the submicroscopic structure serves as an explanation for the macroscopic properties of metals.

As for the PCK-principles, this unit of meaning clearly shows good structuring of information. The analogy of a cloud is used to explain how the freely moving electrons can be imagined. Prior knowledge, however, is only partially considered as the term ‘valence electron’ is not explained in contrast to the term ‘metal nucleus’, which is not only defined verbally, but a definition is also given in an abridged version on the slide (in white lettering).

The media pedagogic principles are largely observed. Here only the concept of minimal explanations is not fully fulfilled as the speech bubbles do not serve any explanatory purpose but are merely a quite useless addition leading to the allocation of feelings and attitudes to fundamental particles and consequently giving way to the development of scientifically inadequate conceptions. Table 3 provides a summary of the analysis of the auditory input of the selected excerpt.

Table 27. Analysis of the auditory input of the selected excerpt.

Auditory input	K1 Content	K2 PCK principles	K3 Media pedagogic principles
The valence electrons can be imagined as an electron gas cloud.	1.1 fully correct 1.1.1 terminology – valence electrons are not explained – electron gas cloud not explained 1.1.3 simile – can be imagined as….	1. clear structure – sequencing of information 2. prior knowledge only partially considered 2.2 analogies – electron gas as “cloud“	1. multimedia principle fulfilled: text fits picture 2. modality principle fulfilled 3. principle of minimal explanations not fulfilled: unnecessary information (speech bubbles) *4.* explanations clarified using illustrations
The bond is caused by attractive forces between positively charged metal nuclei and negatively charged electrons.	1.1 fully correct 1.1.1 terminology – metal nuclei explained earlier		
To say it clearly in German the metal nuclei and the free electrons that are buzzing around attract each other, therefore the metal sticks together.	1.2 partially correct 1.2.2 language 1.2.2.1 – everyday language: to say it clearly in German – incorrect lexis: electrons buzz around		
Due to this structure a lot of properties of metals can be explained.	1.1 fully correct 1.1.2 Johnstone triplet – purposeful transition between the levels of the Johnstone triplet		

The excerpt from the video analysis shows that the video has strengths and weaknesses. Particularly the intermixture of everyday language and chemical technical language is striking. This intermixture is probable due to attempted simplification in order to attract the target group. Similarly, the use of anthropomorphism in the visual input probably resulted from an attempt to be entertaining. Therefore, it can be stated that most weaknesses in the video are caused by problems with chemical technical language that are consequences of miscarried attempts to appeal to the target group. Consequently, it is necessary to raise students' awareness of adequate chemical technical language and help them understand the difference between everyday language and chemical technical language, as content learning is strongly connected to the use of appropriate language.

THE STUDENTS' PERCEPTION SURVEY

In order to find out whether the results of the scientific analyses correlate with students' perceptions the following explanatory question has been investigated: How do students perceive chemical video tutorials? Therefore, a students' perceptions survey was carried out using textmapping (Green, 2015) and a semi-structured questionnaire.

The perception survey was completed by 22 students each of a lower and an upper secondary chemistry class. First, they had to textmap the video in two runs. In the first run the students were asked to take notes of specific info and the gist of the video after watching the video once without stopping or taking notes meanwhile. Then they watched the video a second time and took notes on main ideas and supporting details while watching.

Table 28. Selected results from textmapping for SI and MISD (*N* = 44)

Lower Secondary (beginners)		**Upper Secondary (advanced learners)**	
SI	**MISD**	**SI**	**MISD**
ductility (87%)	Metals are ductile. (78%)	metal nuclei (100%)	Alloys are a mixture of different metals. (91%)
alloy (83%)	Metals conduct electricity. (61%)	alloy (87%)	Metals are ductile. (78%)
conductivity (52%)	Alloys are a mixture of different metals. (57%)	ductility (74%)	Metals conduct electricity. (74%)
metal nuclei (52%)	Metals are everywhere. (57%)	screwdriver (65%)	Metals shine because of reflection. (74%)
screwdriver (9%)	Metals shine. (43%)	conductivity (52%)	Atomic nuclei are positively charged. (65%)

Table 4 provides an overview of the most commonly perceived specific information (SI) and main ideas (MISD) contrasting beginners and advanced learners. The chart shows that the students are able to reproduce presented specific information as well as main ideas and supporting details. Most properties of metals, like ductility, conductivity and the formation of alloys were perceived as specific info and as main idea.

Interestingly, the screwdriver, which served merely as an entertaining detail, was more frequently perceived and mentioned by the more advanced learners, whereas the beginners hardly paid attention to this piece of information. This leads to the assumption that media pedagogic elements gain importance as learners advance in the learning process.

Afterwards the students were asked to fill in a semi-structured questionnaire on their perception, based on Thielsch & Hirschfeld's (2017) standardized WEB-CLIC questionnaire using a 7-step-Likert scale ranging from 1 to disagree to 7 to fully agree. The questionnaire was only slightly adapted as Tielsch & Hirschfeld ask for the perception of websites, so here the term website was substituted with the term video. Additionally, two sets of closed-questions on specific aspects of video design and overall impression were added. There were also several open questions on what the students liked or disliked about the video and why or why not they would use it for learning.

The results of the WEB-CLIC questionnaire, particularly the results for likeability and media design in upper secondary consolidate this assumption. Although in both cases the mode is 7, the means (likability: m_{ls}=5,0; m_{us}=4,9; media design: m_{ls}=5,2; m_{us}=4,7) are comparably low, which indicates that there must be a wide range of answers. The questionnaire shows good results for clarity, informativeness and credibility though. These results suggest that students are probably aware of the fact that a few-minute video can by no way provide extensive information on the topic, but still give sufficient information to get an overview. Additionally, this gives rise to the assumption that students' likeability is potentially more strongly connected to media design than to informativeness, particularly when students grow older and advance in their learning process.

The answers to the open questions show that besides the illustrations, the students particularly like the simplicity and comprehensibility of the video, independent from whether they are beginners or more advanced learners. They feel that the video provides a good overview of the topic. Both learner groups also agree on the weaknesses of the video. Both groups perceive the speed of delivery as well as the jokes as inadequate. Particularly the more advanced learners criticized the perfunctory coverage of the topic as well as the insufficient use of chemical technical language in favour of joking and youth language. Probably this extensive use of youth language also influenced likeability, but fostered perceived clarity in the WEB-CLIC questionnaire.

However, when looking at the results of the textmapping for gist (see Table 5) it becomes obvious that the students, independent of age and advancement, had difficulties identifying the key message of the video that goes beyond mere reproduction. Only 3 out of 44 students altogether were able to interrelate the properties of metals to the model of metal bonding.

Table 5. Results of the textmapping for gist.

Lower secondary (beginners)	**Upper secondary (advanced learners)**
GIST	**GIST**
"The video was about the properties of metals and why metals have these properties." (4eR2007S)	"It was about metal bonding and how the properties of metals can be explained from this bond." (7BA2004S)

"It was about metal bonding, their properties and their structure." (4eE2006D)	"The video was about how the bond – in this case the metal bond – influences the properties of metals." (7BJ2003B)
"It was about chemical bond metal and some facts were mentioned." (4eM2006G)	"The gist of the video was the explanation of metal bonding, its properties, like why metals are ductile." (7BL2004R)

This shows that the video on its own was able to explain the structure on the submicroscopic level and describe the properties of metals on the macroscopic level. However, it was obviously not effective in conveying the fact that the macroscopic properties of metals, like ductility, conductivity and the formation of alloys result from the structure of the metal bond on the submicroscopic level. This corresponds with Salomon's (1984) initially reported findings regarding depth of processing information from audio-visual input.

CONCLUSIONS

In conclusion, it can be said that regarding content, pedagogic content knowledge and media pedagogic aspects, the visual presentation and the auditory input are of varying quality. Mistakes and inaccuracies as far as content is concerned usually derive from inadequate chemical technical language or intermixture of everyday language and chemical technical language, which frequently derives from simplification. At the same time anthropomorphism that occur particularly in visual representations foster the development of inadequate scientific conceptions.

The perception survey shows that students perceive chemical video tutorials as a short, quick and easy way of gathering information. Although they see problems resulting from extensive use of everyday language, they like the videos nonetheless. Additionally, the students accept the presented information quite uncritically.

As far as the challenges are concerned when using video tutorials for teaching and learning conceptional topics in the chemistry classroom, one has to be aware that unsuitable chemical language leads to partially incorrect content, that unsuitable language results from facilitation (use of everyday language) and anthropomorphisms though and that unsuitable language can lead to scientifically inadequate misconceptions.

In due course videos on the other types of chemical bonds shall be analysed. Based on these analyses, research shall be done on how chemical video tutorials can be implemented in the language sensitive chemistry classroom in order to foster students' understanding of chemical content and sensitize them in dealing with video sources. Therefore, differentiating learning tasks will be developed and evaluated in real life classroom settings.

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Part 5 / Strand 5

Teaching-Learning Sequences as Innovations for Science Teaching and Learning

Editors: *Italo Testa & Nikos Papadouris*

Part 5. Teaching-Learning Sequences as Innovations for Science Teaching and Learning

Design of teaching and learning materials. Classroom implementation, refinement and evaluation of teaching sequences. Exchange and adaptation of teaching-learning sequences. Adoption and transformation of teaching materials. Factors that influence teacher ownership.

Part 5: Teaching Learning Sequences and Innovative Interventions for Teaching and Learning Science

Editors: *Italo Testa & Nikos Papadouris*

Introduction

This chapter gathers the contributions to the ESERA 2021 e-proceedings for STRAND 05. The strand focuses on Teaching Learning Sequences (TLSs), namely structured sequences of instructional activities, with well-documented suggestions for teachers and expected student learning gains. In other words, studies in this strand are prominently empirical, including small-group interventions, with emphasis on the evaluation of students' learning and affective outcomes.

ESERA Conference 2021 was held remotely due to the COVID-19 pandemic. Despite such a modality, overall, 19 oral contributions, one symposium and 7 posters were presented in this strand. Eight oral contributions and 4 posters have been included in the e-proceedings.

Amongst the eight studies presented as oral contributions, two concern physics topics, two reports on biology topics, two address teachers' adaptations of TLSs, whereas the last two concern the development of students' modelling skills.

The two contributions in the physics domain address atomic structure and heat and temperature. Kardaras and Kallery present a TLS about the Bohr Atom and spectroscopy using the Model of Educational Reconstruction as a theoretical framework. The TLS also exploits Tracker software to analyze Sun's spectrum. Results show a significant positive impact on students' learning outcomes. Monti and Daffara describe a TLS that focuses on heat and temperature. The TLS uses online sensors and thermal cameras to study temperature *vs* time graphs and heating processes. The TLS was implemented with prospective primary teachers. Results show that the prospective teachers found helpful the use of sensors and thermal cameras to introduce the targeted topics.

One of the two contributions about biology topics address biodiversity. Alitto et al., in particular, present a TLS to improve Brazilian students' knowledge of marine biodiversity. The second contribution concerns genetics. Specifically, López-Fernández and Franco-Mariscal used the Simpsons characters to address genetics topics in a TLS implemented with prospective teachers. Results suggest that the proposed TLS could facilitate the teaching of science topics, although adaptations were deemed important for classroom implementation.

The latter issue, namely the teachers' adaptations of TLSs when incorporating them into their classroom practice, is addressed by two contributions. Gieske and Bolte present the adaptation of a chemistry-based TLS in different phases (disaggregated instruction approach) to meet the conditions of a diverse student population in a multilingual, urban setting in Germany. Despite a promising, positive effect, the results of the main study do not show significant differences between the treatment and control groups. The second study by Michailidi and Stavrou specifically concentrated on teachers' adaptations of TLSs and focused on innovative topics such as nanotechnology, microplastics and milk carbohydrate. The results show that teachers carried out adaptations along three dimensions of the TLS: the activity sequence per se (adding or skipping an activity), the kind of teaching materials used, and the targeted science concepts.

The two contributions to modelling present different methods and contents. Muñoz-Campos et al. present a TLS about models of milk fermentation. The results show that students' models evolved towards a scientific view during the implementation of the TLS. Taramopoulos and Psillos explored the development of procedural knowledge and experimentation skills in high-school students after an inquiry-based TLS about AC electric circuits. The results show that the TLS was effective in helping students advance both their design and experimentation skills.

The four remaining papers concern the poster sessions of the conference. In the Carvalho and Guerra paper, a 4-hour TLS about the effects of microorganisms on human health is presented. The paper also reports the TLS development and validation by two external experts. Angele et al. developed an interdisciplinary TLS about foodstuffs and alcoholic long drinks. The authors present the design principles, example materials and how they drew on the empirical data to redesign the initial version of the TLS. The third paper, by Becker and Hopf, describes the development of a TLS about energy – field approach. The authors present the activity sequence and two cycles of design and evaluation, including examples of how the initial TLS was revised. Finally, Sutrini et al. discuss a TLS about quantum computation and information. Using the Model of Educational Reconstruction, the authors describe the activity sequence and preliminary results concerning students' engagement in the activities and conceptual understanding of the targeted concepts.

Overall, the studies presented in this chapter of the e-proceedings expand the current TLS field, drawing on a range of theoretical and methodological frameworks. All papers provide useful insights into the research field of TLS development with implications that could be relevant to a broad range of contexts.

TEACHING THE MODEL OF THE BOHR ATOM USING THE LINE SPECTRUM

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Line spectra generated by electron transitions between energy levels of the atoms are important for the understanding of contemporary physics. Teaching them with experimental activities can motivate students to learn and help them obtain a more profound and qualitative understanding of the atomic structure and its applications. In this study, we present a module for teaching the model of the Bohr atom using linear spectra of chemical elements. The design of the module was based on the model of educational reconstruction. Students' previous ideas were investigated, and textbook analysis was carried out. The students in upper secondary education were engaged in a combination of computer simulations and hands-on activities that helped them develop a more complex and structured knowledge of the subject. A ten-multiple choice questionnaire was administered before and after the implementation. The data was analyzed both qualitatively and quantitatively. The results showed that the intervention had a significant positive impact on the students' learning outcomes.

Keywords: Conceptual Understanding, Inquiry-based teaching, Models in science

INTRODUCTION

The understanding of linear spectra plays a key role in the study of atomic structure. Although teaching linear spectra is a fundamental part of teaching Physics in many schools, research on students' learning and teaching is lacking in this content area (Ivanjek et al., 2020; Savall-Alemany et al., 2016). This, especially in the Greek curriculum (since the study has been carried out in Greece), places a greater emphasis on mathematical formalism than on the knowledge of the phenomenon and leads students to memorize mathematical equations without fully understanding them. Added to the above is the fact that the textbook used in the 2nd grade of Lyceum follows a similar structure as university textbooks without modifying or adapting the topic to the student's cognitive level or pre-existing knowledge, thus adding further difficulties in comprehension. In view of all the above, our aim was to assist students in secondary education to acquire an integrated view of the model of the Bohr atom and line spectra of the atoms. In the present study, we investigate how the experimental activities used in an intervention with the above aims impact on students' learning of the model of the Bohr atom.

Theoretical background

In the 19th century, scientists discovered that each element produced its own discrete set of spectral lines. They used the spectroscope to observe these atomic spectral lines. After examining the atomic spectra of various chemical elements, they noticed that hydrogen could emit and absorb only four wavelengths in the visible spectrum.

In 1885, Balmer noted a regularity in the frequencies of the Hydrogen spectral lines, and to calculate the wavelengths of the spectral lines that specific energy transitions produce, he proposed the following formula:

$$\frac{1}{\lambda} = R\left(\frac{1}{n_x^2} - \frac{1}{n_i^2}\right)$$

where n_x and n_i are integers and R is Rydberg constant with a value of $1.0973732 \cdot 10^7 m^{-1}$.

Rydberg also noticed that the sum of the frequencies of two lines in the spectrum of hydrogen often equals the frequency of a third line (Hewitt, 2014). Although Balmer and Rydberg could not explain the cause of this phenomenon, this regularity had an enormous impact on the description of the atomic structure. It was Bohr who formulated a theory to explain the spectral lines.

In 1913, Bohr applied the quantum theory of Planck and Einstein to the nuclear atom of Rutherford and formulated its model. The basic ideas of the Bohr theory, as it applies to an atom of hydrogen, are as follows: Electron moves in circular orbits with varying radii around the proton under the influence of Coulomb's attractive force and occupy "stationary" states (of fixed energy) at various distances from the nucleus. These orbits are stable and are the ones in which the electron does not radiate. He also supported the idea that radiation is emitted by the atom when a quantum jump occurs from a higher to a lower energy state. Thus, the equation that can be used to calculate the energy and frequency of the emitted radiation is

$$\Delta E = E_i - E_f = h \cdot f$$

Where E_i is the energy of the initial state, E_f is the energy of the final state.

Bohr proposed that the emitted photon's frequency is not the classic frequency at which an electron is vibrating but, instead, is determined by the energy differences in the atom. From there, Bohr could take the next step and determine the energies of the individual orbits (Hewitt, 2014).

To describe the model of the Bohr atom, several concepts and phenomena such as circular motion, Coulomb's law, kinetic and potential energy, energy conservation, emission and absorption of light, and discrete energy levels are required. The synthesis of these concepts and phenomena assists students to gain a deeper understanding of them (Arons, 1990).

Bohr's hydrogen model was extended to other elements in which all but one electron had been removed. These atoms are called hydrogen-like atoms. If the atomic number is Z, then the nuclear charge is Ze and such one-electron atoms are singly ionized He^+ or doubly ionized lithium Li^{2+}. Then, since the energy levels of the Bohr atom are $E_n=E_1/n^2$, the energy levels of these atoms are multiplied by Z^2. Also, atoms of the alkali metals are approximately hydrogen-like.

Ionized elements such as He^+, Li^{2+} and Be^{3+}, were suspected to exist in hot stellar atmospheres where frequent atomic collisions occurred with enough energy to completely remove one or more atomic electrons. Bohr showed that several mysterious lines observed in the Sun and stars could not be due to hydrogen but were correctly predicted by his theory if attributed to singly ionized helium (Serway et al., 2004).

METHODOLOGY

Design and implementation of the module

The teaching intervention was designed taking into consideration the physics curriculum of the country (Greece) and, in particular, the concepts of physics that it includes, as well as the duration of the course. The design of the module was based on the model of educational reconstruction (Duit et al., 2012): it is iterative, with three intertwining components: (i) analysis of the content structure, (ii) empirical investigation (textbook analysis and student ideas), and (iii) construction of instruction.

In order to help students, deepen their knowledge and acquire a functional understanding of the atomic structure according to the model of the Bohr atom, we developed experimental activities for a direct and articulate experience of the line spectra. The main learning objectives of these activities are for students to understand the description of the model of the Bohr atom, to observe and measure the wavelengths of the spectral lines and determine the relationship between these wavelengths and the atomic energy levels, to be able to relate theory to starlight spectra, and to process the Sun's spectrum and observe the lines of absorption. On the one hand, Starlight can help students acquire a more profound knowledge of the topic and, on the other hand, strongly motivate their learning of the subject.

The present study was guided by the following research questions:

(1) How can we design a teaching module based on a sequence of activities that helps students understand Bohr's atomic model within the frame of linear spectra?

(2) What is the effectiveness of the designed teaching module in students' conceptual understanding of the topic related to the linear spectrum of the atoms, especially of the Hydrogen atom?

The first steps towards an educational reconstruction of Bohr's atomic model and its linear spectrum consisted of identifying key concepts and laws and reviewing students' conceptions of this topic**.**

Our intervention lasted 4 hours and was implemented to 38 students aged 17. The final implementation was preceded by a one-year pilot implementation. The instructional approach used was that of structured inquiry. The students were engaged in a combination of computer simulations and hands-on activities. They recorded and processed their observations.

In the first activity, students were introduced to Bohr's model of the atom by using software (available at https://astro.unl.edu/naap/hydrogen/hydrogen.html) and investigating the interaction of a Hydrogen atom with photons of various wavelengths. With the use of the software, the students predicted and confirmed the assumptions of the model.

In the second activity, students observed the linear spectra of several gas discharge tubes (Hydrogen, Helium, Mercury, and Neon) and measured the wavelengths of the lines that appeared in the spectrum, focusing on the Hydrogen spectra (Figure 1). Then, by applying the mathematical equations of the Bohr model, they calculated the energy of the atomic levels of Hydrogen and found the electron transitions which produce the lines of the spectrum. Having established the description of the Bohr atom, we sparked students' interest and fostered useful discussion by posing the following question: How can we calculate the Planck constant using a spectroscope and a lamp containing a heated gas of Hydrogen? The purpose of this experiment was to assist students to work using the scientific method and observe the spectrum, measure the wavelengths of the lines, calculate the energy levels, and finally calculate the Planck constant.

Figure 1. The light emitted from a lamp containing a heated gas of H_2 and its line spectrum.

In the third activity, we initially started discussion by posing the following question: how can we determine the wavelengths of the dark lines in the Sun's spectrum knowing that the Sun, among other elements, also consists of Hydrogen? Firstly, we described the formation of the stellar absorption spectra, and subsequently, students used the spectroscope to analyze the sunlight and observe the resulting spectrum (Kardaras & Kallery, 2020). Also, a camera, which was adjusted to the spectroscope's eyepiece, took a photo of the solar spectrum. We asked students to calculate the wavelengths of the dark lines of the solar spectrum due to Hydrogen in order to apply their theoretical knowledge in practice, providing them with experience from authentic situations (Figure 2).

Figure 2. The spectrum of the Sun, taken with a spectroscope, shows the expected dark lines drawn by the students and considered to be the result of the existence of hydrogen.

Students then processed the photo of the Solar Spectrum they took and specifically analyzed it with the Tracker software (see Figure 3), (available at https://physlets.org/tracker/), which is an Open-Source Physics tool built on the OSP code library (Brown, 2020). After that, they extracted the experimental data obtained from the spectrum, processing the wavelengths of the spectral lines, and confirmed that the Sun consists of Hydrogen, Sodium, and Iron (Figure 3). In particular, for the Hydrogen atom, students determined the corresponding electron transitions that produced its lines.

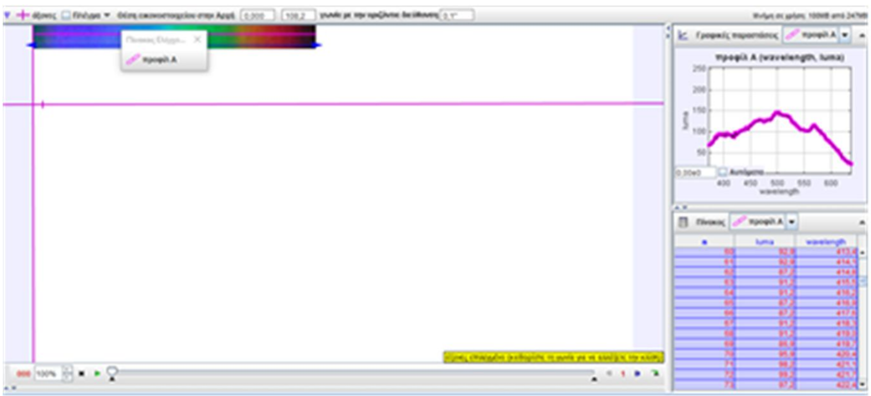

Figure 3. Screenshot of the Tracker analysis of the Sun's spectrum having defined the range of the wavelength. Many lines are observed as absorption peaks (H_a, $H_β$, Na, Fe).

In the fourth activity, students were shown images of the stars' spectra and were asked to find out what chemical elements the stars are made of. Also, students compared the positions of the spectral lines of the Solar spectrum with those of the chemical elements and matched the lines that appeared at the same wavelengths (Figure 4).

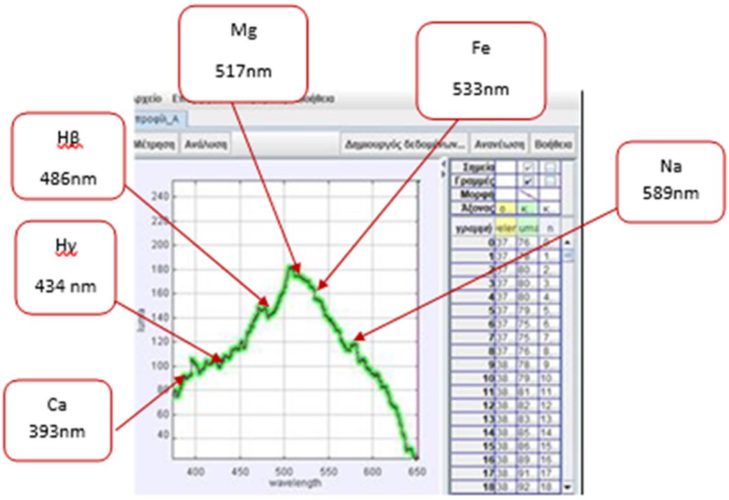

Figure 4. Identifying chemical elements in the Solar spectrum.

Assessment of students' learning outcomes

To evaluate students' learning progress, in addition to the other evaluation tools (worksheets and interviews), we used a questionnaire of ten multiple-choice items, two of which are presented in Table 1.

Table 1. Sample questions for the evaluation of students' learning outcomes.

Q1. Excited hydrogen atoms are at energy level n. If there are six lines in the linear emission spectrum, then n is a. n=3 b. n=6 c. n=5 d. n=4
Q2. An excited hydrogen atom is in energy level n=3. Which is the least energy for the excited atom to be ionized? a. 13.6 eV b. 1.51 eV c. 12.09 eV E_4 = -0.85eV ——— n=4 E_3 = -1.51eV ——— n=3 E_2 = -3.4eV ——— n=2 E_1 = -13.6eV ——— n=1
Q3. An atom with three energy levels (the ground and two others) absorbs photons of white light and its electrons make the transition to the two other levels. During its deexcitation, it emits photons: Which of the following spectra will we notice? a. An absorption spectrum with a single dark line. b. An emission spectrum with two dark lines. c. An emission spectrum with three colored lines. d. An emission spectrum with two colored lines.

Students were also asked to complete a questionnaire with open-ended questions (see Young et al., 2014; Hewitt, 2014) to test their understanding of the topic and to examine whether they had developed critical and scientific thinking about this subject area. They were asked to justify their responses in writing by explaining their reasoning in words and mathematical calculation. The levels of understanding of each response were evaluated as correct, partially correct, or incorrect. Two of the questions are presented in Table 2.

Table 2. Sample open-ended, explanation-type questions for evaluating the quality of students' argumentative discourse.

Open-ended questions
Q1. Could you explain why the Hydrogen spectrum has many lines although the Hydrogen atom consists of only one electron?
Q2. In the Sun's spectrum, with your spectroscope, you can observe the lines of the Balmer series, especially the blue-colored line. Could you explain the electron transition that produces this line? 

Implicit in the question Q1 is the idea that the observed lines are produced from the electron transition between the large number of atomic energy levels in an atom, and in Q2 is the idea that the blue line corresponds to the visible range of radiation and therefore the transition from a higher energy state to the state with quantum number 2.

DATA ANALYSIS AND RESULTS

Multiple-choice questions

We performed a dependent t-test that compared the mean difference between our samples (Field, 2013). Specifically, each correct answer was assigned 1 point. Thus, for a student who had answered correctly all the questions, the total maximum score was 10. The statistical analysis of the responses showed that the impact of the intervention on students' understanding was noteworthy, since the mean value and the standard deviation before the main implementation were M=1.55, SD=0.91, while after M=6.84, SD=1.70 respectively. The difference in performance, as evaluated using the statistical package SPSS 23, is statistically significant ($t=34.107$, $df=37$, $p<10^{-4}$). The results obtained from these three questions, before and after the intervention, are shown in Figure 5. High scores were attained after the intervention, and a noticeable improvement can be seen.

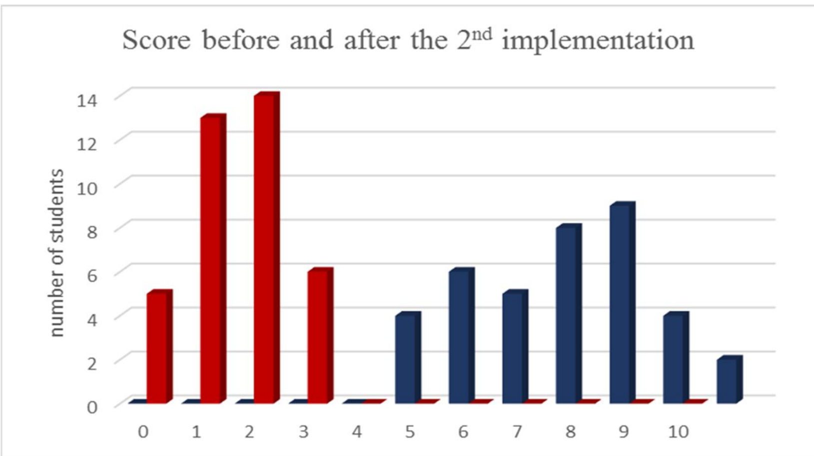

Figure 5. Distribution of students' scores for the overall test before and after the intervention.

The results of the students' responses to three questions of the multiple-choice questionnaire that we described above are presented in figure 6.

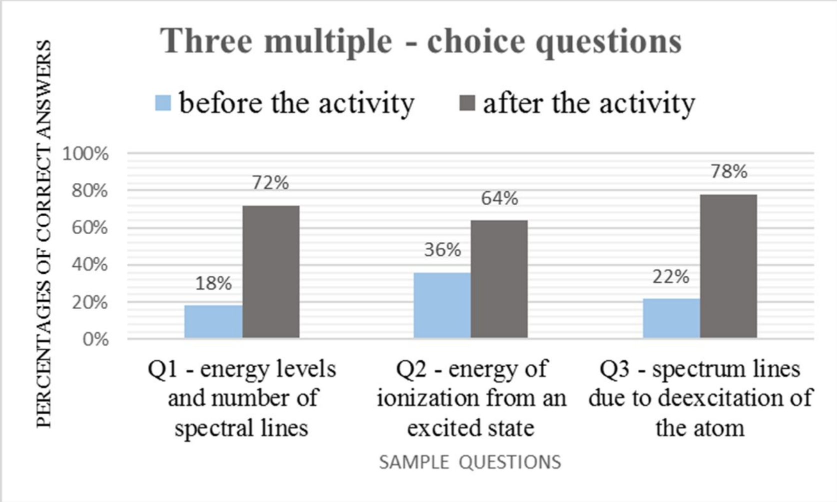

Figure 6. Percentages of students' correct answers to three questions before and after the teaching intervention.

Questionnaire with open-ended questions

The qualitative assessment of the data indicated that before the intervention, none of the students answered correctly. Only a small percentage of them were able to answer partially correct, due to their lack of knowledge, having many difficulties in answering the questions. After the intervention, students were able to answer correctly and partially correctly, achieving average scores of 24% and 34%, respectively, for question Q1 and average scores of 26% and 42%, respectively, for question Q2, as shown in Figure 7.

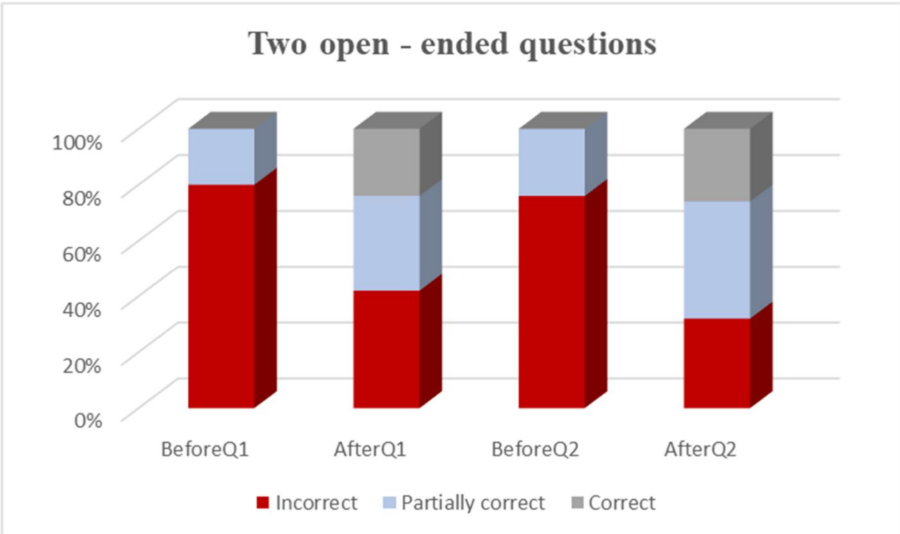

Figure 7. Quantitative assessment based on students' answers to the question Q1 before and after the implementation of the teaching module.

DISCUSSION

The present study provides an insight into how upper secondary students can be introduced to concepts and laws that describe the atomic energy levels of the model of the Bohr atom using the linear spectra of several light sources, including the linear spectra of the Sun and several chemical elements. The findings of the study create perspectives that the combination of the specific content with hands-on activities, simulations, and software and their application in the laboratory in astrophysical settings can be effective for the teaching of such complex and difficult concepts and laws in secondary education. Overall, teaching the physical quantities and equations of the model of the Bohr atom by studying line spectra, was fruitful. Nevertheless, our study continues with further applications for the improvement of the intervention as well as with investigations of the students' attitudes towards the implemented experimental procedures.

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INTRODUCING THE CONCEPT OF ENERGY THROUGH HEAT AND TEMPERATURE BY MEANS OF INFRARED THERMAL CAMERAS

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The historical development of the concept of energy can be brought back to the early studies on heat by Mayer and Joule, suggesting that a unified treatment of heat, temperature and energy can be a possible route for teaching these complex subjects in an integrated way. We projected and experimented a learning path centred on the relation of the concepts of heat and temperature with the concept of energy and proposed it to a class of prospective primary school teachers (PPTs) in the framework of the Lab module of the course in Physics Education in a combined bachelor and master degree in Primary School Education in Italy. The intervention extends a previously developed approach based on the use of online sensors so as to highlight the concept of energy through the use of thermal cameras. In this work, we investigated how much the proposed path, activities and methodologies can help PPTs in learning and teaching the concepts of heat, temperature and energy as related to the use of online sensors and/or of thermal cameras. The study has been conducted through post-assessment questions, worksheets and final interviews.

Keywords: Infrared thermal cameras, Temperature, Energy

INTRODUCTION

Research literature has widely addressed the problem of how the concept of energy should be introduced and treated at the school level and the debate is still open [Heron 2014, Takaoglu 2018]. The importance of addressing it already at the primary school level has also been recognized [Heron 2009]. On another side, the historical development of the concept of energy can be brought back to the early studies on heat by Mayer and Joule [Coelho 2011], suggesting that a unified treatment of heat, temperature and energy can be a possible route for teaching and learning these complex subjects altogether. As a matter of fact, the concepts of heat and temperature have also been deeply investigated from the point of view of Physics Education [de Berg 2008]. To this respect, the use of infrared thermal cameras has recently acquired increasing interest [Haglund 2015].

In this context, we projected and experimented a learning path that allows introducing the concept of energy starting from the concepts of heat and temperature.

The formative module was proposed to a class of 65 prospective primary school teachers (PPTs) at the second year of the combined bachelor and master degree in Primary School Education of the Italian University of Verona [Monti 2021] and integrates content reconstruction and active learning strategies inside an experiential and situated modality [Berger 2008]. The activities were proposed as part of the laboratory module (1CFU) of the Physics Education course (9CFU). No previous treatment of the subject of Heat, Temperature and Energy was done in the Physics Education course.

The intervention is characterized by the use of thermal cameras inserted in a well-run previously developed approach [Michelini 2010, Daffara 2016] that was focused on the concepts of heat and temperature and centred on the usefulness of online sensors as compared to more traditional thermometers in teaching and learning heating as a process towards thermal equilibrium.

This study investigates how much the proposed path, activities and methodologies can help PPTs in learning and teaching the concepts of temperature, heat and, starting from these, the concept of energy, as related to the use of online sensors and/or of thermal cameras.

THE LEARNING PATH

The intervention was organized into four phases including interactive lectures and laboratory activities. The first and third phases were developed as interactive experiment-based lectures following active learning and inquiry-based strategies to introduce the operational definition of temperature, the concept of energy, and the sensors utilized for measuring the temperature. In the second and fourth lab-work phases, four experiments were autonomously carried out by the PPTs divided into groups: 1) heating of different masses of water with a boiler; 2) heating by irradiation with a halogen lamp; 3) thermal interaction of different masses of water; 4) Locke experiment. Experiments were performed in the Prediction - Experiment - Comparison modality using both a thermal camera and a system of four online sensors for real-time measurement of temperature. In particular, PPTs were introduced both to the qualitative and quantitative use of the pre-calibrated infrared thermal camera allowing the visualization as well as the measurement of 2D temperature maps.

First phase: introduction of the online sensors

In the first phase, we introduced the concept of thermal equilibrium and the operational definition of temperature through the use of 1D online sensors that allow real time simultaneous measurements of temperature using a graphical computer interface [Figure 1]. The instrument, called "Termocrono", was developed at the Udine university [Michelini 2010].

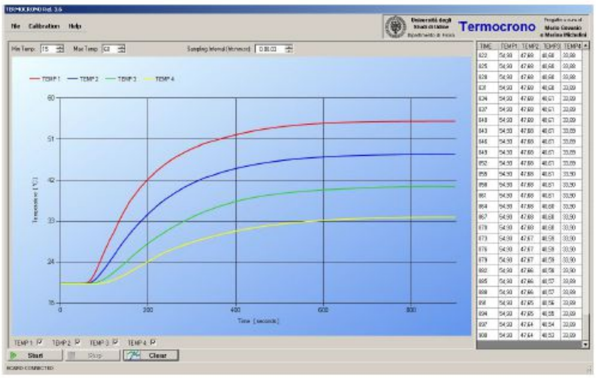

Figure 1. Graphical interface of the "Termocrono".

Second phase: use of the online sensors

In the second phase, students were conducted into the concept of heating as a process leading to "increase of temperature" by autonomously carrying out two experiments in the Prediction-Experiment- Comparison (PEC) modality using the online sensors: 1) heating of water with a boiler; 2) heating of water by irradiation with the light emitted by a halogen lamp [Figure 2].

Figure 2. Heating of water by irradiation with a halogen lamp.

Third phase: introduction of the thermal camera

In the third phase, starting from the results of the former irradiation experiment with the halogen lamp, students were interactively guided into the concept of energy as "what is capable of heating", to associating the concept of "amount of heating" with the concept of "transferred energy", and to recognizing that light carries energy.

At this point, the thermal camera was introduced as a two-dimensional remote sensor of the energy emitted by all bodies in the form of non-visible (infrared) light which is in turn related to the measurement of temperature. In particular, students experienced the possibility of "viewing" themselves in darkness conditions.

In our intervention, we utilized a FLIR C2 thermal camera [Figure 3] equipped with a bolometric sensor (80x90 array) sensitive in the long IR range 8-14 micron and calibrated in temperature. The FLIR camera acquires also a visible image (320x240 pixels) superimposed to the thermogram. An interesting option for this proposal is the possibility of visualizing in real-time on the display the thermogram, the visible, or a blending of the two images.

Figure 3. The FLIR C2 thermal camera.

Fourth phase: use of the thermal camera

In the fourth phase, students first repeated the two experiments done in the second phase using the thermal camera in place of the online sensors. Then, they carried out two other experiments, always in the PEC modality, using both the online sensors and the thermal camera: 3) thermal interaction of different masses of water, reaching thermal equilibrium and 4) the so called "Locke experiment" about thermal sensation [Michelini 2010, Daffara 2016] [Figure 4]: given three glasses of warm, hot and cold water, fingers first immersed in hot water and then in warm water feel it cold, while fingers first immersed in cold water feel warm water as hot.

Finally, students were also lead to explore with the thermal camera the increase in temperature of a current carrying wire and the process of heating a surface by friction: these experiences allow opening the way to extend the concept of heat and energy to other fields of physics such as mechanics and electrical phenomena.

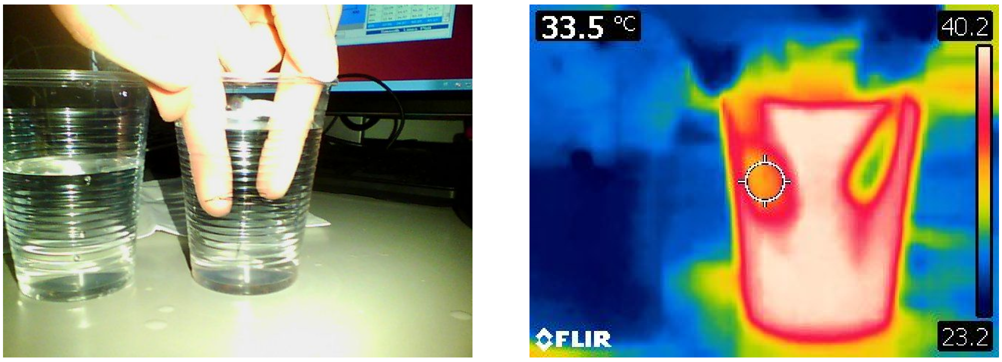

Figure 4. Locke experiment using the thermal camera.

The learning path ended with final considerations that emerged from the discussion with the students conducted in an interactive guided modality (a kind of Socratic conversation):

- measuring temperature means "finding a way of associating a number to a state of thermal equilibrium"
- heating means "causing an increase of temperature"
- heating is energy transfer
- heating can be obtained through conduction, convection and irradiation
- thermal sensation is related to the rapidity of heating or cooling
- heat is transferred energy related to heating or cooling
- temperature is a measure of an energy which is internal to bodies (internal energy)

RESEARCH METHODS

This study has been conducted through post-assessment questions, worksheets and final interviews addressing the following points.

In the post-assessment questions, PPTs were asked which ways they know for measuring temperature. In the worksheets, they were asked to plan a learning path on thermal phenomena highlighting the addressed concepts and the corresponding related activities. Final interviews were mainly focused on whether and how PPT used or would use a thermal camera in their proposed activities and, if so, related to which concepts.

Based on PPTs' answers we investigated how much the utilized learning path and methodologies can help PPTs in understanding the proposed concepts through the following research questions:

1) Do PPTs cite (in the proposed post-assessment question) thermal cameras among the possible instruments for measuring temperature?

2) Which concepts and corresponding activities do PPTs choose (in the worksheets) in constructing the proposed educational path on thermal phenomena?

3) Do (from the worksheets) or would (from the final interviews) - PPTs propose the use of thermal cameras in their activities and, if so, related to what concepts?

RESULTS

Qualitative data analysis was performed focusing: a) on the instruments (online sensors and thermal cameras) as cited in the post-assessment questions and as utilized in the activities proposed in the learning path by PPTs for their pupils; b) on the concepts addressed by PPTs as related to the instruments utilized in the activities.

The addressed concepts were grouped into three main categories that were identified from students' answers given in the worksheets as well as in the final interviews as particularly meaningful for the purposes of the present investigation: temperature/thermal equilibrium/thermal sensation; heat and energy; heating through irradiation.

Use of the online sensors

In the post-assessment questions, the "Termocrono" is cited among the possible instruments for measuring temperature by almost all the 65 students (64/65); in the planned didactic path, it is utilized by 41/64. Among these: 37/41 propose it for introducing the concept of temperature through the difference between thermal equilibrium and thermal sensation; 28/41 for addressing the concept of heating through irradiation; 26/41 propose its use for both these purposes [Figure 5].

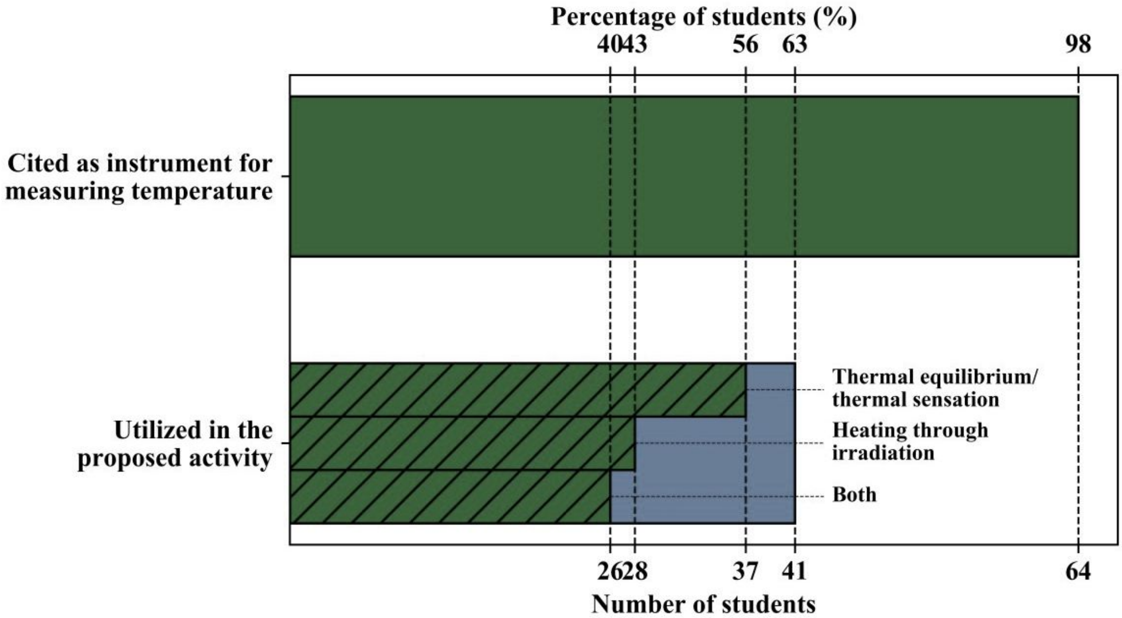

Figure 5. Use of the "Termocrono".

Use of the thermal camera

The thermal camera is less cited (42/65) than the "Termocrono" among the possible instruments for measuring temperature; in the planned didactic path, the thermal camera is utilized (or would be possibly utilized if available, as it emerged from the interviews) - always for visualization purposes- by 28/42, of which 13/28 for addressing the concept of heating through irradiation and 19/28 for introducing the concepts of heat and energy; 8/28 propose its use for both these purposes [Figure 6].

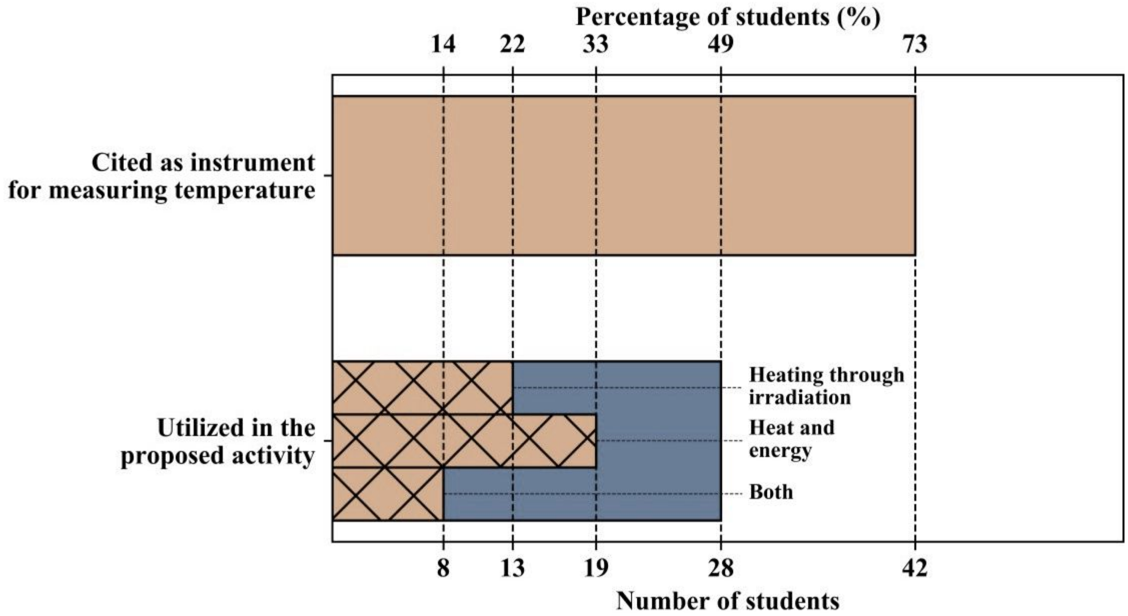

Figure 6. Use of the thermal camera.

Addressed concepts

From the point of view of the treated concepts, our analysis pointed out three most significant aspects [Figure 7].

The comparison between temperature and thermal sensation is addressed by 57/65 and is associated to the use of the "Termocrono" by 37/57. In the other cases, the use of more traditional thermometers is foreseen. The comparison between temperature and thermal sensation is never associated to the use of a thermal camera.

The process of heating through irradiation, addressed by 43/65, is associated to the use of both the "Termocrono" (28/43) and the thermal camera (13/43): in the case of the thermal camera, 6/43 actually proposed an activity while 7/43 would possibly propose it if the thermal camera would be available in the classroom, as it emerged from the interviews.

Heat and energy are considered as important concepts to be treated in an educational path by 28/65. Of these, a total of 19/28 actually proposed (only 7/28), or would possibly propose (12/28) an activity with the thermal camera if it would be available in the classroom: the remaining 9/28 proposed either an alternative visualization with sawdust or ink or even no activities at all. The concepts of heat and energy are never associated to the use of the "Termocrono".

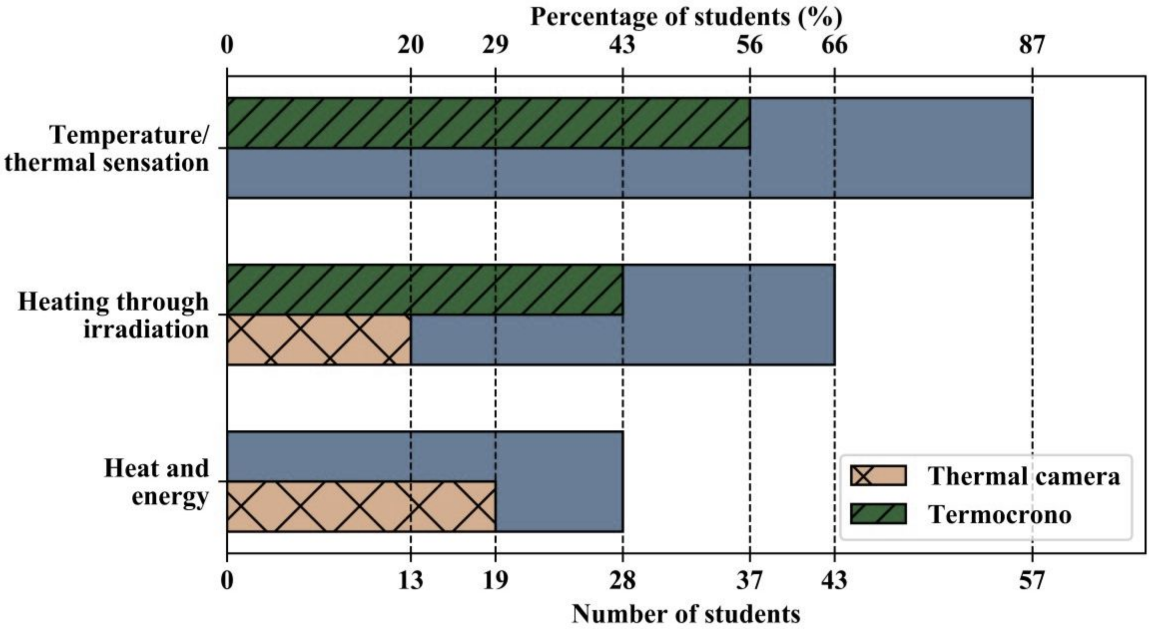

Figure 7. Addressed concepts and instruments proposed for related activities.

DISCUSSION

Two general considerations emerge from our study.

The first one, more practical, is that typically PPTs consider the thermal camera as an expensive specialistic instrument, not easy to be found in school: this is the main reason why they tend not to propose its use in their worksheets.

The second and more fundamental one is that we found an exclusive correspondence between addressed concepts and chosen instruments, which seems to be based on the fact that, differently from the online sensors, thermal cameras have been considered as instruments for *visualization* purposes rather than a radiometer for *measuring* temperature, although the possibility of measuring temperature with a thermal camera has been experimented in the laboratory activities.

The activities that PPTs would propose to pupils are mainly concentrated on the concepts of thermal equilibrium, temperature and thermal sensation with a corresponding use of online sensors (strongly preferred as compared to more traditional thermometers) that excludes thermal cameras. This suggests that the comprehension of heating and cooling as *processes* leading to a common equilibrium state is better gained using the online sensors, indicating that these processes are better understood in terms of *measuring temperature*.

When the concepts of heat and energy are addressed in the planned educational path, there is a corresponding use of the thermal camera that excludes online sensors (and traditional thermometers as well). This suggests that the comprehension of heat in terms of *energy transfer* is more easily grasped through *visualization* using a thermal camera. As a matter of fact, in parallel to their tendency to discard the use of thermal cameras - not so much because they do not understand its use or its didactic potentialities, but rather due to its cost and to the supposed difficulty of having it in a primary school classroom – PPTs tend to omit addressing the concepts of heat and energy transfer, which they consider particularly difficult for children.

Finally, the concept of heating through irradiation was understood by PPTs both in terms of measuring temperature (use of the online sensors) and in terms of energy transfer (visualized through the thermal camera) showing that this process indeed allows introducing the association between temperature, heat and energy.

CONCLUSIONS

On the practical level this study confirms that the proposed approach including the use of a thermal camera can indeed be useful in helping primary school teachers in the task of introducing the concept of energy at the primary school level (otherwise considered too difficult), because thermal cameras allow associating the concept of energy to the concept of heat (which is, in turn, related to a variation of temperature) through the related experimental activities. In this respect, the advent of more recent low-cost thermal cameras, such as those designed for smartphones, could make this potentially successful approach more appealing.

From a more fundamental point of view, understanding this result requires to investigate at the cognitive level the reasons of the exclusive correspondence between addressed concepts and instruments highlighted in the previous sections. To this aim, we can let ourselves be guided by the key word used, repeated and stressed by PPTs in the assessment questions as well as in the worksheets and in the interviews: *visualization*.

The thermal camera allows the experimental 2D **visualization** of heating in terms of **flow** of **an abstract physical entity** (energy), regardless of any numerical value. The online 1D sensor allows the graphical representation of heating as a **process** where **a numerical value** (temperature) **changes** in time, but it misses the idea of flow, which is a common feature of heat and energy since heat is energy flow.

Therefore, what emerges from our data is the key point of the centrality of the idea of *flow* and of an *abstract entity that is transferred and exchanged,* to the concept of energy and heat; abstract entity of which, in a certain sense, the thermal camera allows the visualization.

In this perspective, our findings suggest that the proposed didactic approach, based on a unified treatment of temperature, heat and energy, is grounded at the cognitive level. The historical evolution itself of the concepts of heat and energy, cited in the introduction, can be likewise brought back to the same cognitive level. To deepen this fundamental aspect, we are planning an incoming future work that integrates didactics and history of physics focused on the concept of energy also beyond thermal phenomena, extending it as a unifying concept to different fields of physics, as partially mentioned in the intervention proposed for the present study.

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IS ARAÇÁ BAY DEAD? A DIDACTIC SEQUENCE IN A SCIENCE-TECHNOLOGY-SOCIETY-ENVIRONMENT PERSPECTIVE

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The Biota/FAPESP Program (BFP), created in March 1999, is considered one of the largest biodiversity programs in Brazil. However, BFP failed to translate scientific advancements into teaching material to be used by schools. To fill this gap, a thematic project was conceived entitled "The Biota-FAPESP program in basic education: possibilities for curricular integration" (BFP-BE), whose main objective is to promote actions aimed at the use and dissemination of data generated by the BFP. In this work, we describe a didactic sequence to improve Brazilian students' knowledge regarding marine biodiversity. We choose the database from one of the major projects in the marine area, Biota/FAPESP - Araçá (BFA): "Biodiversity and functioning of a subtropical coastal ecosystem: support for integrated management", due to its valuable contributions to marine science as well as conservation and marine management. As BFA demonstrated how the advancement of scientific knowledge on biodiversity and how its socio-economic relevance is essential to improve the legal instruments, our material was developed in a Science-Technology-Society-Environment (STSE) perspective. The databases from the projects "Relevance of Science Education" (ROSE) and "Student Knowledge in the International Perspective: Evolution, Nature, and Society" (SAPIENS) were also used as a guide to apply the real demands and interests of students from different Brazilian regions. The didactic sequence, entitled "Is Araçá Bay dead?", is composed by three main sections regarding: i) to explore what students know about the marine environments, particularly a bay; ii) to present and discuss the Social-Scientific Issue (the expansion of the São Sebastião Port using the Araçá Bay) as well as to discover the marine biodiversity of Araçá Bay; and iii) to assess what students have learned.

Keywords: Interdisciplinarity, Problem Solving, Socio-Scientific Issues; Native biodiversity

INTRODUCTION

The Biota/FAPESP Program (BFP), created in March 1999, is considered one of the largest biodiversity programs in Brazil in conservation issues. However, BFP failed to translate scientific advancements into teaching material for use in schools (Joly et al., 2010). To fill this gap, there has been a public call for specific educational projects in the summer of 2016, and the project entitled "The BIOTA-FAPESP program in basic education: possibilities for curricular integration" (BFP-BE) was qualified. Its main objective is to promote actions aimed at the use and dissemination of data generated by the BFP.

One of the BFP-BE research lines explores Brazilian students' knowledge regarding marine biodiversity, trying to identify possible gaps and expectations, using the large BFP database to plan didactic materials to address those needs. For this proposal, we chose the database from one of the major projects in the marine area, Biota/FAPESP - Araçá (BFA): "Biodiversity and functioning of a subtropical coastal ecosystem: support for integrated management", due to its valuable contributions to marine science as well as conservation and marine management.

The BFA aimed to understand how the coastal zone behaves as a complex system, considering the integration between physical, biological, and social processes within the Araçá Bay (located on the Northern Coast of São Paulo State, Brazil), such as sediment circulation and transport, food webs, energy and matter fluxes, and fishing production and activity (Amaral, Turra, Ciotti, Rossi-Wongstschowski, & Schaeffer-Novelli, 2016). After many pieces of research, scientists concluded that Araçá Bay hosts one of the most environmentally diverse areas along the Brazilian coast, which gives it significant ecological importance, and it is fundamental for the sustainability of caiçaras families (traditional inhabitants) and the maintenance of their cultural identity (Amaral, Migotto, Turra, & Schaeffer-Novelli, 2010; Amaral et al., 2016).

We believe that these data generated by the BFA can support educational moments of interdisciplinary connections, including Science-Technology-Society-Environment (STSE), that can illustrate Socio-Scientific Issues (SSI). They often involve controversies and both scientific information and value judgments, stimulating functional scientific literacy and students' understanding of the nature of science (Sadler & Zeidler, 2005). Our aim is to use the database generated by the BFA to produce teaching and learning materials, taking into account the real demands and interests of Brazilian students in addition to being able to assist in the Scientific Literacy process and provide a citizen formation.

METHOD

We conducted a literature search up looking for records about Araçá Bay as well as BFA published until December 2020. The following databases and literature sources were consulted: Google, Google Scholar, ResearchGate, and *Biblioteca Virtual da FAPESP* (Research Supported by the São Paulo Research Foundation - FAPESP). In addition, the results of studies on the interests, attitudes, and knowledge about science and technology among young Brazilian students were analysed: "Relevance of Science Education" (ROSE) and "Student Knowledge in the International Perspective: Evolution, Nature, and Society" (SAPIENS) (Franzolin, Garcia, & Bizzo, 2020). These databases serve as a baseline for a better understanding of the real demands and interests of students from Brazil.

RESULTS

One major subject of demand and interest of students from Brazil pointed by Franzolin et al. (2020) was chosen: "How people, animals, plants, and the environment depend on each other?". Araçá Bay has a complex network involving a thousand species of organisms in addition to the human population. We aim to emphasize the bay as fundamental for the sustainability of caiçaras families (traditional inhabitants) and the maintenance of their cultural identity. This information will be significant to show students the close relationship between people and many different forms of life.

The teaching material was produced in a STSE perspective (Auler & Bazzo, 2001; Carmona & Vieira, 2017) and the SSI defined as a controversial problem was the expansion of the São Sebastião Port (SSP) because it will be necessary to landfill (partial or total) the Araçá Bay.

The material was projected to be used for students of the last year of Brazilian primary education (age 14–15 years), taking into account the *Base Nacional Comum Curricular*, the new Brazilian 'common core' curriculum known as the BNCC (Brasil, 2018). The thematic unit is "Life and Evolution", and the object of knowledge is biodiversity preservation. The first version of the teaching material is presented below, which will still undergo evaluation by primary school teachers.

Teaching material: "Is Araçá Bay dead?"

The title "Is Araçá Bay dead?" intended to be attractive and reflect the content and training intentions. Altogether, it contains 11 lessons (each lasting 45 minutes), which are organized into three main sections. Figure 1 represents the main steps.

The first section aims to find out what students know about the theme "seas and oceans". For this, a diagnostic questionnaire was constructed with the following questions: 1) When thinking about the seas and oceans, what words come to your mind? 2) What did you learn in your school about seas and oceans? 3) Is there any relationship between your daily life and the seas and oceans? Justify. 4) Is there any topic related to the seas and oceans that you are interested in studying? If yes, which one? After, the teacher will be able to present a photo board of the main marine environments (Figure 1A) and ask students several questions, such as what these environments have in common and what differentiates them (e.g., abiotic components). This will be a good opportunity to introduce students to an unfamiliar environment, the bay.

The second section aims to present the Socio-Scientific Issue as well as encourage students to reflect on the causes and consequences of impacts in the coastal region. For the first activity, entitled "Knowing the problem to be investigated", it is proposed that students read the first text adapted from Xavier, Stori, and Turra (2016) and Florio (2017). Subsequently, students will participate in a debate with the following guiding questions: 1) In your opinion, what would happen to this ecosystem (Araçá Bay) if the São Sebastião Port is expanded? 2) What would be the environmental impact of expanding the São Sebastião Port using piles and slabs on Araçá Bay?

For the second activity, entitled "Discovering the Araçá Bay", it is proposed that students read the second text adapted from Andrade (2015) and Amaral et al. (2016). This text contains a description of the biodiversity of the Araçá Bay and presents the Biota/FAPESP - Araçá project. In the text, there is two photos with several marine organisms registered in Araçá Bay (Figure 1B and 1C). From the detailed observation of the photo, the teacher can discuss with students on various topics such as biodiversity and ecosystem. To finish the activity, students will watch a part of the video "Pulsante | A film about Araçá Bay" (**Figure 1D**, https://youtu.be/HneSn9Pu0iA, video time to watch: 0 to 13 minutes) and then discuss the question: "Is Araçá Bay dead?".

For the third activity, entitled "The expansion of the São Sebastião Port: possible consequences", it is proposed that students read the third text adapted from Andrade (2015). Then, students will participate in a debate with the following guiding questions: 1) What would be the problems caused by the expansion of the São Sebastião Port using slabs on the Araçá Bay? 2) Some researchers are against, and others are in favor of this expansion. What are their arguments, and which would you agree with? Justify your choice. Finally, the students can watch the last part of the video “Pulsante | A film about Araçá Bay” (video time to watch: 13 to 25 minutes).

For the fourth activity, entitled “Getting to know the people who live in/from Araçá Bay”, it is proposed that students read the fourth text adapted from Amaral et al. (2016), referring to Chapter III Resource Management. Afterwards, students will participate in a debate with the following guiding questions: 1) With the expansion of the São Sebastião Port, using Araçá Bay, what will happen to the caiçaras families there? 2) Why is it important to know to protect? As a conclusion of the activity, it is proposed that students make a video or write a letter in defense of Araçá Bay.

The third section aims to assess what students have learned. Three questions were elaborated: a multiple-choice question, a true/false question, and an exercise to complete sentences.

Figure 1. Representation of the main steps of the teaching material. A) Photo board with main marine environments; Authors: Renata Alitto (*oceano*, *mar*, *costão rochoso* and *praia*); Gabriel Monteiro (*baía*);

Guilherme Abuchahla (*manguezal*). **B)** Polychaete (sea-worm, *Branchiomma luctuosum*), with intense and exuberant color, abundant on the rocky shores; Author: Gabriel Monteiro. **C)** Ophiuroidea (brittle star, *Hemipholis cordifera*); Author: Renata Alitto. **D)** Video Pulsante | A film about Araçá Bay, available on https://youtu.be/HneSn9Pu0iA.

DISCUSSION

The STSE perspective was chosen to produce a teaching material using Araçá Bay as an educational resource. This can be an efficient strategy to address socio-environmental problems (Auler & Bazzo, 2001; Sadler & Zeidler, 2005) such as that pointed out by the thematic project Biota/FAPESP - Araçá (BFA): the expansion of the São Sebastião Port.

The teaching material has 11 lessons organized into three main sections aiming: 1) to find out what students know about the theme "seas and oceans"; 2) to present the Socio-Scientific Issue as well as encourage students to reflect on the causes and consequences of its impacts in the coastal region; 3) to assess what students have learned. Altogether, four texts (which comprise the second section) were written considering the target audience of students (ages 14–15 years).

Several photos of marine environments, including Araçá Bay, as well as marine biodiversity were chosen to compose the teaching material, making it more illustrated and more attractive. An illustrated material will enable the visualization and recognition of environments and marine biodiversity, which unfortunately, are difficult to access for most Brazilian people.

The didactic material was made according to the BNCC in the thematic unit "Life and evolution" since there is no specific unit for "Ocean Literacy" (OL). OL is defined as the understanding of the ocean's influence on human beings and vice versa. It aims to improve knowledge on marine environments, enabling citizens to make responsible decisions concerning marine-related issues (Santoro, Santin, Scowcroft, Fauville, & Tuddenham, 2020).

Despite all this importance, OL is not valued in Brazilian curricula. In a recent study, Pazoto, Silva, and Duarte (2022) pointed that the representativeness of OL in Brazilian documents is below the recommended for a person to be considered ocean literate, especially for topics dealing with environmental risks in coastal zones. The authors also concluded that actions aimed at expanding the presence of OL principles and concepts in Brazilian school curricula must be taken.

For students to be able to assess the Socio-Scientific Issue presented in our material, it is necessary that they know and understand the importance of marine environments and their biodiversity. Addressing these topics has become increasingly important especially towards the study of marine biodiversity.

Unfortunately, there are no nationally representative studies to recognise how much teachers emphasize Brazilian biodiversity in their classrooms. However, a recent exploratory study carried out with 147 teachers (Araújo & Alitto, 2021) found that there is little emphasis on this topic. According to these interviewed teachers, the absence of adequate teaching materials was pointed as a common factor that negatively affect the teaching of native biodiversity.

In Brazil, learning materials are distributed by the Ministry of Education and they are the same for all schools. Therefore, it is easier to find pictures of large, exotic, charismatic megafauna (e.g., polar bears, elephants, etc.) rather than native South American animals and plants in the bestselling biology textbooks (Oliveira & Cook, 2019). This condition does not reflect the demand of Brazilian students, who are interested in learning about the fauna and flora in their area (Franzolin et al., 2020).

Therefore, produce and share the didactic material about Araçá Bay is relevant since it can help to fill the gap in the teaching of biodiversity in Brazil. Moreover, the material can be used by teachers and students from all over the country including those close to Araçá Bay, who which study the native biodiversity of other places and not where they live.

The next step is to apply the material in a single Brazilian public school, test, improve, and then it will be available to Brazilian and foreign schools. Other subjects published by Franzolin et al. (2020), papers, videos, and news reports regarding the BFA are being studied and, if necessary, they will be used to improve or produce new sequences. All the didactic sequences (for both teachers and students) will be available on the Portal EDEVO-Darwin (https://sites.usp.br/edevodarwin/).

Considering that 2022 is the second year of the Decade of Ocean (proclaimed by the United Nations), using a small bay as Araçá in the classroom is an ideal opportunity to show how the management of our oceans and coasts is important for the conservation of biodiversity. As a result, we expect students to have an increase in their critical thinking and effective attitudes to solve problems related to marine biodiversity.

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TEACHING GENETICS USING THE SIMPSONS. AN INNOVATIVE PROPOSAL WITH SPANISH PRE-SERVICE SCIENCE TEACHERS

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Television and internet often include science-related content that may affect consumers. As such, they may be good teaching-learning resources. With this is mind, this study presents the results of an activity based on use of the well-known TV series "The Simpsons" to teach genetics. This proposal was implemented with 24 pre-service science teachers (PSTs) studying the Masters in Secondary Education Teaching at the University of Malaga (Málaga, Spain), in the Biology and Geology field, as part of an educational innovation course in the academic year 2020-2021. The study was carried out in the classroom as follows. Using a family tree for the Simpsons family containing three generations, the PSTs were asked to design an activity for secondary students using the laws of Mendelian inheritance. They were given 30 minutes to discuss different proposals as a group and then presented their designs. Finally, they completed a questionnaire to evaluate different aspects of the activity. The proposals to explain the family tree were based on the characteristics of hair colour and hair type. Hair colour generated significant debate as it proved difficult to explain all the phenotypes. However, they chose an autosomal recessive explanation assuming that other possible factors were likely involved. The hair type characteristic was explained using an intermediate inheritance. The evaluations of the PSTs were very favourable, with the questionnaire reflecting the ease of design and implementation and the marked versatility. Indeed, activities based around TV series were considered to be effective for teaching science. However, this resource must be adapted to the age group, interests and context of the students in which it is to be implemented

Keywords: TV series, pre-service science teachers, task design

INTRODUCION

Media such as television and the internet are widely used in the general population due to their widespread availability, consumption and ability to influence (AIMC, 2018). Various authors have investigated the benefits of using fiction resources such as films, TV programmes, series, stories or novels to teach science (Fraknoi, 2002; Franco-Mariscal, 2021; Hasse, 2015; Hamalosmanoglu, Kizilay & Saylan Kirmizigül, 2020; Kilby-Goodwin, 2010; Koutnikova, 2017). These resources may help to create mental images that can be correlated with an underlying scientific theory, may help to understand abstract concepts, are very visual, fun, improve the applicability of the content learned or enhance the interest in learning science, amongst other advantages (Barnett & Kafka, 2007). According to Evrekly, Inel and Balim (2011), "concept cartoons can be defined as visual aids in which the opinions and discussions of cartoon characters regarding the cause of or solution for a daily life event are presented in written form in speech bubbles".

Biology-related topics appear frequently in these resources. Examples include Jurassic Park, GATTACA, The Martian, Planet of the Apes, an inconvenient truth, Twenty Thousand Leagues Under the Seas, Frankenstein or The Walking Dead, all of which have plots with a biological origin (Barnett & Kafka, 2007). Fiction often presents concepts, situations or ideas related to actual science that cause spectators to think and ask themselves whether it is possible for these to happen in real life (Rose, 2003).

Genetics shows us the strong link between science and society. As well as being present in these resources, genetics is also present in our lives. In addition to genetic inheritance issues related to physical characteristics or hereditary diseases, other examples where its importance is reflected are blood donations, gene editing, compatibility in organ donation, among others. Understanding the scientific basis of these issues helps our students to build critical opinions on these topical issues (López-Fernández & Franco-Mariscal, 2019).

An example of genetics can be studied in the TV show Game of Thrones with the sequence of rescue of the dragon from the ice, where you can see that the colour of his eyes changes to blue (Franco-Mariscal, Cano-Iglesias & Hierrezuelo-Osorio, 2020). This sequence allows to discuss different contents about genetics through driven questions. Some driven questions could be: *Why do some dragons have blue eyes and another brown?,* or can two dragons with brown eyes have a dragon with blue eyes? If so, why?

This study makes use of The Simpsons series to learn genetics, a cartoon that has already been used successfully by other authors (Orthia et al., 2012; Perales & Vílchez, 2005). This work presents the results of an activity with pre-service science teachers (hereinafter, PSTs), who were asked to design an activity for secondary students to provide a genetic explanation for the characteristic observed in the Simpsons family.

METHOD

A total of 24 students studying the Masters in Secondary Education Teaching at the University of Malaga (Málaga, Spain), in the Biology and Geology field, participated in this activity. Of these, 58.3% were male and 41.7% female. The activity was performed remotely in a session lasting two hours as part of the "Teaching innovation and introduction to educational research" subject in the academic year 2020-21. The innovation proposed is based on the use of fiction series to teach science.

The Simpsons is an internationally renowned TV series. It is an American comedy series that has been broadcast daily in Spain for many years. The Simpsons is about the life and day-today life of a middle-class family. The PSTs were provided with a family tree for the Simpsons family that included the parents (Homer and Marge), their siblings (Herb, Patty, and Selma), their children (Bart, Lisa and Maggie) and the grandparents (Abraham, Mona, Clancy and Jackie). They were then asked to design an activity for secondary students that could be used to explain inheritance and transmission of genetic characteristics in this family using Mendel's laws, which is one of the objectives included in the Spanish secondary curriculum. The PSTs worked in groups of four for 30 minutes, thus allowing them to discuss and propose different options. After this time, each group presented its results in class.

Finally, and to determine their opinion of the activity, each PST completed a questionnaire in which they were asked to evaluate the activity itself (from 0 to 5), the difficulty in designing it and in implementing it (from 1 to 5, with 1 being not difficult and 5 very difficult), their initial opinion of the teaching possibilities of the activity and the possibility of using it with secondary students (from 1 to 5, with 1 being very limited possibilities and 5 significant possibilities), indicate the best and worst aspects when performing the activity, and explain how they expected secondary students to receive the activity if put into practice.

RESULTS

PSTs' proposals

The students' proposals were based on two characteristics, namely hair type and hair colour. With respect to hair type, they initially attempted to find an explanation based on two alleles (S for straight hair and C for curly hair), with one being predominant, but found that this could not explain the three phenotypes (straight, spiky and curly). To that end, the PSTs established an intermediate inheritance relationship between allele S and C, fitting this to all the crosses shown in Figure 1.

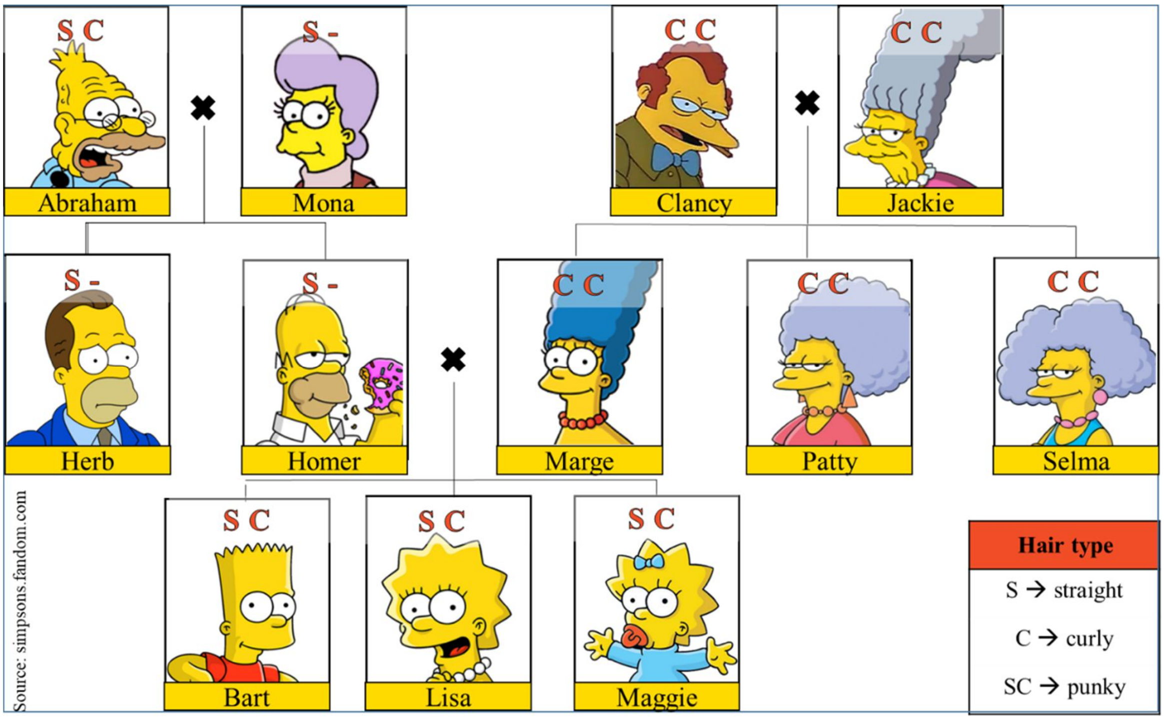

Figure 1. Genotypes and crosses for hair type in the Simpsons family [Source: simsons.fandom.com].

In this way, homozygous individuals (SS) will exhibit straight hair, heterozygous individuals (SC) will exhibit punky hair, and homozygous individuals (CC) will exhibit curly hair. Consequently, it is not possible to know all genotypes (for instance, Mona, Herb or Homer, like you can see in Figure 1).

A similar procedure was followed for hair colour, with the PSTs attempting to propose an intermediate inheritance with alleles *B* for blue hair and *M* for brown hair, although this could not explain and cross between Abraham and Mona and between Clancy and Jackie using a single criterion, as can be seen from Figure 2.

As such, they proposed a possible solution based on an autosomal recessive inheritance for blue hair (*b* for blue and *B* for a colour other than blue). The *B* allele is dominant and the *b* allele is recessive. The phenotypes brown and yellow hair colour cannot be explained with this proposal, thus meaning that other factors must be involved.

Thus, homozygous individuals (BB) and heterozygous individuals (Bb) will exhibit a hair colour that is not blue (for instance, Abraham, Clancy, Herb, Homer, Bart, Lisa or Maggie); and homozygous individuals (bb) will exhibit blue hair (like Mona, Jackie, Marge, Patty or Selma). For this reason, it is not possible to know all genotypes (for example, Abraham or Clancy). Finally, they concluded that, according the Mendel's third law, transmission of these characteristics is independent, in other words they are not linked.

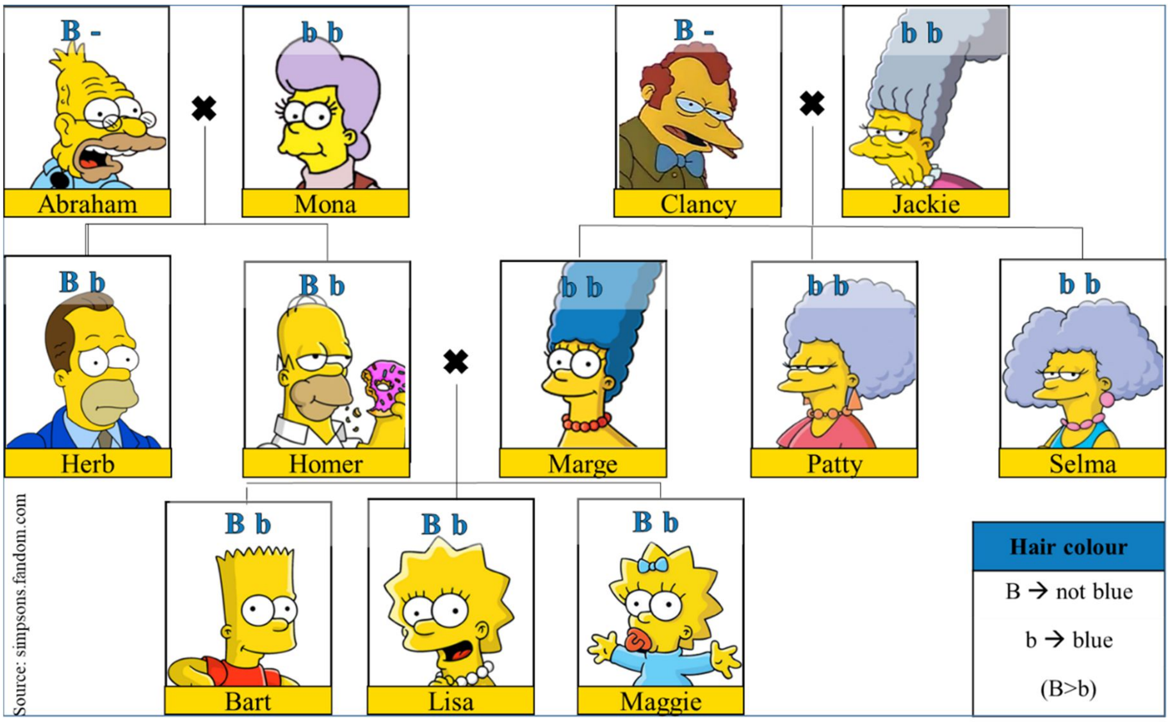

Figure 2. Genotypes and crosses for hair colour in the Simpsons family [Source: simsons.fandom.com].

PSTs' Assessments

The PSTs evaluated the activity very favourably, giving a score of 4.25/5. On a five-point scale, they gave the highest scores to the possibility of using this resource in the secondary classroom (4.0) and the possibility of putting it into practice (4.0). Conversely, they considered it to be difficult to implement (2.67) and to design (3.1) (Figure 3).

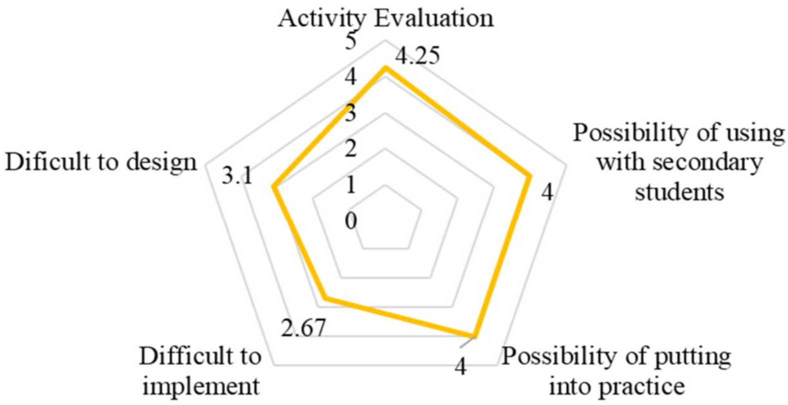

Figure 3. PSTs' activity evaluation.

The majority of the PSTs also considered the "versatility" of the activity to be its best aspect as it can be adapted to numerous series and films and that it was a "fun and motivational activity". The aspects given the worst evaluations were the "complexity of the content", "finding a genotypical response that can explain the phenotypical diversity in the series", or "performing the activity in cooperative groups and online".

As regards how they would expect secondary students to receive the activity if put into practice, the majority responses concentrated on creating interest, enthusiasm and ebullience, amongst students.

CLOSING REMARKS

The effects of integrating films, series, TV programmes, stories or novels in science education can be investigated by designing similar studies in an extended way for different levels of formal education (Hamalosmanoglu, Kizilay & Saylan Kirmizigül, 2020), from kindergarden to secondary education or including the university stage. As noted by Raham (2004) or Perales and Vilches (2005), despite the obstacles that may arise in class, this type of activity is effective for teaching science to secondary students.

This proposal attempted to prepare PSTs for task design and to create an innovative vision in them. In addition, as with previous studies (Franco-Mariscal, 2021), although the use of adult TV series with PSTs does not imply their use in secondary education, it nevertheless allows students taking the Teaching Masters to learn about this type of resource and become aware of the need to adapt series to the age and interests of their future students.

Research conducted with cartoons showed that the students displayed a significant enhancement in their motivation towards science learning and academic achievement. Moreover, they increased students' active participation in the classroom, enabling and enhancing conceptual understanding, and creating environments for cognitive conflict and debate (Evrekly, Inel & Balim, 2011).

Another example is Dalacosta, Kamariotaki-Paparrigopoulou, Palyvos and Spyrellis' research (2009). The research results provide evidence that the use of cartoons significantly increases the young students' knowledge and understanding of science concepts, which are normally difficult to comprehend and often cause misconceptions to them.

The PSTs also highlighted the difficulty of finding a biological explanation for all characteristics as some were impossible to explain with the laws of Mendelian genetics. This may be due to the fact that these aspects were not taken into consideration when creating the cartoons because cartoonists would have not a deep knowledge of genetics. Other options may be that characters are not the same age (when people are older, they have gray hair) or a biological explanation, such as Abraham or Clancy were not the biological fathers.

According to the results obtained, this resource, which is easy to design and implement, is suitable for the teaching-learning of the inheritance of secondary characteristics. The resource studied may be extended to other TV families (The Flintstones, The Incredibles or Harry Potter), for which other characteristics, such as eye colour, intelligence, build, obesity or visual problems, could be studied.

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HOW SEPARATING EVERYDAY AND SCIENTIFIC LANGUAGE IN CHEMISTRY TEACHING ENHANCES LEARNERS' COMMUNICATIVE COMPETENCES

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The pursuit of Scientific Literacy as a response to questions of educational inequality has become much more complex, especially in countries, which have faced immigration and growing diversity in recent years. STEM education should therefore pay additional attention to students' diverse backgrounds, for instance regarding their language resources. Integrated language instruction or language-sensitive teaching are among various approaches to meet this requirement, however, there still seems to be a lack of initiative from the individual subject areas.

The Disaggregate-Instruction-Approach (DIA, Brown et al., 2010) addresses the issue by offering learners new ways to access scientific discourse. Brown and colleagues report that learners with beginner and developing verbal skills benefit greatly from the strict separation of subject-content and language learning. This approach reduces the cognitive load through allowing students to focus first on familiar language in the process of acquiring scientific concepts and introduces scientific vocabulary in a subsequent stage. Picking up the very promising findings from previous studies, we adapted the approach to the conditions in a culturally as well as linguistically highly diverse area and conducted an intervention study with first- and second-year chemistry learners to gather data on how they benefit from a modified DIA. The focus of this paper centers the initial results of the analysis of students' subject-specific learning gains as effects of the treatment.

Keywords: Language in Science Education, Disaggregate Instruction

INTRODUCTION

In times of rapidly increasing diversity – particularly in a growing number of European societies largely affected by immigration – stakeholders in science education are more than ever required to pay special attention to students who face specific challenges in their individual learning biographies (OECD, 2019, pp. 181–183). The make-up of this diverse group contains a substantial number of learners who are second language learners. In Germany, a country that has experienced constantly high numbers of immigrants and refugees during past years, between 34 and 40 percent of the student population are first- or second-generation immigrants (Autorengruppe Bildungsberichterstattung, 2020, p. 27) who to a substantial degree speak a language other than German in their homes (Becker-Mrotzek et al., 2012, p. 2). Recent large-scale assessment like the international PISA or TIMSS surveys identified substantial differences in reading performance (OECD, 2019, p. 185) and STEM learning (Mullis et al., 2020, p. 294; Wendt et al., 2020, p. 298) between immigrant and non-immigrant students in several European countries. Among a variety of supposed factors, researchers consider the family's and student's socio-economic status as well as an imbalance between the languages spoken at home and in school the primary reasons for this alarming gap in reading but also in the sciences (OECD, 2019, p. 185; Wendt et al., 2020, pp. 306–307). Scholars have discussed the interrelatedness of language competences, like reading or writing, and science competences and found evidence that under-developed verbal competences have a substantially negative impact on learning in STEM subjects (Bird & Welford, 1995, pp. 396–397; Childs et al., 2015, p. 421). Therefore, the analysis of students' deficits in academic language proficiency and the question to what extent these deficits impede competence development in STEM education should focus on the entire student population, i.e., second language learners as well as students with low socio-economic status.

THEORETICAL FRAMEWORK

In German education research there has been broad consensus regarding the theory that integrated language instruction (referred to as "Durchgängige Sprachbildung" in German) as a component of every school subject can help the majority of students to overcome their language deficits (Gogolin & Lange, 2011, p. 118). Consequently, it seems plausible and necessary to develop approaches to the integration of language instruction into science teaching from the perspective of the individual subjects and to evaluate the effects of these approaches. Under the assumption that the acquisition of scientific vocabulary in some respects resembles the acquisition of a foreign language (Rincke, 2011, pp. 255–256; Vygotsky, 2012, p. 109), focusing instruction on subject-specific, conceptual understanding and novel items of scientific vocabulary at the same time should result in a significant cognitive load on students' working memory (Roussel et al., 2017, p. 78). While humans have evolved to acquire their native language, the acquisition of foreign languages usually fulfills cultural purposes and thus our brains need to apply different cognitive processes (Roussel et al., 2017, p. 72; Sweller, 2015, p. 190). Geary theorizes this distinction with the concept of biologically primary and secondary knowledge which demand differentially extensive efforts from learners to be acquired (Geary, 2008). The cognitive load when dealing with two types of biologically secondary knowledge, e.g. a foreign language and scientific knowledge, is higher as we need explicit instruction and dedication to succeed (Roussel et al., 2017, p. 73).

Different studies have shown that the challenges for learners in science subjects are particularly high because of the simultaneous focus on scientific concepts and vocabulary, i.e. two types of biologically secondary knowledge, due to a high cognitive load (Brown et al., 2010, pp. 1479-1480; Brown et al., 2019, p. 766). Research in multilingual settings in the United States revealed that the acquisition of scientific concepts induced improved learning efficiency as well as an enhanced articulation of the acquired knowledge for students if the instruction mainly used everyday terminology initially (Brown et al., 2010; McDonnell et al., 2016). Using this idea, Brown et al. (2010) and Ryoo (2015) designed a series of science lessons in the field of photosynthesis and empirically analyzed the effects of the so-called *Disaggregate-Instruction-Approach (DIA)*. According to their approach, the introduction of scientific terms should only happen after the students have internalized the corresponding scientific concepts (Brown et al., 2010; Ryoo, 2015).

Brown and colleagues used the idea of *Disaggregate Instruction* to design a teaching sequence which they call Directed Discourse Approach to Science Instruction (DDASI). It subdivides a given sequence into four phases (2010, pp. 1474-1475):

(1)Pre-Assessment Instruction
(2)Content Construction

(3)Introduction of Explicit Language

(4)Scaffolding Opportunities for Language

After familiarizing the students with the new topic and students' preconceptions (1), the teacher introduces new content which the learners negotiate only using everyday language (2). Afterwards the teacher presents the new scientific terminology (3) and eventually provides the students with activities to apply the acquired vocabulary (4).

RESEARCH QUESTION

Our ideas to adapt the promising *DIA* to meet the conditions of a diverse student population in a multilingual, urban setting led us to the following overarching research question:

To what extent does the separation of teaching sequences into initial phases in which the teacher primarily uses familiar language and only later introduces new scientific terms (in accordance with the DIA) assist students in the acquisition of chemistry-related knowledge and the development of chemistry-specific communicative competences?

RESEARCH METHOD AND STUDY DESIGN

Instead of merely replicating Brown and colleagues' study, we have made several adaptations to the proposed instructional design with the aim to complement their research in the field of chemistry education in the German educational system. For example, Brown and colleagues did not examine their participants' language abilities and based their categorization solely on the individual's cultural and language-learning background instead (2010, p. 1473). In contrast, we decided to conduct an analysis of students' general and scientific language abilities as we expect specific effects of the approach, especially for learners with developable communicative competences. Furthermore we faced the challenge to establish a border between the concepts of everyday and scientific vocabulary which we intend to meet with the help of Brown and Spang who draw parallels to vernacular and nonvernacular language (2008, pp. 710–711). We believe that terms and the corresponding concepts that the students are already familiar with (like water molecule or state of matter; SenBJF, 2015) should be considered vernacular as the chemistry class as a community knows how to use these terms properly even though they might seem nonvernacular (or scientific) to people outside of this community (Brown & Spang, 2008, p. 710). Hence, nonvernacular or scientific terms are only those terms which are completely new to the students (here: all the words that describe the subatomic structure of salts and the dissolving process). In contrast to Brown et al. (2010, p. 1475) we decided to refrain from virtual teaching and opted for an authentic in-person classroom setting. Even though this added the teacher as a possibly confounding variable, we are convinced that we can mitigate the effect if the teacher stays the same person for every group.

We designed a sequence of four 90-minute units aimed at early-stage, secondary-level chemistry learners with the adapted *Disaggregate Instruction* teaching approach (Brown et al., 2010) serving as the treatment. To evaluate its effectiveness, we use a treatment-control study design with pre- and post-test measures. The treatment and control groups receive instruction of the same content using identical teaching methods. The treatment group studies the scientific concepts initially only using familiar language and acquires the scientific terminology afterwards. The control group does not experience a strict separation of content- and language-learning, i.e., the teacher introduces a new scientific term and the corresponding concept simultaneously.

In the pre-test and thus prior to the instruction, every student takes two c-tests measuring their general (Institut für Bildungsmonitoring und Qualitätsentwicklung Hamburg, 2008) and scientific (test developed and sampled by ourselves) language abilities. C-tests are a test type closely related to cloze tests[5] but here only the first or second half of a word is erased and needs to be completed. According to their scores, the students can be classified regarding their verbal skills. This will be considered in the statistical analysis but does not affect the assignment to treatment or control group.

Before and after the treatment the students also complete a subject-matter knowledge test in a multiple-choice-single-select format (Gieske, 2021) to detect knowledge gains as effects of the instructional approach. The test consists of 14 items; each item contains 3 distractors apart from the correct answer. In addition, the participants have to indicate how confident they feel answering each item on a four-level Likert scale (Erb & Bolte, 2012, pp. 16–17). Hence, each student receives two separate scores representing their learning gains: the *performance score* purely reflects the selection of correct answers whereas the *performance & confidence score* also takes into account the confidence in answering and thus reduces the probability of assessing answers which the participant only guessed correctly.

The treatment itself, as outlined in figure 1, covers the topics chemical structure of salts as well as the dissolving process of salts in water. It incorporates student-centered, collaborative activities as well as a variation of media. The teaching sequence is embedded in the context "The Dead Sea is Dying" which as a socio-scientific issue creates a learning environment that is both interesting and challenging for the students (Sadler, 2009, p. 36). The scientific vocabulary of this teaching sequence consists of ten items which we mainly drew from the local

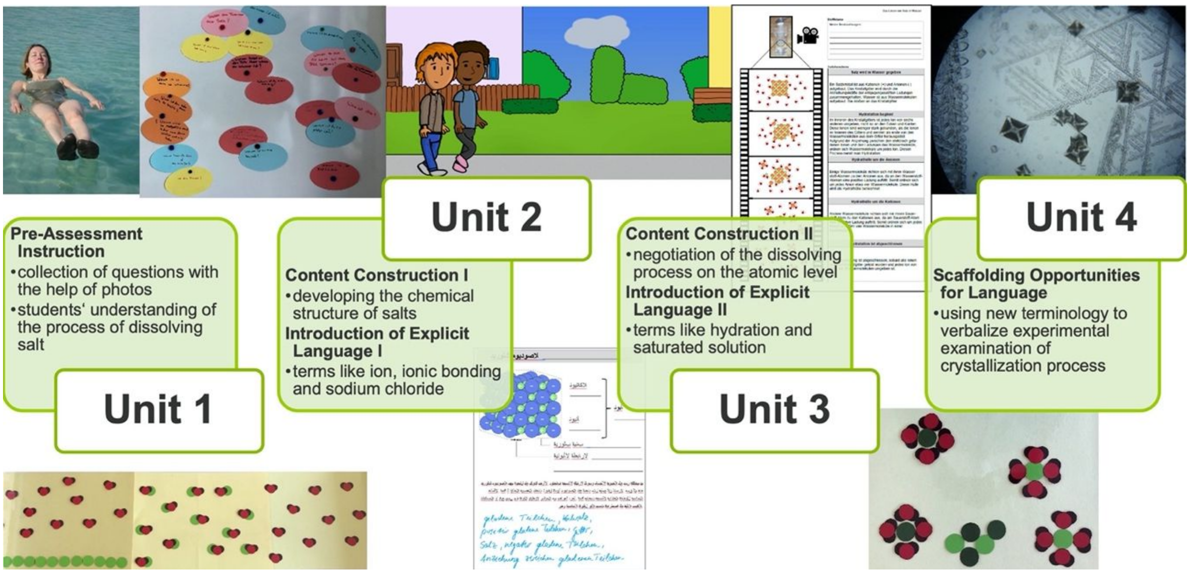

Figure 1. Overview of the teaching sequence including teaching material and student products.

[5] Oller & Jonz define cloze tests as „written applications … [in which] single words are replaced with blanks of standard length and the respondent tries to fill in each blank" (1994, p. 3).

chemistry curriculum (SenBJF, 2015, p. 36) and supplemented with some linguistically directly related terms, e.g. ion, cation and anion.

The four phases of the DDASI approach are not identical with the four units of "The Dead Sea is Dying" but they are woven into the sequence. The first unit serves as the Pre-Assessment Instruction. Here the teacher makes the students familiar with the context as well as the topic and invites the class to pose questions which the learners would like to discuss throughout the sequence. During the second half of the first unit the students work with applications to depict their pre-instructional ideas of the dissolving process (bottom left corner in figure 1) which gives the teacher the opportunity to monitor students' language use and prior knowledge. In the second unit the teacher introduces the chemical structure of salts and the concept of ionic bonding with the help of two fictional characters who remember a visit to a museum at the Dead Sea during their holidays. As they do not have all details and terminology in mind, their conversation serves as the vantage point to discuss the subatomic structure of salts without dense scientific vocabulary (Content Construction I). A scientist helps the characters to understand the scientific concept of ionic bonding and to become aware of the different purposes of colloquial and scientific language (Introduction of Explicit Language I). The third unit then brings together the conceptual findings and introduces the process of dissolving a salt in water (Content Construction II). Here we use a movie bar worksheet where students have to arrange the correct order of visualizations and textual elements (Introduction of Explicit Language II). Afterwards the students use and consolidate their knowledge and depict a saturated solution with salt-ion and water-molecule applications (bottom right corner in figure 1). The fourth phase and final unit provides the learners with meaningful opportunities to demonstrate their understanding applying the new terminology during a hands-on activity and scaffolded teacher-student interaction.

After the teaching sequence, the participants attend to two items measuring their ability to communicate in a manner that addresses the text recipient. In this test they write two texts addressing an expert (their chemistry teacher) and a novice (a peer who did not participate in the teaching sequence) explaining the dissolving of salt in water. We are currently developing an analytical framework to map chemistry-specific ways which students use to establish audience design in their writing. This framework helps us to investigate the role of the newly acquired scientific terminology in students' writing and text construction processes.

STUDY SAMPLE AND INITIAL FINDINGS

Pilot Study

First investigations with four groups took place at two different schools with diverging conditions concerning student attainment in May and June of 2021. We tested our teaching sequence at a so-called academic high school and a regular high school with lower student attainment in general. The two classes at each school were randomly assigned to treatment (TG) or control group (CG).

The allocation of 102 subject-matter knowledge tests (pre and post) revealed a satisfactory reliability of Cronbach's $\alpha = .802$. A substantive drop-out due to COVID-19 prevention measures reduced the sample to only 36 students who completed both, the pre- and the post-test. Table 1 shows selected statistical characteristics for the *performance (perf)* and the *performance & confidence scores (perf & conf;* cf. Research Method and Study Design*)* of the treatment and control groups from both schools.

Table 1. Descriptive statistics of the pilot study treatment and control groups.

Group	**Treatment (N = 18)**		**Control (N = 18)**	
Score	***perf***	***perf & conf***	***perf***	***perf & conf***
Mean score t_0	3.83	1.17	5.06	1.56
Standard Deviation t_0	1.38	0.92	2.56	1.46
Mean score t_n	8.78	6.44	9.56	7.56
Standard Deviation t_n	2.32	2.46	2.01	3.17
Mean score Δt_n-t_0	4.94	5.28	4.50	6.00
Standard Deviation Δt_n-t_0	2.80	2.16	2.33	2.72

The results reveal a substantive gap between the *performance* and the *performance & confidence scores* for the pre-test in both groups. In the post-test this gap still exists but has become smaller in relation to the generally improved scores. There is a tendency of the treatment group to slightly outperform the control group when the *performance scores* are taken into account *($M_{TG} = 4.94$; $M_{CG} = 4.50$)*. The control group, however, exhibits a greater learning gain compared to the treatment group when *performance & confidence scores* are considered *($M_{CG} = 6.00$; $M_{TG} = 5.28$)*. Yet, this difference does not become statistically significant *($p = .384$)*.

Main Study

The main study started after the summer break of 2021 with four groups at two different academic high schools. These two schools are located in fairly privileged areas of Berlin and their educational attainment can be considered substantively higher compared to the pilot study groups. One class at each school was assigned randomly to the treatment and the other to the control group. Table 2 shows descriptive statistics for both groups.

Table 2. Descriptive statistics of the main study treatment and control groups.

Group	**Treatment (N = 48)**		**Control (N = 47)**	
Score	***perf***	***perf & conf***	***perf***	***perf & conf***
Mean score t_0	5.69	1.83	5.51	2.21
Standard Deviation t_0	1.99	1.59	2.19	1.84
Mean score t_n	10.94	9.88	10.70	9.55
Standard Deviation t_n	1.69	2.28	1.69	2.38
Mean score Δt_n-t_0	5.25	8.04	5.19	7.36
Standard Deviation Δt_n-t_0	2.23	2.51	2.38	2.40

The initial results of the main study show a similar trend regarding the students' confidence when completing the test compared to the pilot study. The pre-test scores are much higher for both groups when only performance is considered. In the post-test the *performance* and *performance & confidence scores* are more similar. This time the treatment group achieved a greater learning gain compared to the control group when we consider the *performance & confidence scores* (M_{TG} = 8.04; M_{CG} = 7.36). However, this trend does still not become significant in a two-tier t-test (p = .180). Regarding the performance scores, the difference between both groups is only marginal (M_{TG} = 5.25; M_{CG} = 5.19).

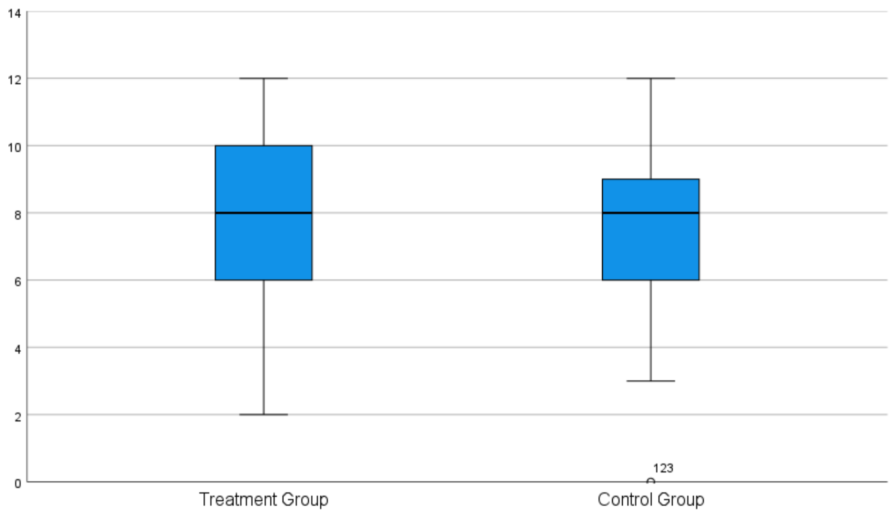

Figure 2. Boxplots of knowledge test *perf & conf score* gains from pre- to post-test.

DISCUSSION OF FINDINGS AND OUTLOOK

The pilot study in June and May 2021 was constrained by the pandemic situation and consequently exhibited a significant drop-out of participating students. Nevertheless, the data reveal important implications for our main study. The very satisfactory reliability of the subject-matter knowledge test confirms the appropriateness for measuring students' learning gains throughout the teaching sequence. The pre-test scores are similarly low in both groups as the students only bring marginal prior knowledge to the classroom, however, the teaching – independent from the type of treatment – leads to substantially improved results afterwards. In order to eliminate the chance of guessing the correct answer, the *performance & confidence score* turned out to be a helpful measure as the students systematically scored below the level of probability in the pre-test when their confidence was considered. The teachers' and students' informal feedback on the teaching sequence turned out very positive and encouraging which is another reason why we only had to carry out minor modifications prior to the main study.

Our findings from the investigations of the first four main study groups confirm the suitability of the subject-matter knowledge test and our focus on the *performance & confidence scores*. The mean pre-test scores are slightly higher but as anticipated still on a low level but (M_{TG} = 1.83, M_{CG} = 2.21). One main parameter that provides evidence for the effectiveness of the teaching approach is the mean learning gain score. The treatment group outperforms the control group by a margin of Δ = 0.78 (M_{TG} = 8.04, M_{CG} = 7.36). This means that students who received *Disaggregate Instruction* answer on average 8 more items correctly in the post-test than they did before the teaching sequence – compared to a bit more than 7 items in the control group. Even though this tendency does not become statistically significant, we think it indicates an imaginably superior effectiveness of the *Disaggregate-Instruction-Approach* in relation to high-quality chemistry teaching without a strict separation of content- and language-learning.

The sample size in both, pilot and main study, however, places some limitations on our conclusions. Our objective is to expand the data set to solidify statistical effects paying particular attention to groups from less privileged backgrounds as we assume that students who already perform very well at school potentially do not struggle a lot with the simultaneous acquisition of scientific concepts and terminology. Consequently, we will primarily include classes from regular high schools in the course of our main study as we expect lower-attaining students to benefit substantially and even to a higher degree from the disaggregation and the reduced cognitive load. We suspect that the amplification of the sample will likely help to find robust statistical evidence for the effectiveness of the *Disaggregate Instruction-Approach*.

In addition, the classification of the students regarding their c-test results as well as the analysis of student text samples addressed at two different people with varying prior knowledge will certainly help to complement our initial findings and further pursue our research question. By adding more data and new insights to the findings from previous studies on *Disaggregate Instruction* we hope to contribute to the global linking of research on language instruction in science teaching and, most of all, to support students who struggle with the diverse demands of science learning.

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IN-SERVICE TEACHERS' ADAPTATION OF CONTEMPORARY RESEARCH TOPICS TEACHING MODULES UNDER MENTORING SUPPORT

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The negotiation of cutting-edge research topics in science lessons may contribute to students' scientific literacy. Even though respective teaching modules have been developed, their dissemination requires appropriate preparation and support for teachers to meet the challenges of such a venture. In this context, this study examines adaptations in-service teachers make to modules on cutting-edge research topics with the support of their mentors. In total 5 mentors and 32 in-service teachers participated in the study. The adapted modules and transcripts of the mentoring meetings were analysed. Data indicate that both teachers and mentors contributed to the adaptations, which were mostly focused on the activities of the teaching modules and that teachers' initiatives for adaptions were related to their mentor's guiding style.

Keywords: Teaching Innovations, Teaching Learning Sequences, Mentoring in Teacher Education

INTRODUCTION

Integrating teaching modules related to cutting-edge research in science classes familiarizes students with the process of scientific research and provides them with the opportunity to experience scientific knowledge as an ongoing procedure and to elaborate on its social implications (Wong et al., 2008). However, such an endeavour has not yet been broadly incorporated in science curricula and therefore it is still considered as an innovative practice for teachers. We consider as an educational innovation any new idea, teaching approach or practice which is novel for a specific target group and concerns an intentional activity that aims at changing an existing practice (Rogers, 2003). One of the means used to inform the practice of in-service teachers and to operationalize and disseminate educational innovations is the implementation of innovative teaching modules (Pintó et al., 2014) as they comprise a powerful learning experience for teachers, who are introduced to new educational approaches.

However, the dissemination of innovative teaching materials from the original context to the multiple implementation contexts is an inherently transformative process to the extent that teachers evaluate, adapt and finally implement the respective teaching module, in the light of their own personal teaching style, their students' needs and the particularities of their classroom (Pintó et al., 2005). To represent that interpretive process, Brown & Edelson (2003) introduced a framework that emphasizes the active role played in this participatory relationship by both the teachers (who bring in their personal resources) and the teaching material with its particular characteristics. The result of this interaction that takes place between the teacher and the teaching material falls into a range that extends between exact adoption of teaching material, its adaptation and the improvisation of the teacher. Thus, an innovation, in order to be disseminated and sustained, must embrace the active, interpretive teachers' role and their need to develop ownership of the innovation (Melville, 2008).

Hence, the introduction of an innovative teaching module should be appropriately supported during its implementation in order teachers to cope with the problems that arise in their daily teaching practice (Bitan-Friedlander et al., 2004). In particular, this ongoing support can be most effective when provided within a learning community, by a more experienced colleague acting as mentor and as a scaffold to support teachers in acquiring ownership of the innovation (Rogan, 2007). In our study we adopted the approach of mentoring in collaborative settings as it involves teachers in active learning processes by implementing teaching innovations, collaboratively exploring ways to improve their day-to-day practice and reflecting on it (Bradbury, 2009; Feiman-Nemser, 2012).

Based on this approach, the aim of the present study is to give an insight on the adaptations in-service teachers make to modules on cutting-edge research topics with the support of their mentors within learning communities. The main research question is: *How do in-service mentee-teachers adapt modules on cutting-edge research topics in order to implement them in their classrooms with the support of their mentors?* and it is examined through the following sub-questions:

(i) What adaptations do mentee-teachers and mentors propose?

(ii) What kind of practices do mentors use in order to support their mentors while adapting the modules?

METHOD

Research Design

In the context of our research, 5 mentors (who were previously trained in nanotechnology education and had developed and piloted a nanotechnology module) supported 32 primary and secondary education teachers in groups of 6-7 persons, in implementing a module on a cutting-edge research topic. The selected topics were: Nanotechnology applications, Microplastics in the ocean and Carbohydrates of baby formulas. All three modules were developed in the framework of the EU-project IRRESISTIBLE (www.irresistible-project.eu). Their innovative elements resided on:

- the negotiation of current research topics,
- the introduction of Responsible Research and Innovation (RRI) framework from educational standpoint in order to negotiate social implications of science (Owen et al., 2012),
- inquiry-based approach to learning, a process in which students are actively engaged by scientifically oriented questions, develop evidence-based knowledge of scientific phenomena and get acquainted with scientific practices (Minner et al., 2010) and
- the development of interactive scientific exhibits by the students as a means of communicating their newly acquired knowledge with their classmates and the public.

The mentoring process lasted for about 9 months during which each group held about 8 mentoring meetings and was divided in three successive phases. In the orientation phase, mentors and mentees elaborated on the scientific content of each module, the involved social implications and aspects of inquiry-based learning. In the redesign phase, mentees thoroughly examined the modules and then re-designed them in order to adapt them to each school context.

The implementation phase concerned the enactment of the modules in real class conditions and the mentees' reflection on the mentoring experience.

Data collection and analysis

Our main data source was the adapted teaching materials that were produced by the teachers and the audio-recordings of all the group mentoring meetings.

Due to the explorative nature of the research, qualitative methods of content analysis were used. Teachers' adaptations in all three teaching modules were identified through the detailed examination of the final lesson plans and teaching materials and their comparison with the original material they had received. As adaptation we defined any variation from the original teaching module, which was implemented by the teachers, whether it was originally suggested by a mentor or a teacher of the learning communities. These adaptations were categorized as related to (i) the scientific content of the modules, (ii) the activities carried out by students or teachers in the classroom and (iii) the materials which students interacted with (Table 1). Moreover, through the examination of the transcripts of the meetings we distinguished the adaptations as originally proposed by a mentor or by one of the teachers.

Table 1. Coding scheme for teachers' adaptations.

Categories	Criteria
Subject matter	Addition of related concepts
	Omission of concepts
Activities	Addition of activities
	Modification of activities
	Omission of activities
Physical Materials	Use of different materials
	Modification or development of new worksheets
	Use of different digital materials

Regarding mentors' style, the mentoring practices that emerged from the data were organized into two broad categories, according to Crasborn et al. (2011). Mentoring practices who tended to bring in information (e.g., sharing ideas and suggestions, giving feedback, giving instructions) were categorized as directive. In contrast, mentors' practices that aimed to extract information from the teachers (e.g., asking questions, reflecting, encouraging the development of alternatives) were categorized as non-directive.

RESULTS

Data analysis revealed that the majority of the adaptations were focused on the activities of the teaching modules, followed by the adaptations regarding the materials, while the number of those concerning the scientific content of the modules was more limited (Figure 1). This trend was common throughout all three teaching modules. However, noteworthy differences were observed in the number of adaptations suggested by teachers compared to those suggested by mentors in each teaching module. In the Nanotechnology module, teachers and mentors contributed equally to its adaptation, even if mentors' suggestions were mainly focused on the module's activities while the teachers proposed and carried out more practical modifications regarding materials of these activities. On the other hand, in the Microplastics and the Milk carbohydrates module we observed that mentors' suggestions for adaptations were far more limited than the teachers' across all the categories (content, activities and materials).

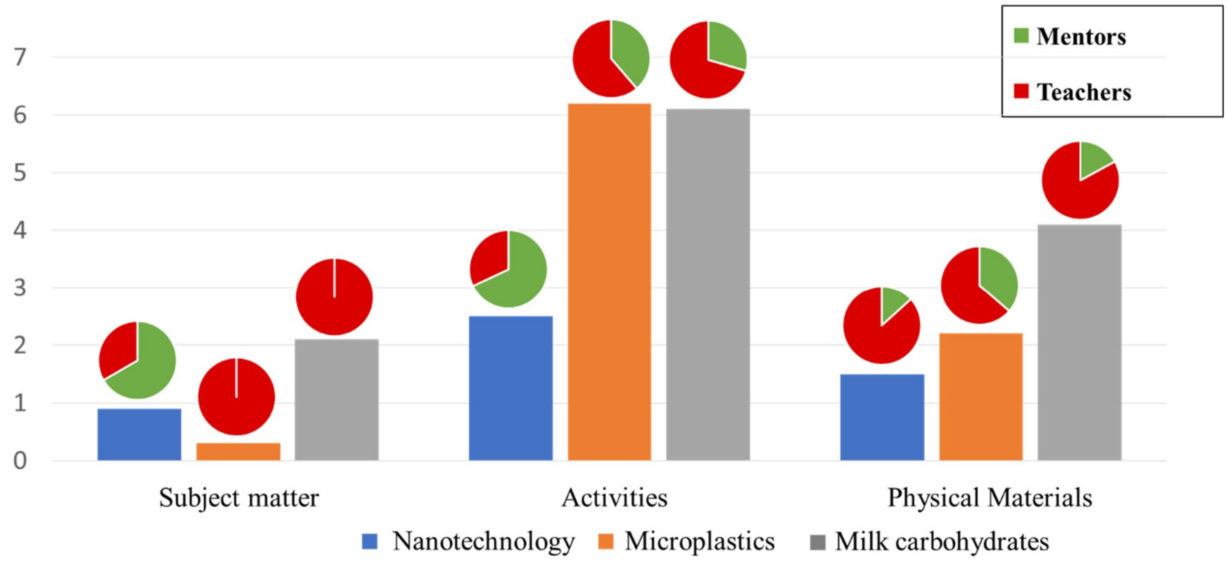

Figure 1. Absolute frequency of adaptations per teaching module and person that introduced them.

The results among the three modules were also similar in case of the practices mentors employed to support their mentee-teachers. Across all five learning communities mentors tended to use mostly directive practices in order to guide the teachers throughout the re-design phase, as sharing their opinion and experience from previous implementation of the Nanotechnology module and explaining the significance of the incorporated innovative elements. However, they adopted a far more directive mentoring style when supporting the implementation of the Nanotechnology module than the Microplastics and the Milk carbohydrates module.

Table 2. Percentage of use of mentoring practices.

Mentoring Practices		Nanotechnology	Microplastics	Milk carbohydrates
Directive practices	Model	32%	11%	9%
	Advise	29%	27%	34%
	Give feedback	17%	20%	28%
	Evaluate	7%	11%	7%
Non-directive practices	Posing questions	5%	13%	9%
	Encourage	8%	12%	10%
	Summarise	2%	6%	3%

In fact, our results revealed a negative correlation between the adoption of a more directive mentoring style and the suggestion of adaptations by the teachers themselves for all three modules (Figure 2). This means that the less directional the mentors were, the more initiatives teachers took to suggest modifications of the modules.

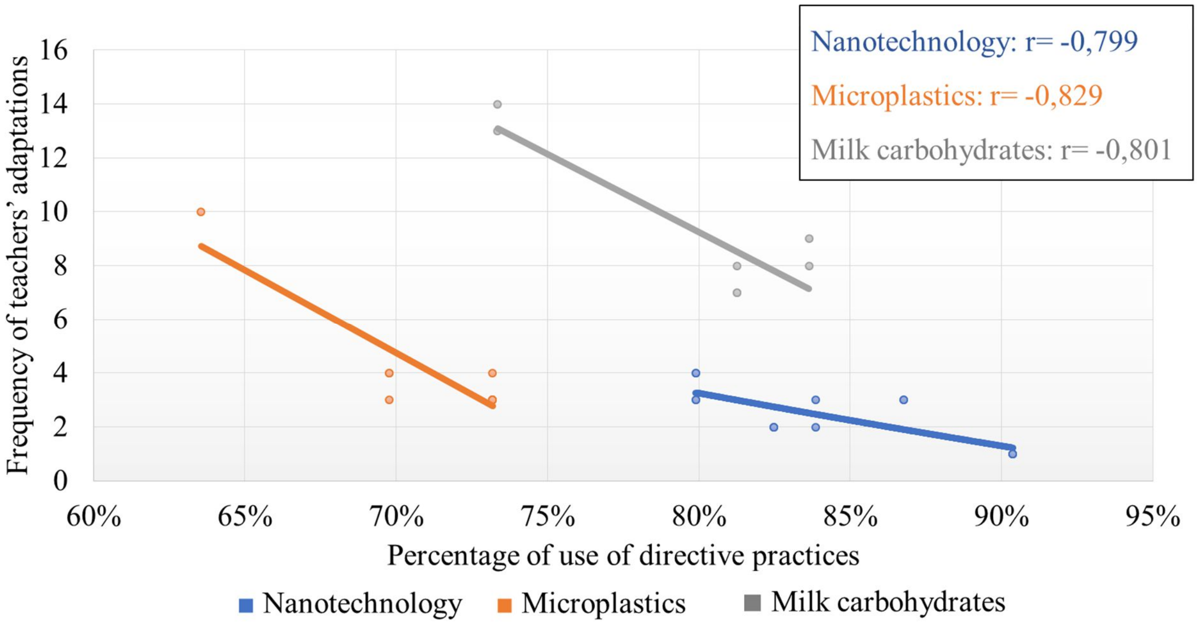

Figure 2. Correlation between mentors' use of directive practices and the absolute frequency of teacher-introduced modifications.

DISCUSSION AND CONCLUSIONS

In the context of our study, the participating teachers were invited to apply in their classrooms ready-made innovative teaching modules on cutting-edge research topics. However, as highlighted by Brown (2009), the preparation of their lessons had a strong redesigning orientation, through which teachers developed ownership of the innovation adapting the modules to their teaching style, their students' needs and school context. The above took place in a safe environment shaped by the non-evaluative guidance provided by mentors, and in collaboration with colleagues who had a common goal. In this process, the mentors did not just have a supportive role, but actively participated by proposing themselves and supporting a significant number of modifications based on their previous experience. Moreover, mentors' contribution in this process was crucial as it was their intervention that ensured that the adapted modules would remain faithful to the spirit of the innovation, despite the requisite teachers' modifications. Finally, the results on the correlation between the mentoring style and the development of the teachers' sense of ownership may also contribute to the formation of guidelines regarding the support that should be provided to teachers in order to implement an innovation, emphasizing the balance between freedom to adapt innovations and guidance to ensure that these adaptations do not alter the rationale of the innovation. All the above elements reinforce the position that group mentoring is not only a useful tool for teachers' professional development but may also be used to support the implementation of innovative teaching modules.

Given that teacher modifications are intertwined with the degree of ownership and their importance in the sustainability of the innovation the results on the correlation between the mentoring style and the development of the teachers' sense of ownership may also contribute to the formation of guidelines regarding the support that should be provided to teachers in order to implement an innovation, emphasizing at first the ongoing support throughout the implementation phase and secondly the balance between freedom to adapt innovations and guidance to ensure that these adaptations do not alter the rationale of the innovation. Therefore, the active participation of in-service teachers in the process of both developing and disseminating a TLS is considered beneficial and as such it must be evaluated by science education research.

ACKNOWLEGMENTS

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EVOLUTION OF THE MODELS OF MILK FERMENTATION OF SECONDARY STUDENTS IN THE DEVELOPMENT OF A TEACHING LEARNING SEQUENCE ON THE NEED TO TAKE YOGURT

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Modeling is a scientific practice that allows students to learn, describe and predict scientific phenomena through representations, images, models, etc. However, modeling is a complex process that requires the acquisition of several scientific skills. As students acquire skills to work with models, they develop not only scientific skills, but also social, linguistic, etc. This study presents the evolution of the models on the transformation of milk into yogurt (lactic fermentation) by 23 10th grade students from two schools in the province of Malaga (Spain) at different times of a teaching-learning sequence (TLS), focused on the preparation of yogurt and if this is a healthy food. In order to analyze the models proposed by the students, a simplified school model was used, consists of three phases (1. reproduction of bacteria, 2. acid formation and 3. protein denaturation), finding 5 categories depending on the phases that could be identify in their answers. The evolution of the models was studied over 4 moments: before the TLS, after knowing the composition of milk and yogurt, after making homemade yogurt, and at the end of the TLS after knowing the scientific model. The results showed that the student models are getting closer to the reference school model as the TLS progresses, detailing all the phases in the last two moments and decreasing the frequency of students who do not indicate any model. However, there is not a significant number of students who include the three phases in the model, so work must continue in this regard.

Keywords: Models in Science, Secondary School, Teaching Learning Sequence

INTRODUCTION

The teaching of the chemical reaction model in the context of fermentation, poses a challenge to the most common approaches in the initiation to the learning of chemistry, in which the chemical reaction models are raised from simple phenomena of the inorganic world (Aragón, Oliva & Navarrete, 2010). We consider that, although it can be teaching from a more complex way and requires a careful educational transposition (Chevallard, 1998), the importance that the model can have in explaining everyday phenomena is gained. The importance of food in daily life, both personally and socially, makes this context relevant for the chemistry teaching at the secondary school. Specifically, kitchen chemistry is considered a very useful context in science education given the large number of chemical and physical concepts that can be addressed in it, the ease in preparing some recipes, and the similarity of the kitchen with a science lab. For this reason, this study uses yogurt as a context to study the evolution of Spanish grade 10 students' models on the transformation of milk into yogurt (lactic fermentation) at different times of a teaching-learning sequence (TLS) that addresses this topic.

METHOD

The study is carried out in a TLS focused on the production of yogurt and if this may or may not be considered a healthy food (Muñoz, Franco and Blanco, 2020) implemented with 23 10th grade students from two secondary schools in Malaga (Spain) (A and B) in the field of chemistry. The age of the participants was 16 years and 52% were girls. The TLS was developed in 9 one-hour class sessions in which different tasks related to modeling were interspersed. To identify the student models, a simplified school model involving three phases was used. Phase 1, reproduction of bacteria, consists of an increase in the number of bacteria in the milk as the temperature increases through a biological mechanism. In the second phase, a chemical transformation occurs where milk sugar (lactose) is divided into glucose and galactose, transforming glucose into lactic acid by the action of bacterias. In phase 3 the transformation is completed by intervening the lactic acid obtained as a product in the previous phase. This phase consists of the denaturation of proteins by the action of lactic acid through a chemical transformation, producing a decrease in pH (Muñoz, Franco and Blanco, 2020).

In order to know the evolution of the lactic fermentation models proposed by the students, four moments of the TLS were analyzed in which they were asked to explain this transformation with a model and a drawing: (1) before the TLS, (2) after to know the composition of milk and yogurt, (3) after making homemade yogurt, and (4) at the end of the TLS, after knowing the scientific model. At moments 1 and 2, the students were helped by indicating that bacteria were responsible for the transformation of milk sugar into acid (phase 2), while in moment 3, the help consisted in indicating that the components involved they were bacteria, sugars and milk (phases 1, 2 and 3). Moment 4 differs from the others in that it requires an open explanation of the process. The aim is to analyze the evolution of the student models with the same type of questions and less help.

The transformation of milk into yogurt is from the ontological point of view (Chi et al., 1994) a concept related to a process and for an adequate explanation of it, it is necessary to attend to the following aspects: What material things are involved? (systems), what happens between them? (type of interaction), and what things change during the process? (type of transformation). In a previous paper (Franco-Mariscal, Blanco-López and España-Ramos, 2018) this scheme was used to analyze the models of the students on another process such as dental caries, in which the models were categorized around in two dimensions, the active agent and the mechanism. And based on these two dimensions, a progress scheme of the models identified in the students was proposed. The application of this scheme to the transformation of milk into yogurt involves identifying the entities (milk and bacteria), the interaction that occurs between them and those that result (yogurt).

For this, a reading of the answers was carried out, and through an inductive and iterative process the different categories emerged. In order to categorize the answers, the drawings and explanations offered by the students were analyzed jointly in each of the tasks about models during the different moments of the TLS, from which the possible underlying models could be identified. In this study, it is considered that a mental model on the transformation of milk into yogurt must have the three phases mentioned above and in each of them indicate two components (the agent and the mechanism).

Of the answers given by the students, it has been possible to identify five categories: (C1) no model, (C2) models that explain the transformation including only phase 1, (C3) models including only phase 2, (C4) models including phases 1 and 2, and (C5) models including phases 2 and 3.

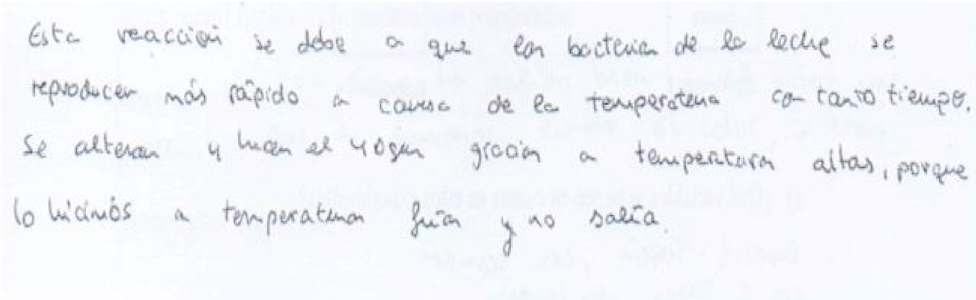
RESULTS

Analysis by phases of the scientific school model

Phase 1. Increase in the number of bacteria

First, it is necessary to point out that very few students mention this phase of the process and all of them are from group B. Furthermore, these models only appear when the students have prepared homemade yogurt.

A model has been identified that considers that during this phase a biological transformation takes place that consists of the reproduction of bacteria. This model indicates that the agent is the bacteria and as a mechanism the reproduction of the bacteria itself with the help of temperature, as we can see in figure 1.


Esta reacción se debe a que las bacterias de la leche se reproducen más rápido a causa de la temperatura con tanto tiempo. Se alteran y hacen el yogur gracias a temperaturas altas, porque lo hicimos a temperatura fría y no salía.

Translation: "This reaction is due to the fact that the bacteria in the milk reproduce faster by high temperature. They get excited and make the yogurt, because it was made at a low temperature and the milk did not turn into yogurt"

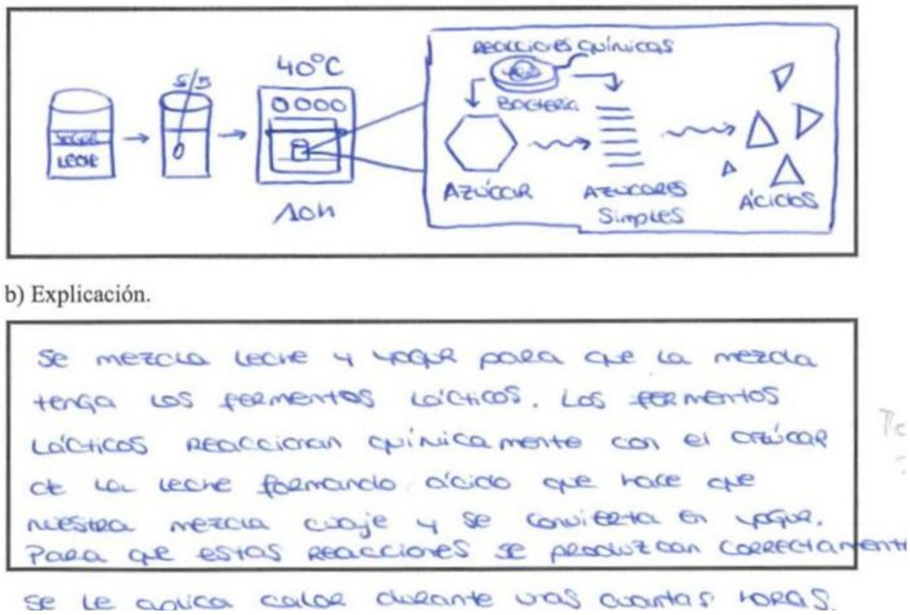
Figure 1. Biological transformation (Phase 1).

The fact that this model is only found in one of the groups shows that it is not an aspect that students can achieve on their own through the experience of making yogurt. It may be due to the knowledge that certain students had about the reproduction of bacteria and the factors that accelerate it. These results show the need to devote specific attention to this phase of the process, addressing specifically to students the role that temperature plays in the transformation of milk into yogurt.

Phase 2. Transformation of sugar into acid

In this phase, the students' answers are more complex to analyze since they include references to the four elements of the model (agent, support, product and mechanism). A large number of models appear when different agents are combined with mechanisms being mentioned by both groups.

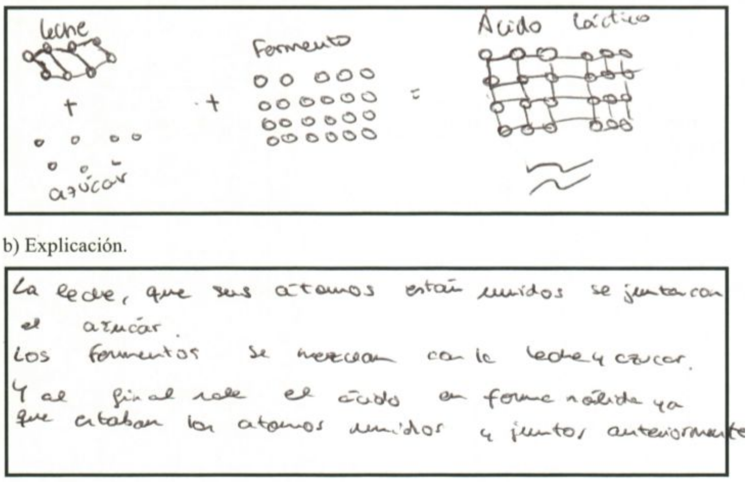
The most frequent model is the closest to the reference school model, indicating that by the action of bacteria, milk is transformed into yogurt through a chemical transformation (figure 2).



Translation: **"**Milk is mixed with yogurt so that the mixture has the lactic ferments. These chemically react with the sugar in the milk to form acid, which causes the mixture to curdle and turn into yogurt. For the reaction to take place, high temperature is necessary for a period of time**".**

Figure 2. Chemical transformation whose agent is bacteria (Phase 2).

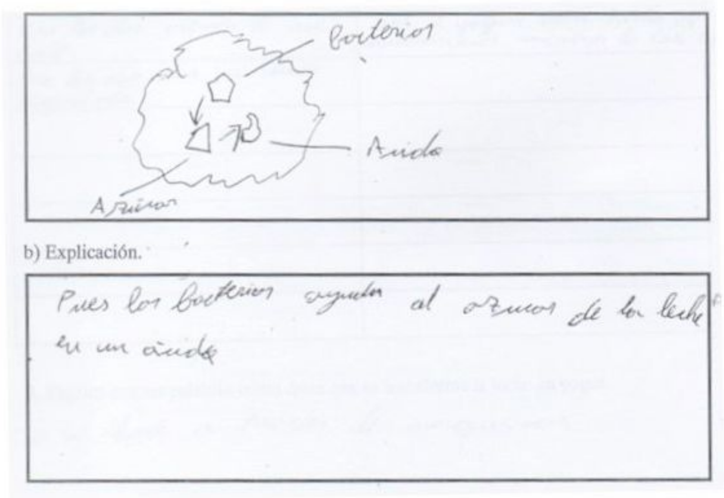
Considering the agent, in all the moments of the TLS, the one that is most mentioned is that of "bacteria" followed by "bacteria and other components". Almost all the answers of the students that mention "bacteria and other components" as an agent indicate that the process goes through a physical transformation (figure 3).



Translation: "The lactic ferment mixes with the atoms of the milk, in such a way that the atoms come together and form the yogurt".

Figure 3. Physical transformation whose agent is bacteria (Phase 2).

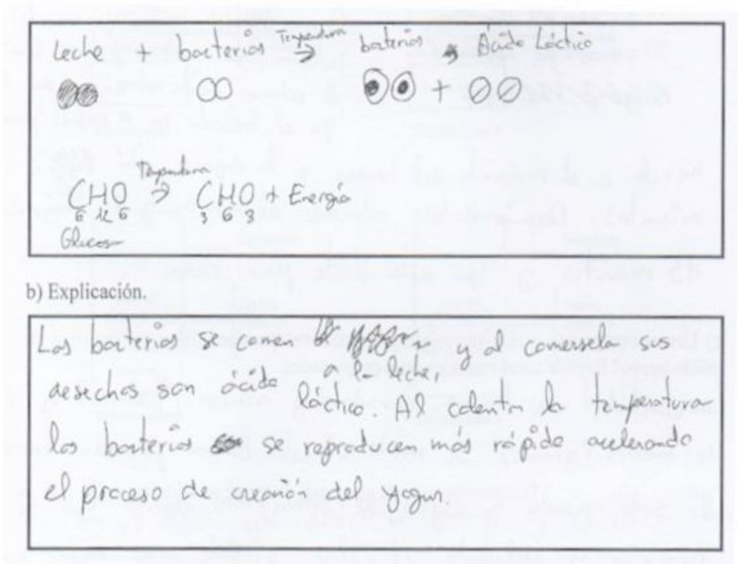
From the point of view of the mechanisms, the chemical transformation is the one that the vast majority of students' answers. Only three students do not indicate the type of mechanism that the process of transforming milk into yogurt undergoes and these answers are given before starting with the teaching sequence (figure 4).



Translation: "Bacteria convert milk sugar into acid".

Figure 4. Does not specify transformation, bacteria agent (Phase 2).

This phase is the only one where the mechanism related to biological functions appears (figure 5), in which the students mention that the transformation process takes place through the digestion of the bacteria considered as an agent.

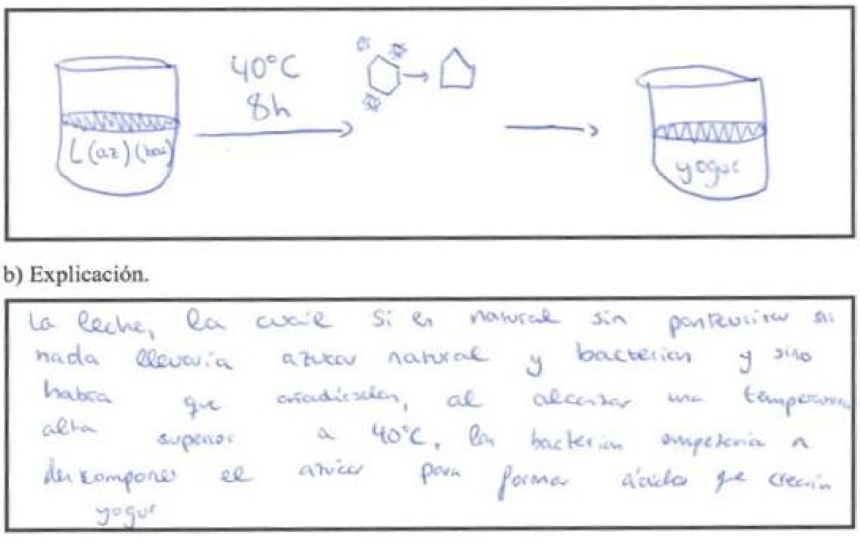


Translation: "Bacteria eat sugar and their waste is converted into lactic acid. As the temperatura increases, bacteria reproduce faster, accelerating the reaction".

Figure 5. Biological transformation whose agent is bacteria (Phase 2)

Phase 3. Protein denaturation

Contrary to what happened in phase I, this phase is only mentioned by students from group A. To categorize the answers to some model of this phase, it has been taken into account as a criterion that there were explicit indications or references to a transformation subsequent to the second phase. The frequent model is the closest to the reference school model, indicating that a chemical transformation occurs through an agent that is acid (figure 6).



Translation: “Milk carries sugar and bacteria, at a temperatura above 40ºC, bacteria begin to break down the sugar in the milk to transform i tinto acid”.

Figure 6. Chemical transformation whose agent is acid (Phase 3).

Analysis by moments of the TLS

Before TLS (moment 1). Categories C1 (minority), C3 and C5 were detected (Figure 7).

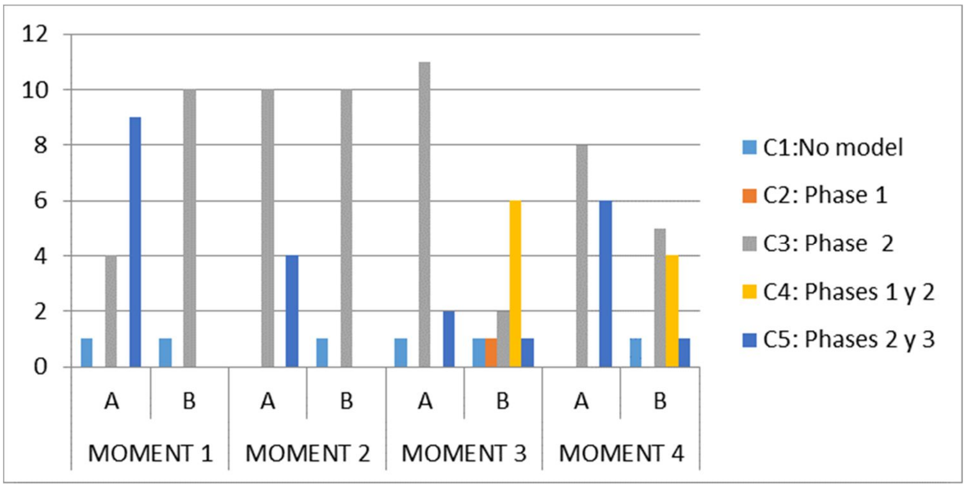


Figure 7. Overall results of both groups at the different moments of the TLS.

While in group B the responses were only related to phase 2 (C3), some students in group A relied on phases 2 and 3 (C5), this type of response being the majority in this group**.**

After knowing the composition of milk and yogurt (moment 2). Same categories were found as at moment 1, with the majority response being C3 (phase 2 only), cited equally in both groups. A student without a model (C1) was found in group B. Only in group A were responses that referred to both phase 2 and 3 (C5) detected. Attending to moment 1, the number of students in group A that indicated phase 2 increased, while in group B it remained.

After making homemade yogurt (moment 3). The five categories were found, with C3 being the majority category, as in the previous moments. Only in group B explanations were detected that included phase 1 (C2), or phases 1 and 2 (C4), the latter being the majority response. However, in group A, the most numerous response continued to be that indicated only in phase 2 (C3). Comparing these results with those obtained at other times, in group B there are fewer students who mention phase 2 (C3), increasing this category in group A.

*At the end of the TLS, after knowing the scientific model (moment 4)***.** Four categories were found (C1, C3, C4 and C5) being again the majority C3. Students in group A only mention either phase 2 (C3) or phases 2 and 3 (C5) exclusively. With respect to previous moments, in this group there was an increase in the frequency of students who considered that the process is carried out through two phases (categories C4 and C5) and not just one. However, there is still a significant number of students who consider a single phase. On the other hand, the student who did not indicate a model, disappeared. In group B, they again mentioned C3, C4 and C5, the answer that states that the process is only carried out through phase 1 (C2) disappears and the student continues who does not recognize any pattern (C1). Also decrease the number of students indicated by C4 by increasing the answers for C3. In both group A and B, the majority category is C3.

CONCLUSIONS

The results show an important progress in the lactic fermentation models expressed by the students when advancing in the TLS, finding all the phases of the school model in the last two moments and decreasing the frequency of students who do not indicate any model. It seems that making yogurt in the classroom and knowledge of the scientific model are important to better understand how transformation occurs. The results also show, that the TLS achieves that a good number of students are able to explain lactic fermentation with more advanced models than those usually found in the literature (Moreno & López, 2013). However, not all students have been able to include all three phases at the moment, so more modeling tasks must continue in the classroom to achieve this goal. Finally, the differences found between the two groups regarding the mentioned phases, may be due to the initial background of these students in understanding the chemical reaction or the role of bacteria in biochemical reactions, a topic that will be the object of study in future research.

ACKNOWLEDGMENTS

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DEVELOPMENT OF PROCEDURAL KNOWLEDGE AND EXPERIMENTATION SKILLS IN SECONDARY EDUCATION

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This study examines the development of procedural knowledge and experimentation skills in high-school students after a context-specific Teaching Learning Sequence (TLS) in a virtual AC electric circuit laboratory environment. The students (N=18, aged 16-17) were subjected to an inquiry-based teaching intervention aiming at developing their procedural knowledge, experiment design and implementation skills. A TLS was developed and enriched with explicit teaching of the experimentation procedures and inclusion of metacognition-enhancing activities. A pre-/post-instructional assessment scheme was used to evaluate students' procedural knowledge and experimentation skills. Our data comprise completed questionnaires for assessing procedural knowledge and worksheets completed during pre- and post-task in-class assignments for assessing experimentation skills. Overall, after instruction, students have significantly advanced their procedural knowledge and experimentation skills on the subject of AC electric circuits. The statistical analysis of our data shows a strong correlation between the procedural knowledge (completed questionnaires) and the experimentation skills (worksheet task assignments) acquired by the students.

Keywords: Teaching Learning Sequences, Inquiry-based teaching, Scientific Experimentation

INTRODUCTION

Studies suggest that inquiry-based teaching using virtual laboratory environments can promote students' engagement in experimental investigative activities thus enhancing their conceptual understanding of physical phenomena (Ruten et al., 2012). Furthermore, being involved in such activities, students may also acquire investigative skills, such as hypothesis forming, variable identification, experimental procedure description and implementation, results evaluation and conclusion drawing (Taramopoulos et al., 2011). The acquisition of such skills by students is an important ingredient towards the understanding of scientific methodologies of experimentation. However, the development of students' experimentation skills alone does not suffice for them to design and implement scientifically valid experiments, since experiment design and implementation are relevant to both the scientific domain being studied, and the scientific methodology (Garratt & Tomlinson, 2001). And there is evidence that students find it difficult to set up and perform well-designed experiments (de Jong & van Joolingen, 1998). Hence the term 'practices' has been suggested to be used instead of the term skills to emphasize the requirement for both knowledge on aspects of experimentation and skills in scientific experimentation (NCR, 2013).

Inquiry-based teaching using either physical (PL) or virtual (VL) laboratory environments can promote students' engagement in laboratory activities and help them acquire experimentation skills (Brinson, 2015), through teaching of the implemented experimental procedures either implicitly (Lefkos et al. 2011), or explicitly (Vorholzer et. al., 2020). Explicit teaching is deemed to be quite efficient for secondary school students in domains like mechanics or DC electricity by the recent study of Vorholzer et. al. (2020) who report that by including explicit teaching of the inquiry phases as part of the instruction and combining this with metacognition-enhancing activities, students' skills and knowledge may be further improved. It seems then plausible that one way to develop students' experimentation skills would be to teach them explicitly scientific procedures of experimentation embedded in normal domain inquiry-based instruction. It is expected that by such explicit teaching students may develop both their understanding of the physical phenomena under study (cognitive knowledge) and their understanding of scientific procedures followed when designing and contacting scientifically valid experiments (procedural knowledge), while developing their experimentation skills through investigative activities. Therefore, it is important that further evidence is provided on the efficiency of such an approach and that the relation between the development of students' procedural knowledge and their experimentation skills is further investigated.

Although research in Teaching Learning Sequence (TLS) is a productive area of research, most TLS studies have focused on examining students' enhancement of domain knowledge rather than on the development of their procedural knowledge or investigative skills. In this context we have developed and applied an innovative inquiry-based technology-enhanced TLS, integrating VL in the area of AC circuits for secondary school students and taking into account TLS design issues suggested in the literature (Psillos & Kariotoglou 2016), aiming at enhancing both students' procedural knowledge and experimentation skills. Our present research aims at examining whether the development of procedural knowledge, being offered explicitly during such an enriched inquiry-based TLS to secondary education students, correlates well with the development of students' experimentation skills in terms of designing and performing scientific experiments in a virtual AC circuit laboratory environment.

METHOD

Participants were 18 students (17-18 yrs) from a senior high school in Greece. All students had some prior knowledge of DC electric circuits, but none of them had received any prior instruction on AC circuits. Our approach drew on teaching the scientific procedures of experimentation explicitly, involving students in inquiry-based guided experimental activities utilizing an open virtual laboratory environment in AC circuits. The virtual laboratory environment used was the open virtual electric circuit laboratory WebLab of the Science Center and Technology Museum (NOESIS), equipped with a user-friendly drag-and-drop interface and an affordance of dynamically-linked concrete and abstract representations of electric circuits, shown in figure 1 (Molohidis et al., 2015).

The TLS consisted of seven hourly units with modular worksheets. The activity worksheets contained an initial problem-question and students were prompted to design an appropriate experiment to solve the problem, construct a suitable circuit and carry out the experimental procedure they had designed. Thus they prompted students to provide answers for various aspects of experimentation, including formation of a hypothesis, proposal of experimental verification of the hypothesis, identification of variables affecting the phenomena being studied, listing of devices and instruments needed, describing the experimental setup, the phenomena taking place and the experimental process, setting up the appropriate circuit for the experiment, taking and analyzing measurements, evaluating and interpreting results, drawing conclusions and evaluating the initial hypothesis.

Students were randomly divided into six subgroups of two and two subgroups of three, while each subgroup had access to a single computer. They were first directed to discuss the questions of the worksheets within their subgroup and if their problems were not solved, they were asked to initiate an open discussion with the whole class. During this open class discussion, subgroups were expected to refer to their views and findings on the issue raised and converge to the scientific answer through the supervision and coordination of the instructor. The instructor also filled in any missing field knowledge so that the students have an understanding of the phenomena taking place in the circuits they were studying.

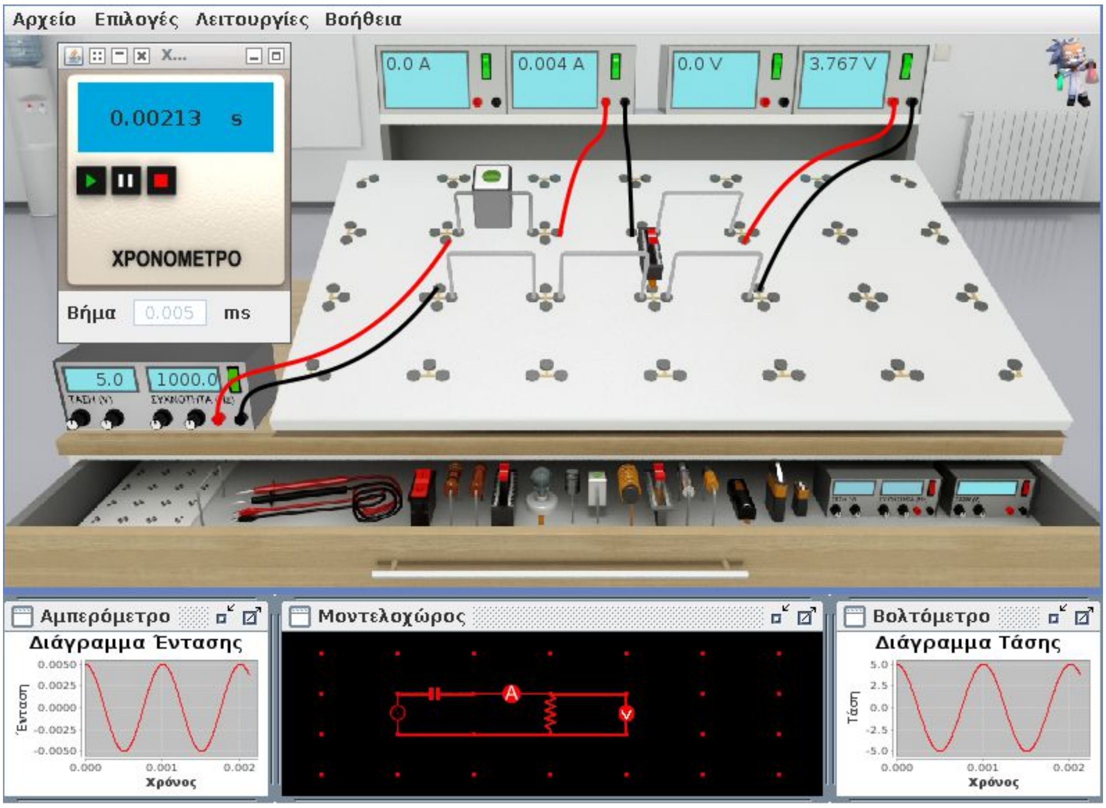

Figure 1. The NOESIS WebLab virtual laboratory environment.

Three experiments were performed in total during this innovative TLS and aspects of scientific experimentation were explicitly taught to the students who were prompted to design each experiment guided by a design activity worksheet and then perform the experiment they had designed guided by an implementation activity worksheet. The design and implementation worksheets of the first experiment of the TLS followed a structured inquiry pattern. Initially the design activity worksheet contained an initial problem-question in order to provoke students' questioning. The students were then guided to design an appropriate experiment to solve the problem, being provided scaffolding through appropriate questions of the worksheet, reflect upon their previous knowledge in order to find the theoretical knowledge being applicable to the problem, take a decision on the physical quantities needed to be measured, design an appropriate circuit to take necessary measurements, draw it schematically and decide on the experimental procedure for measuring the quantities needed. The experiment implementation worksheet, which followed this first experiment, initially asked the students to construct the circuit they had drawn schematically in the virtual laboratory environment. Then, students were asked to carry out the experimental procedure they had designed, understand and analyze their measurements, formulate the answer to the initial problem and evaluate their predictions. After having completed each experimentation phase, students were prompted to reflect upon the experimentation steps they had carried out in order to reach the final result. A part of the first design activity worksheet is included in Appendix A.

The TLS should allow students to take decisions about the experimental procedure they would follow, by designing their own circuits, constructing them in the virtual environment and exploring their behaviour, rather than reading about, constructing and exploring given circuits. Therefore, the guidance embedded in the activities varied during the TLS. After the first unit, instruction gradually moved towards guided and finally open inquiry as the TLS was progressing and students became more familiar with the scientific experimental procedure (Zion & Mendelovici, 2012). Appendix B shows the activity worksheet of the last unit which followed an open inquiry pattern with a given initial problem.

During instruction students were involved in reflection upon the actions carried out as part of the experiment design and implementation procedures. The teacher guided the students and explicitly named and described each procedure followed by them. Also, one of the units, halfway through the TLS, contained a reflection on the experiment design and implementation process, during which the teacher and students reviewed and after discussion wrote down the scientific experimental design and implementation procedures applied in the previous units.

A pre-/post-test design was implemented, with pre- and post-tests assessing both students' procedural knowledge via a paper-and-pencil written questionnaire and experimentation skills in AC electric circuits via the design and implementation of certain experiment tasks. The questionnaire contained 18 multiple-choice questions about various aspects of experiment design and implementation. All questions were expressed in the context of electric circuits and did not require any knowledge other than the one students had received instruction for in previous school years. The questionnaire assessed aspects of experimentation, such as forming hypotheses, variable identification, choosing materials and instruments, describing experimental procedure, obtaining results, forming and evaluating conclusions. The same questions were used both as a pre-test and a post-test but the order of the questions in the pre-test differed from that in the post-test. Also, the order of the answer items for each multiple-choice question in the pre-test differed from that in the post-test to minimize the effect of any memorizing strategy students might have adopted. The questionnaire was developed and verified for content validity and reliability in a previous pilot study (Taramopoulos & Psillos 2020). Measurements of Cronbach's alpha for the current study gave values of 0.756 (pre-test) and 0.778 (post-test), indicating sufficient reliability. The students' scores were adjusted to a 100-point scale and the mean test score was then calculated.

The students’ experimentation skills were assessed through a pre- and a post-test task in-class assignment. Before the beginning of the TLS, students were asked to design and perform an experiment in order to answer if Ohm's law for resistors holds in AC circuits similarly to DC circuits (pre-test task). The post-test task asked the students to design and implement an experiment in order to answer whether a circuit, with an inductor connected in parallel to a capacitor, behaves in AC as a bandpass filter. Both tasks were accompanied by appropriate worksheets which did not contain any guidance other than the initial question and a prompt to design and perform an experiment to answer it describing in detail their actions. Two experienced researchers scanned the worksheets for statements which showed skills in any of the experiment design and implementation phases and then classified their statements according to a three-level Likert scheme for each experimentation phase. A lack of statement or a statement which did not contain any correct experimentation elements was classified as level 1, a partially correct or a partially complete statement as level 2 and a correct and complete statement as level 3. This level classification was considered to be a process which sampled students' experimentation skill level at each experimentation phase. Students' levels were averaged and then adjusted to a 100-point scale.

RESULTS

We have avoided using parametric tests in the comparisons to ensure that our results do not depend on the assumptions of these tests and are not affected by our small sample size or other characteristics of our data. We therefore based our conclusions on the overlap of the 95% confidence intervals, which were calculated using BCa CI (Bias Corrected and accelerated Confidence Intervals) with 1000 samples, randomly selected from the current research sample. In effect, this technique, known as bootstrapping, treats our sample data as a population from which 1000 random smaller samples are taken. From these samples, the properties of the sampling function of our data, like the 95% confidence intervals, can be estimated avoiding possible bias due to our small sample size (Efron & Tibshirani, 1993). No overlap between compared BCa Confidence Intervals implies that the means come from different populations and are significantly different at the $p<0.01$ significance level (Cumming & Finch 2005). Significant overlap of the order of half the length of the confidence interval or greater implies that there is no statistically significant difference between the means of the compared populations ($p>0.05$) (Cumming 2012).

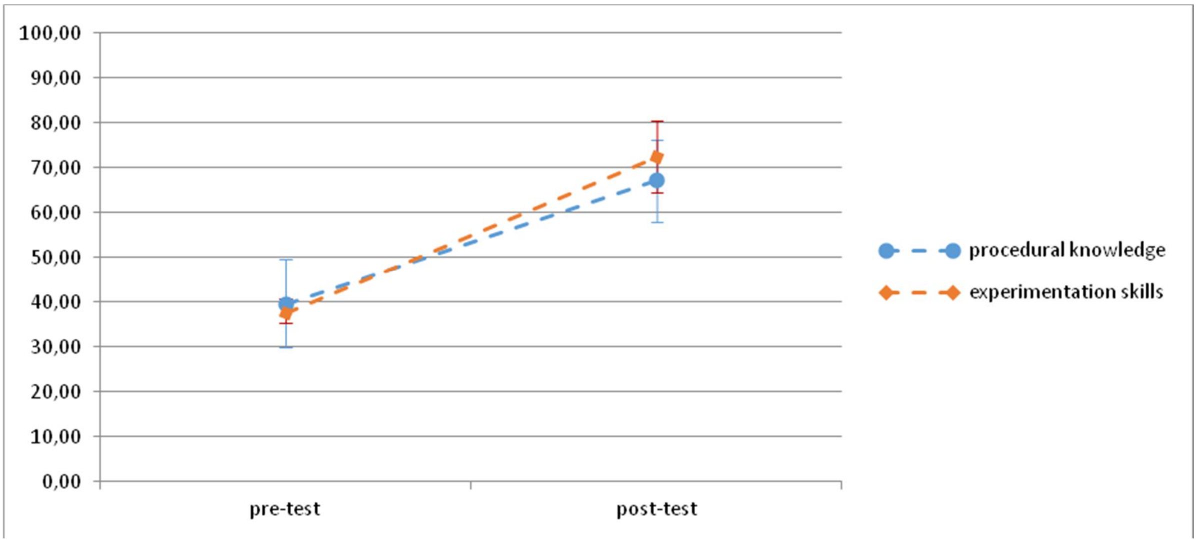

Figure 1. Pre-and post-test scores for procedural knowledge and experimentation skills.

Comparing the students' scores in the procedural knowledge pre-test questionnaire with the scores from the worksheets in the pre-test task we have found that there is significant overlap in BCa CIs and therefore these scores were statistically similar ($M_{procpre}$=39.78 [29.87,49.70], $M_{taskpre}$=37.73 [35.28,40.88]). The same was true for the scores in the procedural knowledge post-test with the scores from the post-test task worksheets (Mprocpost=67.33 [57.88,76.16], Mtaskpost=72.45 [64.64,80.40]) (results are shown in Figure 1).

There was a statistically significant increase for both the procedural knowledge and the experimentation skills of students between the pre- and post-test scores (no BCa CIs overlap, $p<0.01$) with a strong statistically significant positive correlation between them, $r=0.91$ [0.86,0.99].

DISCUSSION AND CONCLUSIONS

In order to help students, understand the procedures of scientific experimentation in AC electric circuits during normal in-class instruction, an innovative inquiry-based technology-enhanced Teaching Learning Sequence (TLS) was developed. The TLS, which utilized an open virtual AC circuit laboratory environment, was enriched with reflection metacognition-activities and aimed at the development of both procedural knowledge and experimentation skills. Results show that after the TLS, students seem to have significantly developed both their procedural knowledge and their experimentation skills. Thus, our TLS appears to be effective in helping students advance their procedural knowledge on designing and implementing experiments in AC circuits and simultaneously develop students' experimentation skills on performing aspects of the scientific experimentation procedures.

Our results also indicate that the development of procedural knowledge may correlate well with the development of experimentation skills. Thus, in the context of a technology enhanced inquiry-based TLS it seems that by enhancing students' procedural knowledge, e.g. through explicit teaching in the classroom, and involving students in designing and implementing experiments through investigative activities, the experimentation skills of secondary school students may also be enhanced. Therefore, the term "practices" may justifiably be used instead of the term "skills" to emphasize that engaging in scientific investigation requires not only skills but also knowledge that is specific to each aspect of experimentation (NRC, 2013).

Our results, combined with the results of previous studies (Taramopoulos & Psillos, 2020), in which it is reported that after instruction utilizing such a TLS the students' cognitive knowledge is also advanced, seem to indicate that by enriching instruction with the explicit teaching of the experimentation procedures, teaching may achieve several goals simultaneously: advance students' cognitive knowledge, advance their procedural knowledge and develop experimentation skills. In this way students may acquire the knowledge and the skills to investigate physical phenomena on their own and through this acquire a deeper understanding of physical sciences. Hence our results put forward the claim that by including explicit teaching of the experimentation procedures combined with metacognition-enhancing activities as part of the instruction, secondary school students' experimentation skills and knowledge may be significantly improved, in accordance with other recent similar reports (Vorholzer et. al., 2020). More research is necessary to reinforce this claim given the limitations of our current study, such as the lack of comparison with implicit teaching of experimentation procedures.

Examining the relation between the development of students' procedural knowledge and experimentation skills, a strong correlation is observed. This is indicative of the fact that both are developed simultaneously during the TLS. However, it does not necessarily imply any causal relation between them, nor does it provide clues as to how this may have been achieved during the TLS. Further investigation is necessary to clarify the nature of this correlation.

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Appendices

Appendix A

A part of the first structured inquiry, experiment design, activity worksheet:

I. Experiment Design

Activity 2 (physical quantities recognition)

Which quantities will be needed to be measured in the output of the circuit which will be constructed? (A. dependent variable recognition - physical quantities recognition dimension)

....
....

Since we want to explore what happens in both high and low AC frequencies we will have to change a certain physical quantity during our experiment. So, which physical quantities do we need to change in order to observe the changes in the quantity measured in the output? (B. independent variable recognition - physical quantities recognition dimension)

....
....

When we conduct an experiment we do not alter many variables simultaneously, because if we do so and a change occurs in a measured quantity then we will not know which variable we changed resulted in the change in the measured quantity. Thus we wish to preserve constant all the rest of the quantities which affect the measured quantity. Which quantities need to remain constant in our experiment? (e.g. the amplitude of AC voltage, time of measurements, instrument properties) (C. recognition of variables which need to be controlled - variable control strategy - physical quantities recognition dimension)

....
....

* What are the 3 actions, the 3 steps done in activity 2? (reflection activity)

A)____________________________

B)____________________________

C)____________________________

(Activity 2 conclusion: In order to design an experiment it is necessary to find which quantities are involved, A. which ones should be measured, B. which should be altered, and C. which ones should be kept constant.)

Appendix B

A part of the last open inquiry activity worksheet:

I. Experiment Design

Based on the behaviour of RC and RL circuits in AC, what do you think happens when a resistor (R), a capacitor (C) and an inductor (L) are connected in series? Which AC frequencies have the highest voltage amplitude in the output and why?

....
....

How can you check experimentally the hypothesis you made above? Design an appropriate experiment. Describe your design below in detail.

....
....
....
....

II. Experiment Implementation

Open the virtual electric circuit laboratory in your computer and perform the experiment you designed above. Follow the steps described, record and process your measurements, report the results and state your conclusion below.

....
....
....
....

Does your conclusion agree with your prediction? If not, why is there a discrepancy?

....

UNDERSTANDING THE EFFECT OF MICROORGANISMS ON HUMAN HEALTH: A DIDACTICAL PROPOSAL FOR SCIENCE EDUCATION

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Understanding the effect of microorganisms on human health is essential to change people's thoughts and hygiene habits. This educational goal becomes even more significant nowadays, due to the global pandemic caused by COVID-19, where day-to-day citizens' hygiene practices have become even more relevant for public health. Furthermore, science teachers take on a special role in promoting teaching and learning strategies. They also provide resources that raise students' awareness of this theme. The didactic sequence "Effect of Microorganisms on Human Health", designed and evaluated during a Research and Development (R&D) project, presented an innovative educational proposal regarding Microbiology in Natural Sciences of the 6th grade in Elementary Education (11 years old students). The sequence includes a set of activities and educational resources that study the effects of microorganisms on human health in an innovative way. Subsequently, to ascertain the scientific and didactic quality of the designed activities and educational resources, the educational contribution of the sequence was evaluated, through the involvement of two researchers of the scientific community: one in Science Education and the other one in Microbiology. The perceptions of the two researchers about the scientific and educational potential usability of the sequence were collected through an online survey and an online interview. Data analysis allowed to present and discuss the potentialities, constraints, and suggestions for improving activities and educational resources from a scientific and educational point of view. Thereby, it is intended with this article: i) To present a didactic sequence that integrates didactic activities and resources on Microbiology; ii) Discuss the potential contributions of activities and educational resources proposed at the level of students' awareness of the effect of microorganisms on human health.

Keywords: Health Education; Science Education; Teaching and Learning Sequences

INTRODUCTION

Understanding the effect of microorganisms on human health is relevant today, due to the global pandemic caused by COVID-19. Thus, this project aimed to develop (conceive, evaluate and improve) a didactic sequence entitled "Effect of Microorganisms on Human Health" (EMiSH), with the purpose of contributing to the improvement and / or educational innovation of a context of the 2nd cycle of basic education with the (lack of) awareness of Natural Sciences students in the 6th year of schooling about the effect of microorganisms on human health.

The educational problem was identified in a class of the 6th grade, during the phase of characterization of the educational context, where it was possible to observe the students', behaviors regarding to food preservation habits (eg ways of storing and transporting food to school), verifying that some students had healthy habits (ex. use of thermal bags), while other revealed unhealthy habits (ex. such as the identification of spoiled food in the backpack). In view of this situation, it was considered essential to address some problems related to inadequate food conservation, motivating them to learn about the importance of food preservation in preventing diseases due to microorganisms, as well as making a more comprehensive approach to related topics with health education, associated with the contents of the Microbiology area.

Taking into account the educational problem and the purpose of the study, a research question was established for the project to be carried out: *How the teaching and learning activities of microbiology conceived within the scope of the didactic sequence, may contribute to an awareness of 6th grade students about the effect of microorganisms on human health and, thus, for the development of their skills?*

It is considered essential that children are aware of this issue, due to the topicality of the topic. However, due to COVID-19 and the changes that were necessary to be made during the Supervised Pedagogical Practice intervention period, it was not possible to implement the sessions with the students.

THEORETICAL FRAMEWORK

Schools, in general, and science teachers, in particular, should develop health education projects with the purpose of promoting impact on students' health behaviors (e.g., conservation of food in their school bags). In fact, due to different social circumstances of students (e.g., lack of parents' and family health literacy), school ends up having an important role on changing children' behaviors (e.g., improvement of children' health literacy) (Esteves & Anastácio, 2010). In this way, it is considered that it would be pertinent to link health education with the contents to be addressed during the current academic year, in the discipline of Natural Sciences, with the 6th grade. Also taking into account the educational problem, it was decided to link health education with microbiology.

In Portugal, science teachers can address, in a flexible curricular way, "The impact of microorganisms in human health" theme in "Natural Sciences" subject in Elementary Education. During the school year of 2019/2020, an in-service science teacher has identified an educational problem, during the characterization of the educational context at the 6th grade (a class of 27 students with ages between 10 and 11 years old). Specifically, it was possible to observe the students' behaviors regarding to food conservation habits (e.g., food storing and transportation to school). Some students had healthy habits (e.g., use of thermal bags to carry their food), while other revealed unhealthy habits (e.g., existence of spoiled food in the backpack) (Carvalho, 2020).

Microbiology is considered, according to Bernardi (2019), as the scientific area that studies the role of microorganisms in the world, especially when it comes to society, the human body and the environment. Microorganisms are considered a set of microscopic-sized organisms that inhabit diverse ecosystems and have a wide variety of shapes, sizes and functions. Gonçalves (2012) distinguishes two types of microorganisms: useful and pathogenic. The useful microorganisms do not cause disease and, in addition to their usefulness in food production, are also useful in health promotion and in medicines and vaccines production. On the other hand, pathogenic microorganisms can cause diseases, of greater or lesser severity, according to the resistance characteristics of the host. Mafra and Lima (2012) state that students tend to consider that microorganisms represent the only cause for diseases appearance. This image that students have of microorganisms must be (de)constructed and, therefore, it was considered that it would be relevant to address the alternative conceptions (Martins et al., 2007) of students about the effect of microorganisms on human beings. In addition to these concepts, it was considered essential to integrate activities that included practical, laboratory and experimental work (Martins et al., 2007), as well as the involvement of the scientific community (Espada, 2007).

It should be noted that the participation of the scientific-technological community in school is one of the best ways to develop scientific skills, which was what was intended to be done through the presence of a professional in one of the sessions of the didactic sequence (Espada, 2007). The promotion of contact between the school and elements of the scientific community is becoming more common, as it is one of the best ways to develop scientific skills and adequate conceptions about science and it is also known that, due to their experience, scientists are in a crucial position to help science education at school (Seabra & Vieira, 2016).

In this project, in addition to integrating elements of the scientific community in one of the sessions of the didactic sequence developed, they were also integrated in the evaluation phase of the project, in which it was possible to collect their positive and/or negative perceptions at the didactic and scientific knowledge about the didactic sequence and its resources. This was crucial in order to develop the best and most appropriate didactic sequence and so that it could, in this way, be adopted and adapted, in the future, by other science teachers.

METHODOLOGY

A research and development (R&D) methodology (Wang & Hannafin, 2005) was adopted to develop an artfact – the activities and resources integrated on the didactic sequence EMISH "Effect of Microorganisms on Human Health". By an interactive process of design, testing and evaluation process, the EMISH sequence was developed during two R&D phases: first phase – conception of the activities and resources (Table 1); second phase - scientific and didactic evaluation of the didactic sequence with the participation of two researchers of the scientific community (one from Microbiology and other Sciences' Didactic).

Due to the pandemic state caused by COVID-19 in Portugal, it was decided to adapt the activities for Distance Learning, taking advantage of the circumstances of Basic Education in Portugal (Assembleia da República, 2020) and, thus, the first three sessions were designed to be implemented in classroom teaching and the last three for distance learning. All sessions focused on the teaching and learning of Microbiology, taking into account the essential learning foreseen for the 6th year in the discipline of Natural Sciences.

Table 1 - Didactic sequence session, duration and resources (https://youtu.be/5rPRMqIeMpg).

Session	Duration	Description	Resources/materials
1. "What do I think about…?"	50 min.	Survey of students' previous ideas on the themes: pathogenic and useful microorganisms; food preservation and vaccine; use of antibiotics and over-the-counter medications. In this activity i tis also intended to proceed to to the identification and reconstruction of the students' alternative conceptions.	Record sheet of the responses of each student; Diagnostic evaluation questionnaire carried out through the *Typeform* platform.

"Exploring bread molds"	80 min.	Conducting and experimental activity related to the importance of microorganisms (fungi) in food preservation (bread).	Experimental activity planning letter; Materials for carrying out the experimental activity.
3. Molds in detail	20 min.	Observation of the results obtained through the experimental activity, under the optical microscope and realization of some questions about what is observed.	Slices of bread resulting from the experimental activity; Microscopes.
4. "What do you do for diseases due to microorganisms?"	30 min.	Research and selection of information and, subsequently, preparation of a bookmark, according to the information collected and selected, through na autonomous work, in pairs.	Guidance for self-employment; Materials for the preparation of bookmarks.
5. "How can I prevent myself?"	30 min.	Viewing a vídeo from a Microbiology professional about and experimental activity related to the importance of proper hand washing and carrying out a task.	Video of a Microbiology teacher.
6. "What did I learn about…?"	20 min.	Assessment of students' learning after the didactic sequence (the questionnaire will be the same as that applied in the activity "What do I think about…?").	Guide for autonomous work; Final evaluation questionnaire carried out through the *Kahoot!* platform.

The evaluation was caried out by two elements from the scientific community – one from Microbiology (assistant professor in a Portuguese public higher education institution) and other in the area of research in Science Didactics (mentor involved in the "design" phase of the didactic sequence) – were involved due to their specific scientific knowledge and expertise in educational projects. Their collaboration in the evaluation process (phase 2), through an inquiry process (online survey and individual interview) allow to collect and analyze the positive and/or negative perceptions about the didactic sequence EMISH and to ensure the identification of problems and, consequently, necessary improvements.

Data was analyzed through content analysis which, according to Bardin (2016), is a technique that has the purpose of interpreting communications and serves to explore, for example, answers to open questions whose content is quickly evaluated by themes. This data was collected through the techniques and instruments presented in Table 2.

Table 2 – Techniques and instruments used for data collection.

Techniques	**Instruments**	**Moments of use**	**R&D phases**
Observation	Researcher's diary	During all moments of contact, synchronously and asynchronously.	Conception
Inquiry	Questionnaire Interview	Performed by the researchers, at the time of evaluation of the didactic sequence.	Evaluation and refinement

RESULTS

Results have shown potentialities, constraints, and improvement suggestions of the sessions developed within the didactic sequence EMISH. Concerning the potentialities, both external researchers (Microbiology and Didactic of Sciences) have agreed that: i) the activities and resources were elaborated in an appropriate way to fulfill the curricular learning objectives to Elementary Education (6th grade); ii) the didactic sequence has the potential to contribute to the students' awareness of the effects of microorganisms on human health. Regarding the constraints, results have shown that it was necessary to carry out several reformulations (e.g., reformulate some aspects to avoid teaching by transmission). Finally, regarding to suggestions for improvement, some were listed by the researchers, divided into suggestions for improving potential (e.g., clarification of aspects related to the implementation of the sessions) and suggestions to minimize constraints (e.g., adaptation of instruments evaluation). These results are presented in more detail in Table 3.

Table 3 – Evaluation of the didactic sequence by the researchers.

Potentialities	Constraints	Suggetions for improving potencialities	Suggestions for minimizing constraints
- Presentation of the didactic sequence; - Relevance of the theme at this and other levels of education; - Suitability for the age group; - Adequacy from the didactic and scientific point of view; Relevance for raising awareness about the theme; - Existence of two different teaching modalities; - Contextualization in everyday situation (eg COVID-19); - Use of different educational resources; - Innovative character of the proposed sessions (eg involvement of the scientific community).	- Need to clarify aspects in the presentation document of the didactic sequence; - Need for reformulations and/or improvements in aspects of a didactic and scientific nature.	- Clarification and reformulation / improvement of aspects in the document sent with the presentation of the didactic sequence; - Clarification and reformulation / improvement of didactic and scientific aspects; - Clarification of aspects related to the implementation of the sessions (eg explaining if the sessions were implemented); - Inclusion of other activities (eg debate on vaccination).	- Clarification and reformulation / improvement of aspects in the document sent with the presentation of the didactic sequence; - Clarification and reformulation / improvement of didactic and scientific aspects (eg transmission teaching characteristics); - Adaptation of assessment tools; - Reformulation / improvement of scientific language (eg. classification of viroses and prions as living beings).

FINAL CONSIDERATIONS

With this study it was possible to ascertain the potential and constraints of a didactic sequence that focuses on the topic of Microbiology in the 6th grade. All aspects mentioned by the experts were analyzed and allowed changes to be made in the didactic sequence. The final version of the EMiSH sequence can (and should) be implemented by science teachers with 6th grade students, to assess the impact of activities on their awareness of the effects of microorganisms on citizens' health.

It is concluded that the didactic sequence EMiSH has the potential to contribute to the awareness of the effects of microorganisms on human health, it was elaborated in an adequate way and, in a global way, it allows to fulfill the objectives that were intended to be achieved with its development. Thus, this didactic sequence can be adopted and / or adapted by other teachers, in order to contribute to the formation of citizens aware of the role of microorganisms in human health.

With regard to suggestions for future research, it is considered essential that the didactic sequence presented is implemented in a real classroom context, since only in this way will it be possible to evaluate the impact of activities on students' learning. taking into account the students' previous ideas on the theme and to make adaptations according to the characteristics of the context where the didactic sequence will be implemented. In addition, it is recommended that other activities be created, which may be in accordance with the suggestions that were mentioned by the researchers who participated in this study, or others that are considered relevant.

As a final reflection, it is expected to contribute to the sustainability of the research path carried out, advancing in the field of science didactic research that has been concerned, among other aspects, with the resolution of significant educational issues for actors and systems, aimed at the sustainability of research.

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DESIGNING AN INNOVATIVE LEARNING ENVIRONMENT FOR STUDENTS: ‘NMR FOR FOOD PROFILING – LONG DRINK, SHORT EXPERIMENT’

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A central concern of promoting scientific literacy is that students acquire scientific knowledge and are enabled to apply it to issues and questions arising in quotidian life to take impartial well-justified decisions. However, identifying and competently evaluating scientific problems requires of them a high degree of specialist knowledge and methodology. One issue that plays a significant role in students' everyday lives is consuming of alcoholic cocktails/long drinks. However, alcohol is addressed within the school curriculum solely in terms of its chemical composition, and only the very general effects of alcohol consumption are studied. Thus, the fundamental subject-specific scientific and methodological aspects of alcoholic long drinks are dealt with superficially, if at all. This paper describes an international interdisciplinary project to develop teaching innovation in the curriculum areas of Chemistry and Nutrition/Consumer Education. Its aim is that, through proactive experimental engagement with NMR spectroscopy, students will become acquainted with and independently apply one of today's cutting-edge scientific research methods. In addition, we aim to improve their evaluative competencies based on scientific evidence by addressing a topic close to their personal experience, which will, in turn, enable them to make well-considered decisions about leading their lives responsibly. To achieve this, a non-formal learning environment, the extracurricular 'ELKE' laboratory, has been set up on the 'Design-Based Research' model. The paper presents the concept of this teaching innovation along with the Design-Based Research process.

Keywords: Interdisciplinarity, Teaching Innovations, Non-formal Learning Environments

INTRODUCTION

A Google search of German-language websites with the term ‘Long Drink’ generated almost two billion hits (1,960,000,000 on 13 January 2022), including numerous recipes for making them at home. The search produced a vivid snapshot of the cultural popularity of these blends of high-proof spirits such as vodka, gin and whisky with ‘mixers’ such as fruit juice or carbonated drinks. According to a study by the European Food Safety Agency (Zucconia et al., 2013) young people are especially attracted to alcoholic long drinks containing energy drinks that can pose a cardiovascular health risk (Peacock et al., 2014). As alcoholic long drinks play a significant role in young people's everyday lives within their peer groups, and as these drinks are heavily advertised, it is hard for them as consumers to make well-considered and, preferably, health-promoting decisions. Therefore, the school curriculum should include activities that foster young people's evaluative and decision-making competences, especially concerning alcohol as a stimulant and addictive substance (Inchley et al., 2020). Against the background of research in foodstuffs, biochemistry, and nutritional sciences, it is nevertheless plain that more complex, qualitative, quantitative, and analytic methods are needed to shed light on the ingredients of alcoholic long drinks and their chemical structures. One mainstay of such analysis is nuclear magnetic resonance (NMR), widely used in food profiling (Lamanna, 2013).

DESIGN OF AN INTERDISCIPLINARY TEACHING INNOVATION

Based on the theoretical findings and systematic research, the 'NMR for food profiling - Long Drink, Short Experiment' project was set up to engage with the issues of alcoholic long drinks at theoretical, experimental, activity-based, and interdisciplinary levels. By participating, students were to be systematically motivated to identify the ingredients of alcoholic long drinks, understand their effects on their bodies and, based on the scientific knowledge of the long drinks they had acquired, helped to improve their critical faculties regarding advertising claims about such drinks while assessing and reflecting how on they impinge on their own lifestyles. In this sense it is expected that they will acquire competences in science-based decision-making and evaluation, something which is not only a shared aim of Nutrition and Chemistry teaching but also represents a crucial component of consumer literacy and scientific literacy (Moore et al., 2015; OECD, 2009; Holbrook & Rannikmae, 2009). Conversely, consumer literacy and scientific literacy are fundamental prerequisites for proactive participation in shaping one's own community and creating a sustainable society (Angele, 2017). However, the didactic challenges of devising such a project are multifarious; an interdisciplinary approach is vital to address this many-faceted topic (Aikenhead, 1985). Thus, the question arises of what proportions of theory (in the sense of basic scientific knowledge from the various subject disciplines), applied theory (the transfer of subject specialist and interdisciplinary knowledge to the problems of one's lived-in world) and praxis (understood here to be the implementation of scientific methods of knowledge acquisition such as the experiments around NMR spectroscopy) are appropriate within such a learning experience. Especially in the light of nutrition-related issues, it is also crucial to observe the principle of multidimensionality. In particular, when aiming to develop students' evaluative competence.

As the proposed project constitutes a new concept of subject content and methodology in the field of cross-disciplinary didactics, it will be elaborated in the spirit of Design-Based Research (Euler & Sloane, 2014). The aims are: to create an interdisciplinary learning environment within the practical setting of the students' laboratory; to examine its specific applications; and to develop the concept further. Such an iterative approach facilitates systematic configuration, implementation, and validation, i.e., ongoing re-design of the teaching innovation. In this sense, the interdisciplinary learning environment can be progressively developed, optimizing support for students in acquiring the desired evaluative and decision-making competences for a healthy and sustainable lifestyle (Marchand, 2015, Aikenhead, 1985). Particularly in the light of today's complex and ever-changing social challenges, promoting students' knowledge-based evaluative competence in the field of nutrition issues is a lifelong learning task: enabling people to strike a well-founded balance between consumption of, and abstention from, alcoholic long drinks (Inchley et al., 2020).

CONCEPT OF THE INTERDISCIPLINARY TEACHING INNOVATION – FIRST STEPS OF THE DESIGN-BASED RESEARCH PROCESS

The interdisciplinary concept is still in the early stages; so far, just the first design steps of the Design-Based Research process have been taken. The first practical trials (implementation) are currently taking place, whereby no final evaluation data is as yet available.

Starting from a practical problem (the Problem Statement) and taking into account the theoretical context (Theory), a learning structure/concept will be devised in consultation with specialist scientists, subject didactic specialists and experienced teaching practitioners (Design), trialled with school students (Implementation), evaluated according to aims achievement (Analysis) and developed further on the basis of ongoing findings (Re-Design) (see fig.1).

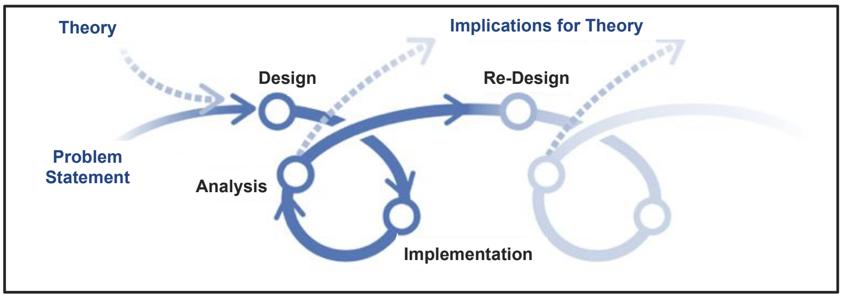

Figure 1. Design-Based Research Process, figure according to Fraefel, 2014.

Such an iterative and cyclic procedure facilitates the successive elaboration of a learning structure that will, when complete, solve the presented initial problem in a didactically appropriate way and foccus on a specific learning objective. Concurrently, theories to substantiate the didactic concept may be deduced, and implications for new theories formulated at every stage. In this sense, the chosen research approach aims to determine: "*how to improve education and learning in authentic educational settings … Further, that explicit goal becomes a day-to-day reference point for collecting and analyzing data, for making modifications to the intervention ..., and at the end of the investigation for determining the extent to which progress has been made (REINKING & BRADLEY, 2008, 19)*" (Euler, 2014, 17). The following account offers detailed insights of the first stages of the Design-Based Research process.

Starting Point: The Problem Statement

As far as school praxis is concerned, Chemistry teaching and Nutrition and Consumer Education both address the thematic complex 'foodstuffs', e.g., alcoholic long drinks, but independently, from different points of view, and with different emphases. While Chemistry lessons concentrate on examination and analysis of constituent substances, Nutrition Education focuses on the provision and consumption of foodstuffs and their effects upon the human body. Thus, knowledge is acquired in isolated fragments while interrelationships remain not perceive. This is where the project intervenes: combining the two approaches to close gaps in school education, addressing modern scientific analysis and its relevance to social and individual consumer habits (see fig. 2).

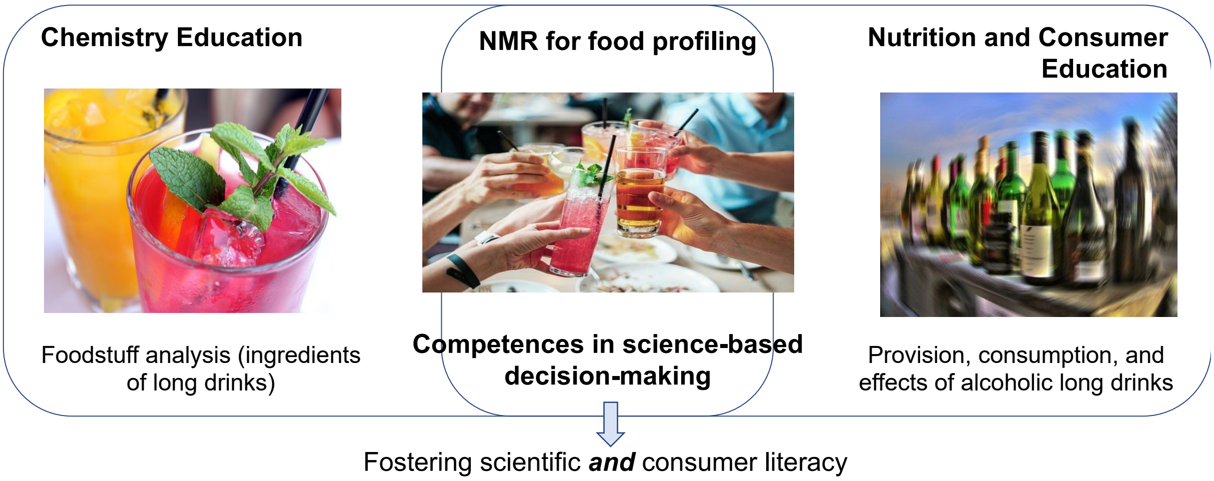

Figure 2. Overview of the project Problem Statement.

The project aims to promote school students' scientifically-founded evaluation competencies by establishing clear and appropriate connections between their scientific and consumer literacy. Through the transfer of the evaluative competencies thus acquired to other socially significant problems, especially in the longer term, the project can enhance the scientifically-based and responsible participation of pupils in broader society.

Theory

As described above, scientific literacy and consumer literacy enhance pupils' ability to make science-based decisions that are important for their active participation in society (e.g., Holbrook & Rannikmae, 2007; Marks, Stuckey & Eilks, 2014; Hofstein, Eilks & Bybee, 2011). Looking at the objectives of science literacy and consumer literacy, both subject matter and analytic methods are relevant; the specific topic, 'alcoholic long drinks', plays a significant role in young people's everyday life and youth culture (e.g., Zucchonia et al., 2013; Peacock et al., 2014; Inchley et al., 2020). Furthermore, NMR spectroscopy presents a cutting-edge scientific research method; pupils become acquainted with this fundamental technique within organic and biochemistry and understand its applications in food profiling (e.g., Lamanna, 2013; Bonjour, Pitzer & Frost, 2015; Bonjour et al. 2017). Inasmuch as non-formal learning environments (an extracurricular student laboratory) are used, it is possible to employ different detection methods (qualitative and quantitative) and also to conduct multifaceted experiments that can place issues and problems in a broader context (hands-on experience with NMR).

Design

To facilitate the appropriate didactic embedment of the learning experience, an established non-formal learning environment, 'ELKE', was used (Gross & Pawlak, 2020). The German acronym 'ELKE' stands for experimenting (German: "Experimentieren"), learning (German: "Lernen") and acquiring competences (German: "Kompetenzen Erwerben"); ELKE is both a conventional student laboratory and a teaching/learning lab for pre-service chemistry teachers. As a student laboratory, ELKE not only invites participating students to places where real research is happening and thus brings them together with professional research chemists but also, through its competence-oriented educational ethos and curriculum-related topics, offers learning-effective networking with regular school lessons. With the 'NMR for food profiling –

Long Drink, Short Experiment' project, the out-of-school lab ELKE was for the first time extended to host an interdisciplinary learning programme specifically for senior high school students and pre-service teachers. Furthermore, 'Long Drink, Short Experiment' is especially suited to implementation as an interdisciplinary project day in the ELKE lab because here it is possible to carry out not only qualitative and quantitative detection methods but also multifaceted experiments that can place issues and problems in a broader context. In this sense, a multidimensional approach to the topic of alcoholic long drinks can be created, capable of supporting students in the development of discerning evaluative skills founded in multidisciplinary knowledge. The actual project day is divided into six steps comprising both theoretical and experimental phases (see fig. 3).

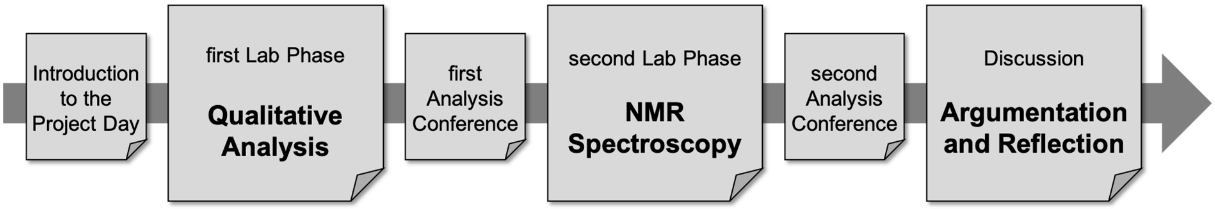

Figure 3. Procedure of the project day, which consists of both introductory and elaborative theory phases as well as practical-experimental laboratory work.

The first devising stage addressed the question of how the topic could be prepared to appeal directly to pupils. After comprehensive literature research and collecting ideas, subject specialists came up with the idea of setting the focus on a specific cocktail/long drink and its varying ingredients within the scenario of a tragic accident (Groß, Kurzbach & Angele, 2020). The refined idea was subsequently discussed with both scientific experts (e.g., with regard to the questions: How, and to what extent, can the topic be purposefully addressed with the help of qualitative experiments? What – else – can the NMR spectroscopy analytic method deliver on this topic?) and with teaching practitioners (e.g., with regard to the questions: How much of the topic be addressed, and in what depth, on the basis of pupils' prior knowledge acquired in Chemistry and Nutrition lessons? Which practical – differentiating – support mechanisms have to be devised and scheduled, so that pupils can develop a scientific understanding of the issues?). As a result of this initial design stage, during which possible experiments and NMR measurements were also carried out, the concept was adapted and amended; the focus was broadened to include analysis of various cocktails/long drinks to reinforce the real-world relevance. Concurrently, this expansion made it possible to devise variable and differentiated tasks within the interdisciplinary learning programme. Finally, the framework scenario was also adapted to reflect the findings of discussions between the various professions: The pupils were to assist Chemistry students in identifying the long drink, Vodka Red Bull, from among 10 different cocktails/long drinks. Thus the main question for the project day was posed as: "Which of the 10 'mystery' samples is Vodka Red Bull?" (*Introduction*). In the *first Lab Phase* (*Qualitative Analysis*) pupils are given a reference sample of Vodka Red Bull and, on this basis, examine the 10 'mystery' samples, initially using qualitative detection methods to identify possible ingredients (see fig. 4).

Cocktails resp. Long Drink	Colour	Test with Fehling's solution	Protein	Ethanol
Vodka Red Bull (reference sample)	**brown/ yellow (p)**	**positive (p)**	**negative (n)**	**positive (p)**
sample 1 (sugar-free Red Bull)	p	n	n	n
sample 2 (Mojito)	p	p	n	p
sample 3 (Whiskey Sour)	p	p	p	p
sample 4 (Pina Colada)	n	p	p	p
sample 5 (Vodka Red Bull) (sample requested)	*p*	*p*	*n*	*p*
sample 6 (Bloody Mary)	n	n	n	p
sample 7 (Vodka Wellness)	n	n	n	p
sample 8 (Cuba Libre)	n	p	n	p
sample 9 (Swimming Pool)	n	p	p	p
sample 10 (Vodka Club Mate)	p	p	n	p

Figure 4. Qualitative investigation of the 10 unidentified samples, and findings of the first laboratory phase; Vodka Red Bull, the reference sample, is in bold type; in brackets, and not revealed to the pupils, are the names of the cocktails/long drinks.

By comparing with the Vodka Red Bull reference sample (fig. 4, 2nd row, in bold type), the pupils can exclude seven samples by means of qualitative analysis (fig. 4, white background). As the remaining three samples (fig. 4, blue background) cannot be distinguished using qualitative experiments, another analytic method is needed: NMR spectroscopy. To prepare them for the second lab phase, pupils are introduced to the essentials of NMR spectroscopy (such aspects as how NMR works and interpreting NMR spectra) and to its importance in food profiling (*first Analysis Conference*). They then measure the spectra of the three remaining samples (*second Lab Phase*). To enable them to interpret the three spectra, pupils are given the spectra of their possible ingredients (among them: vodka, rum, lime juice, caffeine, saccharin, Red Bull). Pupils then compare the spectra of the individual ingredients with those of the three unidentified samples. In this way they first find out which ingredients appear in each sample. Referring to a cocktail recipe book, they can then determine which three cocktails/long drinks they are dealing with, and thereby clearly identify the Vodka Red Bull that they have been seeking (see fig. 5).

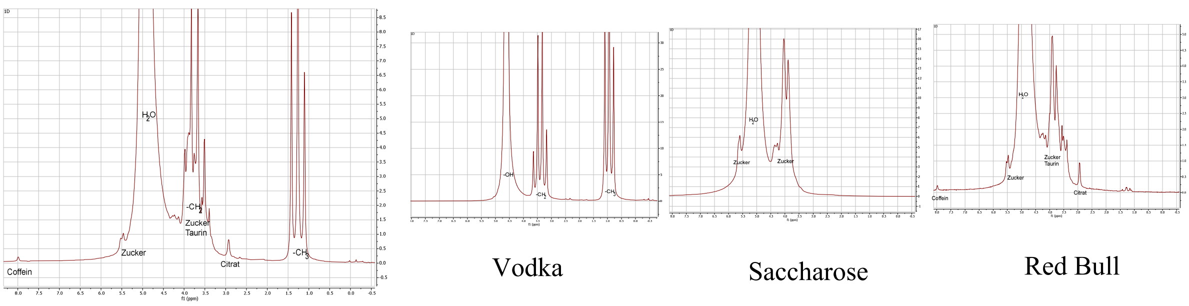

Figure 5. ^{1}H-NMR spectra of Vodka Red Bull (left) and ^{1}H-NMR spectra of different ingredients (right).

The *second Analysis Conference* broadens the field of investigation; pupils use the cocktail recipe book to gather further information about quantities and ratios of ingredients, and the alcohol / energy content of various cocktails/long drinks. While the experimental phase of the learning environment had foregrounded pupils' technical and factual learning, this new knowledge provides the basis for addressing the topic in the spirit of scientific and consumer literacy (*Discussion: Argumentation and Reflection*); using pupils' discoveries during the laboratory and analysis phases and the declarative and procedural knowledge thus acquired, the discussion phase aims to reflect through dialogue on the real-life relevance of the problem-solving task in a multidimensional context. For this, referring to the laboratory journal that accompanies pupils throughout the learning environment and is specifically designed for this phase according to the principle of a decision-making diary (Schmitz & Reiners, 2021), various cues for reflection in four dimensions (Angele et al., 2021) are offered and discussed with pupils: in the first dimension, 'Nutrition', pupils reflect on the qualities and quantities of the cocktail/long drink ingredients and ways in which they can be identified. In the second dimension, 'People', pupils closely address the effects of these ingredients on the human body and assess them with regard to people's health. Finally, pupils work on aspects of the cultural significance of consuming alcoholic long drinks in various social contexts (the third dimension, 'Social Environment') and also on aspects of the natural resources needed for the manufacture of and trade in alcoholic drinks (the fourth dimension, 'Physical Environment'). Bearing in mind the overall aim of the learning environment, these structured cues for discussion and reflection should enable pupils not only to apprehend the scientific background and concomitant social controversy surrounding the important theme of alcoholic consumption in all its complexity but also to develop a well-founded i.e., responsible and situational attitude to alcohol as a consumer product, for themselves and society as a whole. In this way, it may be expected that an intense reflective process is initiated among the pupils, one that will lead them to develop decision-making competences for a healthy and sustainable lifestyle and thereby promote both scientific and consumer literacy.

Implementation

The first trials of the 'NMR for food profiling – Long Drink, Short Experiment' project day are currently being run with senior high school pupils. The process is accompanied by evaluation based on qualitative research design criteria. In the spirit of the Design-Based Research approach, the aim is to elaborate and improve the interdisciplinary learning environment in an ongoing, iterative process in order to achieve the projected aim – to promote pupils' knowledge-based decision-making competences. To gather significant insights for further development, the first design phase is examined both with regard to the fundamental practicability of the innovative learning environment and with regard to possible organisational and content-related amendments and improvements, along with considerations of its learning effectivity for participating pupils i.e., whether and to what extent the promotion of knowledge-based decision-making competence can be achieved in this way. To this end, the project day activities were observed by participating researchers, and both pre-structured interviews and semi-standardised questionnaires were employed to gather views from supervising teachers and participating pupils. Including various survey instruments and points of view in the research methodology produced a methodological triangulation that, at the content-related level, should make it possible to access diverse aspects of the interdisciplinary learning environment. Acquiring such data is, ultimately, the prerequisite for the first comprehensive evaluation of the learning environment – an evaluation that, from this first design cycle, can offer insights regarding its content-related, methodological and organisational suitability but also of the (learning) effectivity.

Re-Design

Once the acquired data have been evaluated, the key findings will be discussed with the various stakeholders (specialist scientists, subject didactic specialists and experienced teaching practitioners), followed by adaptation of various elements of the interdisciplinary learning environment, which are in turn trialled with pupils. In this sense, it can be expected that, through this iterative, cyclic, approach, not only the suitability of the overall learning environment will constantly improve, both in terms of its aims focus and of meeting pupils' needs, but also that new research data will be continually generated that can be used both for the concluding theoretical appraisal and for fundamental theoretical deliberations on the basic underpinning for innovative didactic concepts.

SUMMARY AND OUTLOOK

The research-based development of an interdisciplinary learning programme on the real-life topic of 'alcoholic long drinks', following a Design-Based Research approach, establishes a connection between scientific and consumer literacy within the learning framework, one that both motivates pupils and encourages them develop cross-curricular 'joined-up thinking'. The interdisciplinary didactic approach devised for this topic is transferable to other sociologically relevant issues that, in their complexity, also demand a multifaceted approach (e.g., diverse consumer choices on such criteria as sustainability, climate change etc.). The prerequisite of acquiring knowledge-based evaluative competences is multidisciplinary knowledge that must be didactically developed in all its complexity if it is to serve as the firm foundations of a logically justified weighing-up of objective arguments and thereby as the starting point for well-considered decisions of personal and societal relevance. To this extent, the project described here can offer examples of didactic praxis when the matter in hand is to devise, through research, interdisciplinary learning environments on the burning issues in society in all their complexity, using a problem-solving approach that takes account of the relevant curricular content in an innovative and research-based manner and leads to tangible solutions and/or judgements.

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THE ENERGY FIELD APROACH
A DESIGN-BASED RESEARCH PROJECT

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Energy is an important topic in middle as well as in high school. Although the understanding of the energy concept is crucial for describing and explaining phenomena, school instruction often fails to transmit and ensure a profound understanding of energy. To address this problem, the energy field approach develops and evaluates a teaching-learning sequence which combines energy with the concept of fields by tracing back traditional energy forms to only two: kinetic and field energy. The emerging concept is based on empirical evidence about students' misconceptions as well as didactical reconstructions of scientific content, leading to so called concept (or core) ideas. These ideas are evaluated and re-designed by conducting and subsequent qualitative analysis of teaching experiments as they represent the essence of the teaching-learning sequence. Already two cycles of (re-)designed sequences have been conducted and evaluated with 6 and 7 students, respectively. The results are promising and give information about learning obstacles as well as benefits of the approach.

Keywords: energy instruction, design-based research, teaching learning sequence

INTRODUCTION

Energy is one of the crosscutting concepts (see also NGSS of the National Research Council, 2021) in physics as well as in physics education not only in Austria. It has great relevance for describing and explaining phenomena from a scientific perspective. However, several studies indicate that despite its global character as one of the big principles in science, students have problems with learning about energy and especially energy conservation (see e. g. Driver & Warrington., 1985; Nordine et al., 2019). Although there are several approaches being developed at the time to address this problem, a valid and evaluated way for teaching this topic has yet to be discovered and manifested. In that sense, the presented project, the energy field approach (EFA), challenges the task to find a more effective approach to energy instruction by developing and evaluating a teaching concept for energy instruction at the end of Austrian high school (grade 12). The poster presented on ESERA Conference 2021, and hence this article, presents the basic ideas of the concept as well as the first two steps of (re-)design and evaluation.

BACKGROUND

The following selection gives a brief outline of the most important difficulties and basic ideas of energy instruction as well as the starting point of the presented project.

Traditional energy instruction usually focusses on teaching various energy forms like kinetic, potential, electrical, chemical, solar or nuclear energy, just to mention a few. Instruction in this way requires the students' ability to interpret and connect all these forms in order to understand the underlying concept which shall lead to a sound understanding of energy conservation. Although the idea of splitting the originally unitary entity of energy into forms is supposed to be useful, simple and practical when talking about phenomena from an energy perspective, evidence shows that this is not the case. Students seem to have problems understanding the concept of energy in this way (Nordine et al., 2019). For instance, students often struggle with making connections between different forms of energy and misunderstand that energy forms are not conserved themselves but only energy in total (Nordine et al., 2011). This obstacle seems to be reflected also in the fact that students often struggle with understanding the role of potential energy as a system property as well as the benefits of arguing from an energy perspective in problem solving and, hence, seldom use energy ideas when trying to explain phenomena. Researcher sometimes criticize that introducing energy forms only is a re-phrasing or re-labelling of the same thing (Swackhamer, 2005). This confusing terminology of not well-defined terms (i. e. forms) of energy seems to lead to learning blackboxes rather than understanding what energy actually is (Nordine et al., 2011; Nordine et al., 2019; Quinn, 2014). All these problems leads to the conclusion that students do not reach the desired level of understanding of energy as an important and powerful crosscutting concept and, hence, the traditional course of energy instruction by introducing different forms (via force, work, golden rule) seems not to be the best way. For a brief overview of the most relevant problems in energy instruction see e. g. Nordine et al. (2019).

Therefore, in order to find a more effective and fruitful way to teach energy, several approaches exist that combine the abstract concept of energy with the concept of fields for the sake of framing traditional (especially potential) forms of energy (see Fortus et al., 2019; Nordine et al., 2019; Rückl, 1991). The energy field approach aligns with this idea and merges traditional forms to only two: energy in movement (kinetic energy) and in fields (all forms of potential energy). This way, energy can be treated more as an underlying global concept (Quinn, 2014).

THE ENERGY FIELD APPROACH

The energy field approach (EFA) is based on the knowledge about difficulties above and combines ideas from already existing curricula to develop an approach that provides an interdisciplinary valid and useful concept for energy instruction on the high school level. The following paragraph gives a brief insight into the main features and concept ideas of the EFA which are obtained in the process of educational reconstruction of energy for the EFA. Parts of the following description are already described in Becker and Hopf (2021).

Basis of the EFA

The EFA traces back different forms of energy to just kinetic and field energy as it is also used in the concepts of Rückl (1991) and Nordine et al. (2019). Thereby, kinetic energy is assigned to moving objects with mass (not photons) and field energy is introduced to be a property of fields. While the former is what is already taught in school, the latter term sums up traditional forms of potential energy, i. e. energy in electrical, magnetic, electromagnetic, gravitational and nuclear fields. Thereby, the EFA covers classical fields like electrical, magnetic, electromagnetic and gravitational fields as well as modern fields such as nuclear fields of quarks and the Higgs field.

The general field

A key feature of the EFA is that energy is only attributed to a so called general field: Charges, magnets, masses and quarks are sources of respective fields (electric, magnetic or quark fields). Two sources (generally of one kind) interact via their fields which overlap/superpose to a so called general field. This field, then, stores the energy of the interaction and can take or give up energy while changing in a physical process. When hearing about the concept students are shown a visualization of the general field following the idea of Fig. 1. Thereby, a field itself is depicted as a circle or ellipse due to limitations in drawing whilst students are told that fields in general are not restricted to a specific area. So as long as possible a field has no specific size and two or more fields hence can superpose. The resultant field is called the general field.

An easy example is the acceleration of two close and repelling magnetic carts which speed up due to the repulsion. While accelerating, energy is transferred from the general magnetic field (as the superposition of the two magnetic fields of the carts) to the movement of the carts which move apart. The same principle applies for a falling ball, where energy is transferred from the general gravitational field (formed by the two fields of ball and earth, respectively) to the accelerating ball. Hence, within the EFA, energy is connected to either a moving massive object or a general field (superposition of two or more fields defined by their respective sources).

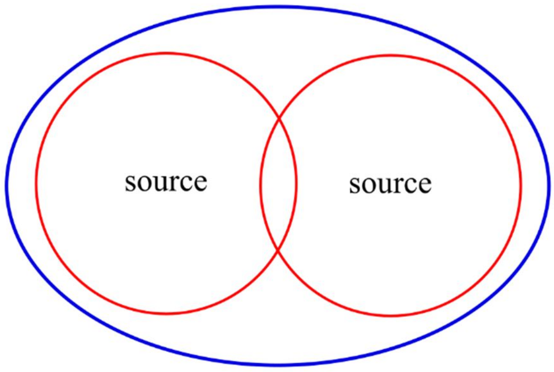

Figure 16. The general field. Two sources (e. g. charges, magnets or masses) interact via their fields (single fields as red circles) and exhibit a resultant general field (blue ellipse). Drawing is limited despite the real size of the fields is ideally infinite.

Direction of energy transfer

When energy is transferred, it can be transferred between fields and moving objects. Thus, processes can be described from an energy perspective by first looking for both, fields and moving objects. Since energy will be found to be in either one of those, energy conservation as the total of kinetic and field energy appears plausible. Furthermore, the EFA provides a simple but effective method to describe the energy transfer process by looking at two indicators: speed (of the moving parts) and distance (of the field sources). By describing changes in these quantities, the energy transfer can be described more easily.

Reasoning on the energy transfer process can be supported by specifying the direction of energy transfer. Therefore, the general field itself plays an active role in phenomena: When two sources interact and a specific process happens (e. g. the ball falling), the general field changes which can be noticed by the distance of the sources changing (ball and earth are approaching). The changing field releases energy to the accelerating ball. By framing the field as an participant (in the sense of a changing system) and describing the processes by means of describing the behavior and change of the field provides two direct advantages compared Newtonian mechanics: First, discussing field and hence energy changes avoids discussing forces and work which was found to be difficult for many students (Jewitt, 2008; Neumann, 2013). Second, assigning an active role to the general field should increase its attractiveness and students' willingness for use when reasoning about phenomena.

Table 2. Traditional energy forms and equivalent EFA terms for different contexts.

Context	Traditional energy form	EFA energy term
repelling magnetic carts	magnetic energy	magnetic field
falling ball or satellite	potential energy	gravitational field
slingshot & firework	elastic & chemical energy	atomic field
decelerating pendulum	thermal & internal energy	micr. movement & atomic field
laser cutter & solar panel	electromagn./solar energy	electromagnetic field
nuclear fission/fusion	nuclear/binding energy	quark field
pair production/annihilation	mass	Higgs field

In addition, the general field cannot only be used when describing the release or uptake of energy but also for specifying the direction, i. e. whether energy is transferred into or out of the field. Thereby, the *tendency* of the general field plays an important role, which means that the field tends to release energy if possible. This, of course, is a rather flexible statement but which should help students understand in which direction a field would change if it was to behave "freely". In other words, if no external forces are applied, the field (system of two or more sources) will change in a way such that it releases energy, i. e. sources move according to the forces of the interaction only. In the case of the falling ball, ball and earth approach and energy is released. In the case of two repelling magnetic carts, they move apart and the magnetic field releases energy. Of course, the other way around would mean an energy transfer into the respective general field (i. e. the case that work has to be done on the system by applying an external force to the sources). In all cases, the general field plays the role of a changing system whose tendency dictates the direction of energy transfer.

Once students can understand this principle, this tendency of a general field to minimize its energy can be used to explain the binding of systems like e. g. atoms or nuclei. Thereby, the atomic (electric) or nuclear (quark) field releases energy to obtain a stable situation that exhibits minimum energy. The following items sum up the most important concept ideas that have just been elucidated:

- Charges, magnets, masses and quarks are sources of a respective fields.
- Two or more sources interact via their fields which superpose to a general field.
- The general field carries energy which can be transferred from or to a moving object.
- There is only kinetic energy and field energy.
- The general field tends (according to its interaction) to minimize its energy: tendency of the field
- The binding of atoms and nuclei is a result of this tendency of the general field.

Table 1 lists different contexts (examples) for processes with energy transfer with the respective traditional energy forms and the corresponding EFA terms.

Research Question

The goal is to develop a teaching concept for energy instruction at the end of high schools. Therefore, the method is embedded within the domain of design-based research and based on the model of educational reconstruction (MER; see Duit et al., 2012). Briefly, a concept consisting of concept ideas and contexts is designed based on knowledge and findings about students' conceptions (about energy and fields) and a clarification and reconstruction of the scientific content.

To design the concept, concept ideas as well as logical connections between them and appropriate contexts (examples, visualizations, etc.) are constructed. Based on the MER, knowledge about students' misconceptions and elements of the scientific structure of the selected content lead to a merged concept which takes difficulties in students' learning into account. The underlying research question based on the developed concept for the EFA does thus ask: How do Austrian high school students understand the concept ideas of the EFA?

METHOD

In order to answer this question, the concept has to be evaluated with regard to clarity and comprehensibility of its concept ideas. Therefore, teaching experiments with students in form of one-on-one interviews are designed and conducted in style of the method of probing acceptance (Jung, 1992). In such an interview, a student receives explanations and is subsequently asked to rate them regarding the plausibility in order to gain information about the appearance of the specific idea (see Fig. 2 for scheme and Fig. 3 for examples). Afterwards, the student is asked to paraphrase the explanation and idea he or she just heard to see whether the content is easy to understand und to get information about the success of transferring the specific input. At last, the student is asked to transfer the idea to a task that treats a specific phenomenon, e. g. an accelerating satellite surrounding the earth. The goal is to observe the

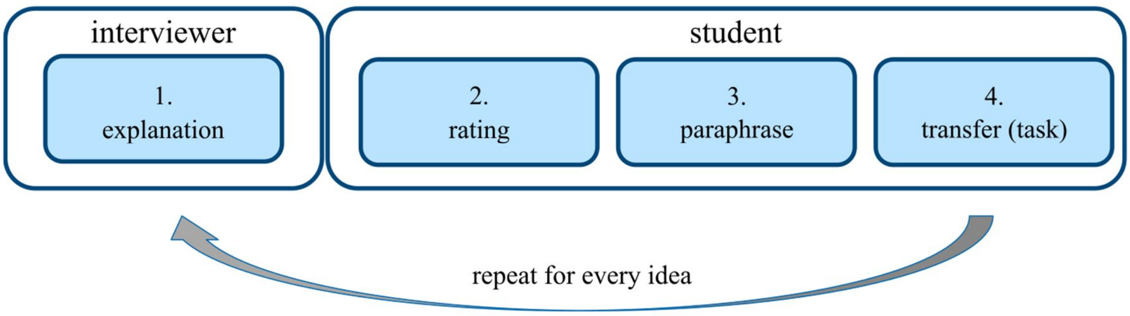

Figure 17. Scheme of the interview procedure according to Jung (1992): Explanation of the concept ideas by the interviewer, followed by rating, paraphrase and transfer of the explanation by the student.

Example 1: microscopic (atomic) fields (shortcut)

1. The elctric fields of atoms superpose. The resulting general field carries energy which is transferred when the field changes.
2. Does this explanation make sense to you? Is it plausible?
3. Please sum up what you just heard in your own words!
4. Please explain where the energy of the moving particles and light of a firework comes from!

Example 2: subatomic fields (shortcut)

1. The mass of electrons and quarks stems from the interaction with the omnipresent Higgs field. The mass of matter mainly stems from the energy stored in the quark field of nucleons.
2. Does this explanation make sense to you? Is it plausible?
3. Please sum up what you just heard in your own words!
4. Please explain what kinds of energy there are before and after the collision of two fast protons at the LHC!

Figure 3. Examples for the steps to explain and evaluate the acceptance and understanding of specific concept ideas of the EFA.

student's reasoning and whether he or she draws on the ideas of the EFA that were just presented. These three steps are repeated for every concept idea (eight in total) which leads to a duration of approximately 2,5 hours for each interview. Every interview is audio recorded.

Afterwards, the interviews are transcribed from the audio recording. Based on audio and transcription, a qualitative content analysis according to Kuckartz (2014) is conducted. According to a coding manual (developed along with the interview guide beforehand), the students' performances are analyzed, coded and summarized in a coding table. By interpreting the rating and paraphrase statements about the acceptance of the concept ideas can be formulated. By analyzing a student's performance on a task (step 4), information about willingness and success in transferring the ideas when solving a problem, and hence, about benefits and obstacles of the ideas can be obtained. Therefore, the analysis provides insights into students' learning and, thus, information about the difficulties and benefits of the concept ideas and contexts. Based on the findings and discussions with experts, suggestions for a re-design can be formulated and implemented into a new version of the concept which then can be evaluated again. This establishes the second cycle of the design and re-design process of the design-based research approach.

Up to now, two cycles of design, evaluation and re-design of the teaching concept have been performed with 6 and 7 students, respectively. This process will repeat until enough information about students' learning is obtained and a satisfactory level of acceptance and comprehensibility is reached which means that no unexpected or new learning obstacles appear and that all concept ideas seem to be useful for learning about energy and fields.

Concept Idea	Phase	S1	S2	S3	S4	S5	S6
Energy in fields and energy transfer	Rating	2	2	2	2	2	2
	Paraphrase	2	2	2	2	2	2
	Transfer 1	1	1	2	0	2	2
	Transfer 2	1	1	2	1	2	1
	…						
	Transfer 3	1	0	2	1	1	2
Thermal energy as kinetic energy	Rating	2	2	2	2	2	2
	Paraphrase	2	1	2	2	2	2
	Transfer 1	2	1	2	2	1	2
	Transfer 2	2	1	2	2	2	2
Electromagn. radiation as field energy	Rating	1	2	2	2	2	2
	Paraphrase		2	2	2	1	2
	Transfer 1		1	2	1	1	2
	Transfer 2		1	2	2	2	2

Concept Idea	Phase	S1	S2	S3	S4	S5	S6	S7
Energy in fields and energy transfer	Rating	2	2	2	2	2	2	2
	Paraphrase	2	2	2	2	2	2	2
	Transfer 1	1	0	1	2	1	1	1
	…							
	Transfer 2	2	0	2	1	0	2	0
Thermal energy as kinetic energy	Rating	2	2	2	1	2		2
	Paraphrase	2	2	2	1	2	1	2
	Transfer 1	2	2	2	1	2	0	2
	Transfer 2	2	2	2	0	1	1	2
Electromagn. radiation as field energy	Rating	1	2	2	2	2	2	2
	Paraphrase	2	2	2	1	2	2	2
	Transfer 1	2	2	2	2	2	2	1
	Transfer 2	2	1	2	2	2	2	2
Quark field	Rating	2	2	2	1	2	1	2
	Paraphrase	2	2	2	1	2	0	1
	Transfer 1	2	2	2	2	2	2	2
	Transfer 2	2	2	2	2	2	2	2
Higgs field	Rating	1	2	2	2	2	2	2
	Paraphrase	2	2	2	2	1	2	2
	Transfer 1	2	2	2	2	1	0	2
	Transfer 2	2	2	2	2	1	2	2

Figure 4. Coding tables (selection) for the results of the first (left) and second (right) cycle of doncuction and evaluation of interviews with 6 and 7 students, respectively (S_i). Students' performance is coded by 2 (good), 1 (satisfactory with only small mistakes) or 0 (insufficient; needs a lot of help). No coding means missing data.

DISCUSSION OF FINDINGS

So far, two cycles of (re-)design and evaluation could be analysed. The data leads to numerous findings and insights about students' understanding when leaning about the concept of the EFA. The following outline shall give a rough overview of the preliminary results.

Aspects to be refined and re-designed

Figure 4 illustrates the results of the first and second cycle of probing acceptance interviews with 6 and 7 students, respectively. Some students of the first circle seem to struggle when it comes to finding the correct type of field and especially to construct the general field in the case of less obvious fields. For example, in the case of the falling ball (first concept idea, transfer 2 in Fig. 4), some students find it hard to think about the earth or the ball as a second field source and sometimes only reason with on single gravitational field instead of a general field. Nevertheless, hints or questions regarding this issue help students to find their way to analyse the whole system.

In those cases where students struggle with reasoning using fields, they still draw on ideas from Newtonian mechanics instead. This happens especially, when the general field or the connection between general field, single fields and sources itself is not understood entirely.

Then, students often argue with an ad-hoc explanation from their mechanics teaching instead of using the EFA concept ideas. It does also appear that some students have difficulties to get the direction of energy transfer right, when they do not have a clear understanding of the role of the general field; for instance, in the case of a satellite surrounding the earth elliptically (cycle 2, concept idea 1, transfer 1). However, it can be observed that students are more likely to draw on the desired explanations when they are taught a more active role of the general field beforehand. This means that wordings like "the field changes", "releases or takes energy" or "the field expands" seem to support a more field-based thinking in students' minds such that they draw on the idea of the general field more likely.

Another aspect that can be confusing, is the separation between kinetic and field energy in the cases of thermal and electromagnetic radiation, respectively (see Fig. 4, second and third concept idea). According to the EFA, students are told that electromagnetic radiation (including light) carries field energy since the radiation has no mass but rather is a superposition of electric and magnetic field. This explanation has to be made very concise, otherwise students tend to confuse radiation with kinetic energy. A similar situation appears with thermal energy, where students sometimes struggle to identify the heating of matter with the acceleration of particles or molecules. In that sense, thermal energy is taught to be microscopic kinetic energy of particles instead of field energy. As can be seen form the coding in Fig. 4, students of the first cycle are able to understand this feature better than students in the second cycle (second concept idea). The reason seems to be that a model for the microscopic behaviour of molecules was shown in the first but not in the second cycle. Hence, students are surely able to understand this idea; however, it is better to give them a visualization or a model while explaining in order to ensure that they get the correct idea.

Promising findings

As can be seen from the previous paragraph, there are possibilities to provide different or additional information so that students are more likely to understand the concept ideas correctly. Most of the mentioned problems disappear after another cycle of re-design or at least become more specific. Hence, the evaluation and re-design process will lead to a deeper understanding of students' understanding, i. e. learning obstacles and benefits of the EFA concept ideas, as the process goes on an eventually produces a concept that can be tested in a class setting.

So far, one can say that students accept and implement the idea of energy stored in fields as well as the role and visualization of the general field in their explanations. Also, the benefits of the EFA in general (simplicity, making sense of traditional energy forms) is noticed and appreciated by most of the students. Even in the case of more complicated phenomena like e. g. fission and fusion (second cycle, quark field, transfer 1 and 2), particle annihilation and creation (second cycle, Higgs field, transfer 1 and 2) or astronomical phenomena of modern physics (e. g. gravitational lens; not coded here), students find it difficult but also triggering and exciting to describe these phenomena by using the EFA ideas. In the end, some students call the approach to be "better than school" or "super exciting" when they are asked to give their opinion on the material.

SUMMARY

The energy field approach (EFA) provides a teaching learning sequence for the high school level that traces traditional energy forms back to kinetic and field energy. Different phenomena can be described from an energy perspective by analysing the energy transfer between field and moving objects. Thereby, the tendency of the socalled general field to minimize its energy plays an important role when determining the direction of energy transfer and when discussing the binding of atoms and nuclei. By linking energy and fields, the traditionally ragged quantity "energy" shall become more accessible, terms and forms of energy are expected to become more meaningful and the concept of energy conservation should become more present in students' reasoning.

Concept ideas and contexts of the EFA have been evaluated in two cycles of probing acceptance interviews (method by Jung, 1992) and provide promising insights into students' understanding when learning about the EFA concept. Especially the general field itself and its active role for describing energy transfer processes in phenomena seem to be helpful for students. Most students are able to paraphrase and transfer the presented explanations in order to explain different phenomena; they draw on the concept ideas in an appropriate way even for phenomena they have not thought about before (e. g. exploding firework or alpha decay). Furthermore, nearly all of the interviews' students find the concept ideas and the concept itself to be plausible and helpful. Of course, implications of the presented findings are limited due to a rather small sample size of the one-on-one interviews. Therefore, further cycles of interviews are currently conducted and further versions of the EFA concept are evaluated and refined. In addition, there will be investigations on how students learn about the EFA concept with a teaching learning sequence in a typical classroom setting. However, recent results show that the EFA concept already supports students' learning about energy. Summing up the findings, the EFA provides a promising concept that is hoped to solve a lot of actual problems in energy instruction.

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A POSSIBLE ROLE OF THE SECOND QUANTUM REVOLUTION IN PHYSICS EDUCATION

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We present a teaching/learning sequence on the introduction of concepts of quantum computation and information which we have experimented with fourth and fifth grade students in Italy. The sequence attempts to bring fields such as propositional logic, physics and probability, which are traditionally scarcely related within the secondary school curriculum, under a unified perspective. Our work aims at understanding whether students are able, if guided within a research-based teaching/learning sequence, to first grasp such integration in the classical context, and then problematize it and extend it to the quantum domain. The analysis of the experimentation data, while providing encouraging indications, shows very rich and complex patterns, allowing to identify activities which may be more productive for students and to uncover weak points and student's difficulties.

Keywords: Teaching Learning Sequences, Technology Education, Interdisciplinarity

INTRODUCTION AND THEORETICAL FRAMEWORK

In the Italian national curriculum guidelines (MIUR, 2012) on the competencies that students should acquire at the end of the "Liceo Scientifico" (science-oriented secondary school), three interdisciplinary aspects are identified: mastering the fundamental procedures of logical-mathematical thinking; becoming familiar with methods of investigation typical of the physical sciences; understanding the methodological value of information technology in the formalization and modelling of complex processes and in the identification of solution procedures. We present a Teaching-Learning Sequence (TLS) attempting to interpenetrate these three aspects in the context of the paradigm change requests expressed in the Strategic Agenda of the Quantum Flagship (European Quantum Flagship, 2020): introducing students to "*the paradigm shift from quantum theory as a theory of microscopic matter to quantum theory as a framework for technological applications and information processing*".

The change of perspective implied in the above statement, when taken with its full implications, suggests the necessity to highlight the limits of the classical paradigm not only strictly within the field of physics - with the development of quantum theory - but also in the areas of mathematical logic, probability theory, information theory. The profound link between classical mechanics and propositional logic was explored by Isham (2001) and a simple redefinition of language terms allows to extend the discussion to concepts of probability theory. When brought into an educational environment, these reflections allow to highlight deep ties between the paradigm of classical physics and the architectures and procedures of classical computers and pave the way for the natural question of whether such unity can still be preserved with the advent of quantum theory. Those aspects of quantum physics which may appear as limits to the human possibility of understanding and knowing (limits of classical propositional logic for systems such as Stern-Gerlach or birefringent crystals, and limits of probability theory, for example in the case of the interference of electrons from a double slit), and as such may constitute epistemological obstacles to learning (Malgieri et al., 2017) can then be framed in a positive perspective, allowing the emergence of a new unitary picture and new possibilities embodied by quantum computation and quantum communication. The principles of quantum theory, and in particular superposition and entanglement, therefore become the heart of a path towards an overcoming of the classical paradigm not only on the side of physics, but in multiple directions. Thus, a TLS exploiting such connections may on one hand introduce students to interpretive and formal tools suitable for modelling contemporary technological advancements, and on the other hand open a broader and fertile theoretical and cultural perspective.

STRUCTURE OF THE TLS

The structure of the TLS is schematically reported in Table 1.

Table 1. Structure of the TLS.

Topic and time employed	Experimental and simulation activities	Methods
1. Introduction to quantum physics in the contexts of polarisation and the hydrogen atom (Distance Learning, 9 h)	Polarizing filters and birefringent crystals. Thought experiments. Simulations of single photons experiments	Individual worksheets, Generation of hypotheses and evaluation of student answers to the worksheet items in a full class discussion, Lecture
2. The physics of computation and its logic, from bit to qubit (DL, 3 h)		Lecture, group worksheet, frontal teaching and individual work
3. The logic of quantum physics: one-qubit gates, two-qubit non entangling and entangling gates (DL, 6 h)	QuVis simulation, optical implementation of gates	Lecture and individual work
4. Classical and quantum algorithms (DL, 3 h)	Mach-Zender implementation of algorithms	Lecture, group worksheet, and individual work
5. Bell inequalities and quantum protocols (DL, 3 h)		Lecture, group worksheet, and individual work
6. Classical and quantum cryptography (DL, 1,5 h)	QuVis simulation	Lecture and individual work

Introduction to quantum theory and the physical problem of computation

In order to provide a consistent and comprehensive access point into the physical picture, the concepts, and the mathematical tools needed for tackling a course on quantum computation, we adopted and revised an educational proposal described in Pospiech et al. (2021), section 4. In our sequence, students are led to acquire respectively the notions of observable, quantum measurement, quantum state and state vector, superposition, quantum interference, entanglement of modes (spatial and spin modes) of a single system, and finally the entanglement of different systems. All of the topics above are examined both from a conceptual and mathematical perspective. The basic features of the quantum description emerge in a modelling activity specifically including epistemic practices of the theoretical physicist, first in the simple context of photon polarization and then in the scientifically significant contest of the hydrogen atom.

After introducing the main elements of quantum physics, students are stimulated to reflect on the profound link between classical physics, propositional logic and probability theory and to evaluate how these aspects can be reinterpreted in a different way in the light of the new behaviour of physical systems studied in the first part of the path. Such reflection paves the way for the introduction of a new logic capable of representing the encoding and manipulation of information in a way which is compatible with the structure of quantum mechanics. The point of arrival of this line of thought is a synthetic circuital representation of quantum processes which, as detailed in the following subsection, contributes to provide with intuitive, conceptual meaning the mathematical structure of quantum theory, and becomes the basic language of almost all the topics addressed in the following.

Educational reconstruction of quantum algorithms

Reasoning within the Model of Educational Reconstruction (MER; Duit et al., 2012), we argue that within the existing research on teaching-learning quantum technologies, and in the specific case of quantum computation, no sufficient attention has been given yet to the clarification and analysis of science subject matter, and in particular to the issue of elementarization. Within the MER, elementarization is the process by which the content matter is analysed with the objective of identifying the elementary features (basic phenomena, principles, laws) which may be said to be the cornerstones for explanation, and understanding, of the field. Thus, elementarizing is not "simplifying", but finding an underlying structure within the subject matter (sometimes, at the expense of some degree of acceptable actual simplification) which can function as scaffold and guide for the learning process.

Based on an analysis of algorithms are of educational relevance for introductory teaching (i.e. primarily the Deutsch and Grover algorithm) we proposed an elementarization of their working principles based on the different identification of three different operational functions that each algorithm has to enact in order to obtain the desired result: 1) the activation of quantum parallelism on input qubits by means of Hadamard gate(s), in order to have a state composed of a balanced superposition of all basis states, so that the oracle can act on all of them simultaneously, although concretely acting on a single physical system; quantum parallelism in essence stems from the possibly of quantum systems of being in a state of superposition of two (or more) basis states; 2) the transfer of information from the oracle to the transfer qubits; this operation modifies the input superposition, in some cases (the Grover algorithm) producing entangled states, in some others (the Dutsch algorithm with less than 3 qubits) not; and 3) the activation of interference to move towards the final output result of the algorithm, which results from the outcome of a measurement. One clarifying note should be added concerning the concept of quantum entanglement: there has been considerable debate among researchers in quantum technologies (Ding and Jin, 2007) on whether the presence of entanglement a necessary element for the explanation of the advantage of quantum over classical over quantum algorithms, or instead entanglement should be considered as an accessory concept, which bears no particular significance to quantum computation. There seems to be at the moment no consensus among researchers, and at the level of an educational reconstruction, the presence of an open research question understandable to students can be of educational and motivational value, as long as students are provided with appropriate instruments for actually grasping the issue. Thus, the concept of entanglement is introduced with students before the introduction of quantum algorithms (see the previous Section), and the existence of an open question is explained, but the full treatment including circuits capable of producing entangled states are delayed to the final part of the course. In the Data Analysis Section, we will discuss on whether such elementarization scheme has been successful in providing adequate scaffolding for students' learning process.

Final part of the sequence: Bell states, teleportation protocol, quantum cryptography

Already in the treatment of quantum algorithms, the introduction of the Mach-Zender interferometer represents the key to connect, one by one, the symbolic elements of the circuital language to physical devices, both those, introduced previously when dealing with polarization, and the ones related to the interferometer. In this way polarizers, birefringent crystals, beam-splitters, and phase delay plates play the role of clarifying to students the correspondence between a step of an algorithmic sequence, its representation in the diagrammatic language, and the properties of physical systems which allow, at least in principle, its realization. From a formal point of view, the course allows students to establish a connection between the algebraic manipulation of states using the Dirac notation and vector algebra and its visualization and conceptual representation through the diagrammatic-circuit approach. Such work opens the way for the introduction in the last part of the TLS of circuits describing Bell states, and to show the most interesting applications of entangled states in quantum protocols and quantum cryptography. The TLS makes use of both available research-based simulation such as QuVis (Paetkau and Kohlne, 2016) and some specially tailored for the present experimentation of our own design.

The first application of the TLS which we report on with this poster was performed with students who self-selected on the basis of special interest in the topics of modern physics. The experimentation should be intended as the first stage of a Design-Based Research (Barab, 2006) project, studying its general feasibility; the final goal is to produce and refine a TLS appropriate for general curricular teaching.

CONTEXT AND DATA COLLECTION

The experimentation involved initially 14 students of the 12th and 13th grade (17–19-year-old) of *Liceo Classico* (4) e *Liceo Scientifico* (10) Galilei - Grattoni di Voghera, self-selected through interest about the topic of quantum computation and information. In fact, the course was performed as part of a school experimentation in which a small part of the curricular courses could be chosen by students electively (unusual in the Italian system). In the Italian system, both *liceo classico* and *liceo scientifico* are types of secondary school attended by students who intend to continue their studies in university; *liceo classico* is more oriented towards literacy and human sciences (for example, it includes Greek) while *liceo scientifico* is more focused on STEM disciplines. Halfway into the course, school rules gave students the opportunity of choosing different courses, and the number of students reduced to 8, 6 of which from *liceo scientifico* and 2 from *liceo classico*. All activities were performed in distance learning because of COVID-19 limitations. Data collected during the teaching experiment includes pre-test. post-test, the laboratory sheets and reports, worksheets used by students for exercises and problems, the notes taken during the activities on students' comments, questions and difficulties.

RESULTS

Student engagement with the course

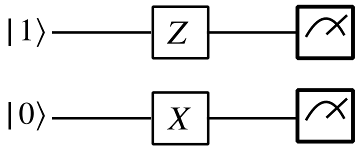
In general, students took part to the proposed activities with interest and a positive attitude. However, the fact itself that 6 students out of 14 switched courses after the first part is clearly an indication of lack of interest/engagement, at least for part of the students enrolled. From a global evaluation of experimentation data, it appears that most students leaving halfway in the course had difficulties with the mathematical/formal aspects of the course, which of course is not encouraging in a sample which was self-selected to start with. Future redesign of the course will have to take this element into account, as will be addressed in the conclusions. On the other hand, the remaining students seemed highly motivated and on par with the mathematical and conceptual requirements (see the following subsections), and at the end of the course most of them expressed the desire of delving even further into applicative aspects of quantum physics.

Understanding and connecting different representations of quantum processes

One of the intermediate worksheets we assigned to students consisted in a series of items probing the capabilities of students in a) translating circuital diagrams into Dirac and matrix notations, and using such notations to perform actual calculations; b) connecting the operations performed by logical gates to the graphical representation of quantum states; c) connecting the formal expression of a state to the probabilities of measurement outcomes. In the approach we adopted, the circuital representation of quantum algorithms played a crucial role in mediating between the mathematical machinery needed for calculations and the physical principles underlying the algorithms. The text of the worksheet is reported in Figure 2.

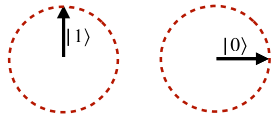
The work made for the construction of the qubit concept starting from polarization, and the subsequent interpretation of logic gates as axial symmetries in the state space seems to have been well understood by almost all students. Furthermore, the 6 students from *liceo scientifico* also solved, for the most part correctly, more demanding questions in terms of mathematical manipulations (mostly item 4), while students of *liceo classico* displayed difficulties in this sense, due to their more limited mathematical background.

Consider the following circuit:



1. Develop the two registers individually in both Dirac and matrix notation explaining, when measuring, which classical bits and with what probability are obtained on each register.

2. Represent the operations carried out algebraically on each register in the plane corresponding to it.



3. Consider the compound system $|10\rangle$ and evolve it in Dirac notation along the circuit. Imagine we make a measurement of the final state: what classical bits would we obtain? With what probability? Explain how the results were obtained.

4. Build the matrix $Z \otimes X$ and explain how it was obtained. Evolve the vector corresponding to the initial state $|10\rangle$ using the matrix obtained.

Figure 22. Problem on the connection between different representations of quantum processes given to students as intermediate worksheet.

Qualitative and conceptual understanding of quantum algorithms

In the final test we preferred to design questions that would allow us to evaluate whether the students had understood the conceptual aspects of the proposed topics, leaving the elements of pure algebraic calculation as optional. Here we report one of the two items related to the third design principle, the decomposition of quantum algorithms into three fundamental processes. To understand whether the proposed approach had supported the conceptual understanding of the Deutsch algorithm, the item asked to analyze the circuit by visually identifying the three processes and conceptually describing their structure, connecting their informational role with the physical principles underlying their action (See Figure 3). Another similar item was contained in the final test, concerning quantum teleportation.

Use Deutsch's algorithm to introduce the main elements of quantum algorithms: quantum parallelism, the role of the operator on target and ancilla, interference and measurement. For each of these elements, identify the parts of the circuit that represent them and identify which aspects of quantum physics are involved. (If you think it is necessary, carry out some calculations)

Figure 3. Final test exercise on the Deutsch algorithm.

We conducted a qualitative analysis of the answers to the final test aimed at determining whether the division in subprocesses we provided students with had been productive for their learning. All students were able to correctly highlight, in the circuital representation of Deutsch's algorithm, the portions of circuit corresponding to each of the three significant subprocesses (the enabling of quantum parallelism, the transfer of information from the oracle to the ancilla and target, the final selection of the result). All students also identified, at least partially, the links between each subprocess and individual features of quantum physical behavior and description, such as quantum superposition, the multiplicative structure of quantum compound systems which allows a phase factor to be considered related indifferently to the target or ancilla, quantum interference. Some students supported their reasoning with explicit calculations, but only as a complement to the considerations made earlier, so that they don't seem to rely solely on mathematics for sense-making. The similarly structured question which was given on the teleportation protocol produced comparable results. By examining students' answers, we can conclude that the elementarization we performed of the internal transformations from input to output within a quantum algorithm was successful in scaffolding students' learning process and providing a general framework to imbue such transformations with conceptual meaning.

CONCLUSIONS

The analysis of the experimentation data on one hand gives us a globally positive feedback on our basic inquiry about the feasibility of the path described with 17-19 year old students, providing encouraging indications on both the sides of conceptual understanding and learning engagement. On the other hand, the fact that 6 out of 14 students chose not to continue with the course after the first part is a strong element of warning, indicating that possibly our strategies for sustaining engagement and interest were not effective for all students, and/or further work is needed to reduce the impact on students' cognitive resources required with the introduction of new mathematical and formal tools. A mitigating consideration may be that the distance teaching/learning process makes it very difficult to promptly address individual difficulties of students; Data also show rich and complex learning patterns, allowing to uncover peculiar reasoning paths and cognitive strategies of students, and to identify which activities may be more productive for students and which ones may show weak points and lead to student difficulties. Future redesign of the course for fully curricular use will have to take into account 1) a more gradual introduction of the mathematical tools needed for analysis of quantum circuits, 2) further enrichment of the interdisciplinary and intra-disciplinary character of the sequence in order to "activate" students with different areas of interest and reinforce knowledge integration. Among the other future directions on which we are currently working we mention:

- The realization of an experimental implementation of the Deutsch and Grover algorithms with macroscopic light beams on the optical bench. In fact, the mathematical identity between the classical and quantum approach to the dual rail allows in principle to run such algorithms with classical polarized light sources, interpreting the relative intensity of light collected at different detectors in probabilistic terms.
- The development of an interactive computer simulation connecting the circuital representation of educationally relevant quantum algorithms and protocols to their possible physical realization using optical elements.

  Both the tools above described are meant to be used in the context of inquiry activities for small student groups, in such a way as to encourage the social construction of knowledge and reinforce the connection between physical reality, the diagrammatic and graphical tools used, and the mathematical model.

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Part 6 / Strand 6

Nature of Science: History, Philosophy and Sociology of Science

Editors: *Ebru Kaya & Veli-Matti Vesterinen*

Part 6. Nature of Science: History, Philosophy and Sociology of Science

The implications of nature of science, its history, philosophy, sociology and epistemology, forscience education. The significance of models and modelling for science education as reflected in the particular importance attached to the use of metaphors, analogy, visualization, simulations and animations in science.

Part 6: Nature of Science: History, Philosophy and Sociology of Science

Editors: *Ebru Kaya & Veli-Matti Vesterinen*

Introduction

In the age of social media, science and scientific perspective seem to be constantly challenged. In addition, growing concerns over disinformation have highlighted the need to improve students' understanding of what science is, how it operates, and how it can contribute to solving global challenges we face. Thus, understanding the Nature of Science (NOS) is seen as an integral part of scientific citizenship.

Two studies presented in Strand 6 (Nature of Science: History, philosophy and sociology of science) were accepted to be published in the ESERA 2021 conference proceedings. Both papers address the issues of teaching NOS.

The first paper by Jan Winkelmann focuses on the beliefs and attitudes about the importance of idealisations within the genesis of scientific knowledge in a teaching context. The author presents a questionnaire including three scales: Epistemological Beliefs on Idealisations in Natural Sciences, Epistemological Beliefs on Dealing with Idealisations in Science Education, and Actual Teaching Practice in Dealing with Idealisations. The questionnaire was developed for teachers to ascertain their perspective on the meaning of idealisations as part of Idealisations in Modelling and Experimentation (IDOMEX) research program.

The second paper was written by Constantina Stefanidou and Constantine Skordoulis. They investigated how pre-service primary teachers plan to teach NOS in their future classes in light of the COVID-19 pandemic. The pre-service primary teachers wrote a report on creating a teaching scenario on NOS. The content analysis results show that most pre-service primary teachers focused on the empirical character of science and the fact that scientists are influenced by their previous beliefs, along with the tentativeness of science and the influence of the social and cultural aspects.

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EPISTEMOLOGICAL BELIEFS ON IDEALISATIONS IN SCIENCE TEACHING – CONSTRUCTION AND VALIDATION OF A QUESTIONNAIRE

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Epistemological beliefs denote personal subjective views, conceptions, and theories about the genesis, ontology, meaning, justification, and validity of knowledge in the sciences. In this context, views of Nature of Science, in general, are often ascertained in science education research. In particular, this paper's subject is the beliefs and attitudes (focusing on the teaching process) about the importance of idealisations within the genesis of scientific knowledge. Idealisations are omnipresent in scientific knowledge acquiring when dealing with models and experiments. Inadequate addressing of idealisations in the teaching context suggests learning difficulties for students. As part of the research program IMODEX (Idealisations in Modelling and Experimentation), a questionnaire was developed for teachers to ascertain their perspective on the meaning of idealisations. The focus is on three scales: 1. Epistemological Beliefs on Idealisations in Natural Sciences, 2. Epistemological Beliefs on Dealing with Idealisations in Science Education, 3. Actual Teaching Practice in Dealing with Idealisations. The questionnaire was constructed based on a pilot study with 103 students in 2020 and revised for a second pilot study in 2021 with science teachers. By using multiple regression analyses, the aim is to obtain recommendations for action on what should be emphasised in training and further education so that idealisations play a more significant role in teaching. The further development of the questionnaire based on the second pilot study with science teachers is presented in this paper.

Keywords: Idealisations, Nature of Science, Beliefs

THEORETICAL BACKGROUND

One primary goal of science education is to give students a better understanding of science concepts and contexts. This goal means having good content knowledge of different domains, e.g., physics, chemistry, or biology, and having adequate beliefs about how science works, assigned to the field Nature of Science (NOS). Together with experiments, models represent the two pillars of scientific knowledge acquisition, which are always based on idealisations. Suppose teachers do idealisations not make to explicit objects of learning (e.g., in models as epistemic artifacts, Gilbert & Justi, 2016, 17). In that case, one can assume that poor consideration with idealisations prevents students from developing appropriate concepts of scientific knowledge acquisition. Reflecting on the meaning of underlying idealisations in models and experiments can contribute to developing the abilities mentioned above. However, in previous approaches to epistemological beliefs in the natural sciences (e.g., Conley et al., 2004) and current research on modelling competence (e.g., Gilbert & Justi, 2016), the cross-sectional topic of idealisation appears to be underrepresented (Winkelmann, 2021a).

Epistemological Beliefs

Epistemological beliefs denote personal subjective views, conceptions, and theories about the genesis, ontology, meaning, justification, and validity of knowledge. Such beliefs show across contexts some stability but can also differ across domains and topics (Muis et al., 2006; Sandoval et al., 2016). In the discourse of science education research, epistemological beliefs are located in the context of NOS (Hofer & Pintrich, 1997, Lederman & Lederman, 2014). The research focus is on a broad understanding of NOS, e.g., the epistemological significance of models and experiments in the process of scientific knowledge acquisition (Urhane & Hopf, 2004; Priemer, 2006). Conley et al. (2004) conceptualised a widely recognised model of epistemological beliefs in science with four dimensions: certainty, development, source, and justification of knowledge. Building on this, a series of studies on students' epistemological beliefs and relations between epistemological beliefs in science and student learning characteristics were carried out and recently brought together in Schiefer et al. (in press).

Idealisations in Science and Science Education

All processes of scientific knowledge acquisition are based on idealisations. Be it experimenting, in which a (natural) phenomenon is examined in the laboratory under ideal conditions, or in dealing with models, only those aspects of the phenomenon that are of interest are considered. Such a willingly adjustment compared to reality is not unusual to scientists. Science teachers will also report that they idealise in very different areas in their lessons, for example, with (air) friction in mechanics or with thin lenses in optics. Based on previous considerations on the relationship between theory, model, and experiment, the yellow box in Figure 1 illustrates the linking character of idealisations (Winkelmann, 2019).

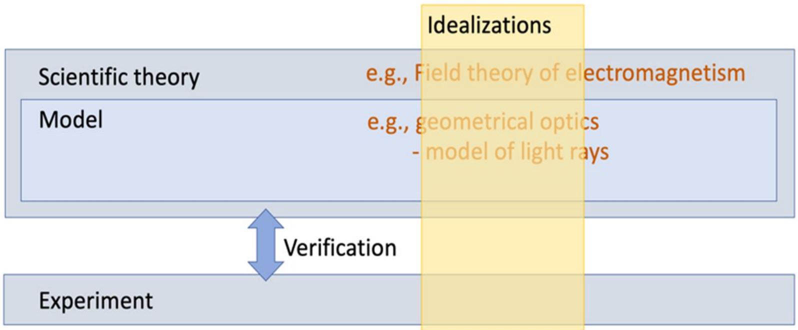

Figure 1. Idealisations take place in all areas of scientific knowledge acquisition.

To promote students' modelling and experimenting competence, it should be conveyed how to construct a model or design an experiment, namely with idealisations. Accordingly, this research program's underlying thesis is that idealisations should be explicitly identified and reflected upon in teaching to achieve an improved understanding among students. To meet this requirement, a definition of idealisation is necessary. In the following, suggestions from the philosophy of science define what is to be understood by idealisations. When science discusses idealisation, it is about approaching a complex reality. For this purpose, individual properties of an object under consideration are consciously replaced. The focus is only on those properties that are felt to be essential for an investigation's goal (Nowak & Nowak, 1998; Strevens, 2017). The aim is to be able to answer a question about nature. Idealisations are based on the requirement of optimising an explanation: In the search for knowledge, idealisations are deliberate substitutions for an original. False assumptions are consciously accepted (Hüttemann, 1997). Idealisations, therefore, have two related properties. On the one hand, idealisations are limited to the essentials. It depends on the question of what is essential in each case. On the other hand, idealisations always represent a deliberately falsifying substitution.

Despite this falsification, it is undisputed that, for example, an evaluation of constructed models is justified concerning their usefulness and not with a view to whether these models are "right" or "wrong".

METHOD

The research program IMODEX (Idealisations in Modelling and Experimenting) examines the importance of idealisations for science education. As a first step, a questionnaire was developed for teachers to ascertain their perspective on the meaning of idealisations. The focus is on three scales: 1. Epistemological Beliefs on Idealisations in Natural Sciences, 2. Epistemological Beliefs on Dealing with Idealisations in Science Education, 3. Actual Teaching Practice in Dealing with Idealisations.

The questionnaire was revised based on initial testing of the scales with 103 students (1^{st} pilot study in 2020). The items of the first scale, "Epistemological Beliefs on Idealisations in Natural Sciences", fit well with the found factor in terms of content but load weak and should be reformulated again. For the scale "Epistemological Beliefs on Dealing with Idealisations in Science Education", an explanatory factor analysis provides indications that a differentiated survey using the two subscales "Concrete Teaching of Idealisations" and "General Importance of Idealisations in Science Lessons" is valid. Additional items for the "Actual Teaching Practice in Dealing with Idealisations" scale had to be constructed to obtain possible subscales (Winkelmann, 2021b).

During an online teacher survey (2^{nd} pilot study, in summer 2021), the questionnaire was piloted by 62 science teachers on a 5-point Likert scale (1 = "does not apply at all" to 5 = "fully applies"). To analyse the scales used, explanatory factor analyses (with maximum likelihood method and varimax rotation) were carried out using SPSS. The modified scales - known from the first pilot study - were again subjected to exploratory factor analyses to identify possible subscales. The conditions for the factor analyses appear to be given for the respective scales (KMO test achieves sufficiently high to very good values: $KMO_{natural\ science}$: .613, $KMO_{science\ education}$: .907, $KMO_{Teaching}$: 773; Bartlett's test is significant in each case: p <.001). However, the sample size is relatively small (according to Bühner, 2006, just enough), so the results should be cautiously interpreted.

RESULTS

The three scales were each subjected to exploratory factor analysis. Summing up, the three scales and their subscales are presented in table 1. In addition, the table gives an example item for each scale and names the number of items as well as the respective reliability (Cronbach's α).

Table 3. Overview of the analysed scales.

Title of the Scale	Sample Item	Number
Epistemological Beliefs on Idealisations in Natural Sciences (• = .72)	see below	8 items
Meaning of Idealisations in Natural Sciences (• = .75)	*Idealisations are omnipresent in scientific knowledge acquisition.*	4 items

Experimenting (• = .68)	*Meaningful experimental findings can only be achieved with idealisations.*	3 items
Model Construction (• = n.a.)	*Idealisations are the basis for the construction of models.*	1 item
Epistemological Beliefs on Dealing with Idealisations in Science Education (• = .86)	*In my opinion, idealisations should be made an explicit subject in science lessons.*	8 items
Actual Teaching Practice in Dealing with Idealisations (• = .93)	see below	18 items
Student Action in Experimenting and Modelling (• = .89)	*My students usually identify idealisations in the models used.*	6 items
Cognitive Consideration of Teacher (• = .88)	*I often think about idealisations in science classes.*	3 items
Explicit-Reflective (• = .82)	*In my lessons, idealisations serve to reflect on an experiment that has been carried out.*	6 items
Model Construction (• = .77)	*In my lessons, we construct models with the help of idealisations.*	3 items

Scale „Epistemological Beliefs on Idealisations in Natural Sciences“

Initially, this scale comprised 14 items. The exploratory factor analysis suggests four factors (eigenvalue criterion and scree plot). Due to partly weak loads on the factors and a subsequent content-related consideration, six items were removed. Another exploratory factor analysis points to three factors. The values of the Measure of Sample Adequacy (MSA) are higher than .5 (except for the item on the "Model Construction" subscale. However, due to the importance of the content, this item was retained, and additional items will be developed, similar to the "Experimenting" subscale). The three factors together explain 54.9% of the variance in the data. The loadings are each sufficiently strong (> .41), and the different factors (subscales) are easy to interpret.

Scale „Epistemological Beliefs on Dealing with Idealisations in Science Education“

Initially, this scale comprised eleven items. The exploratory factor analysis suggests three factors (eigenvalue criterion and scree plot). Due to partly weak loads on the factors and a subsequent content-related consideration, three items were removed. Another exploratory factor analysis points to one factor. The values of the MSA are higher than .8. The factor explains 55.6% of the variance in the data. The loadings are each sufficiently strong (> .41).

Scale „Actual Teaching Practice in Dealing with Idealisations“

Initially, this scale comprised 20 items. The exploratory factor analysis suggests four factors (eigenvalue criterion and scree plot). Due to partly weak loads on the factors and a subsequent content-related consideration, two items were removed. Another exploratory factor analysis points again to four factors. The values of the MSA are higher than .6. The four factors together explain 61.8% of the variance in the data. The three factors together explain 54.2% of the variance in the data. The loadings are each sufficiently strong (> .41), and the different factors (subscales) are easy to interpret.

CONCLUSIONS AND OUTLOOK

Thinking about idealisations in modern sciences is nothing new. However, reflection on idealisation seems underrepresented in science education and science education research. Students should gain an adequate understanding of and beliefs about the nature of science, particularly about the meaning of idealisations. A framework with categories of idealisations is available (Hüttemann, 1997) and discussed and illustrated in Winkelmann (2021a). Furthermore, current considerations with idealisations in the classroom should be surveyed. In addition, it seems useful to investigate teachers' beliefs on idealisation in science and science education.

As part of two pilot studies, a questionnaire was developed for this purpose, including the three scales presented above. After the structure-discovering analyzes have been carried out, validity checks now follow. The content validity is checked within the framework of guided interviews with teachers. The convergent validity is tested regarding a scale from Conley et al. (2004). After that construct validity check, a teacher survey is currently planned to identify the role of idealisations in science teaching. The survey is intended to analyse teachers' epistemological beliefs on the importance of idealisations in science and science education.

It is assumed that only the teaching teacher can initiate a reflection on idealisations. Depending on the actual attention teachers' pay to idealisations, they should be sensitised to this topic during their studies or further training. Using multiple regression analyses, the aim is to obtain recommendations for action on what should be emphasised in training and further education so that idealisations play a more significant role in teaching. In the long term, intervention studies should examine the effect of reflecting on idealisations on students' understanding. Such research would allow students to develop an awareness of their thinking processes when modelling and experimenting. It provides strategies for teachers to develop learning outcomes related to NOS.

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TEACHING NATURE OF SCIENCE IN THE LIGHT OF COVID-19 PANDEMIC CRISIS

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COVID-19 pandemic which began in the end of 2019, changed the whole world. Inevitably it influenced every aspect of education. During the pandemic, we watch how science and scientists struggle between the required scientific research in the level of understanding how the new coronavirus functions, at the level of producing effective drugs and vaccines and at the level of communicating the necessary information to people, to effectively protect themselves. In this paper, we examine how pre-service primary teachers plan to teach Nature of Science in their future classes and especially which Nature of Science aspects they emphasize in the light of the COVID-19 pandemic. The sample, which was a convenient one, consisted of 296 pre-service primary teachers, 272 females and 24 males. Data collection involved the report they wrote at the end of an undergraduate course, called Didactics of Science, which included both lectures and laboratory exercises, in the context of which they were asked to create a teaching scenario on Nature of Science. The qualitative content analysis method was used to analyze the data. The analysis showed that most pre-service primary teachers set as teaching goals the empirical character of science and the fact that scientists are influenced by their previous beliefs, along with the tentativeness of science and influence of the social and cultural milieu. Further research includes content analysis in pre-service teachers' teaching scenarios regarding the activities and the educational material they proposed.

Keywords: Science education, nature of science, socio-scientific issues

INTRODUCTION – THE CONTEXT

The COVID-19 pandemic outbreak has provided an opportunity to get a pulse on how well our society understands science processes. Everyday media provide scientists' findings about the virus as well as predictions, and speculations from doctors and political leaders. These predictions and speculations have changed dramatically over time and sometimes contradict each other (Bloom & Fuentes, 2020).

An example of such contradiction was between findings that supported that that young people are mostly unaffected by the virus, and those findings some weeks later, which revealed a connection between COVID-19 and Kawasaki Disease in children. Further, children are indeed succumbing to COVID-19, and the numbers of children with the disease are likely far undercounted (Lerner, 2020). A World Health Organization (WHO) official drew strong pushback from medical experts when she stated in a press conference that asymptomatic people spreading the disease was "very rare;" she later clarified that the actual number of cases caused by asymptomatic transmission is unknown (Joseph, 2020). But by then, the "the wrong message" had been transmitted. People who doubted the seriousness of COVID-19 used this miscommunication as justification to avoid wearing masks when in public. Others considered this another example of how scientists just do not know what is going on, cultivating a mistrust of science in general.

COVIS-19 pandemic which changed the whole world inevitably, influenced every aspect of education; science education included. It was this time of the year that the authors of this article started the course Didactics of Science in the Department of Primary Education, of National and Kapodistrian University of Athens. The course included both lectures and laboratory classes, where pre-service teachers were engaged to teaching and learning Nature of Science (NoS), through a couple of activities, which varied between historically based and socio-scientific issues (Allchin, 2013; Irwin, 2000; Kolsto, 2001; Klopfer, 1997; Stefanidou et al., 2020).

The arising question was how pre-service teachers' experience of the pandemic has influenced them in designing a teaching scenario for teaching their students NoS through a burning socio-scientific issue such as the COVID-19 pandemic? As McComas et al (1998) have pointed out, NoS is something like how the game of science is played. The "game" of science related to COVID-19 pandemic, a socially significant and culturally important issue, offers some opportunities to realize how science, society, technology, politics interrelate and ask for people's conceptualization, collaboration, and action.

The research is part of a broader study on how pre-service teachers in the era of pandemic conceptualize and design teaching proposals regarding several aspects of NoS. In this paper, the research question is which aspects of NoS do pre-service teachers allege as more important if they were to teach NoS in the context of COVID-19 pandemic and how do they justify them?

METHOD

Fieldwork was carried out at the Department of Primary Education, of the National and Kapodistrian University of Athens, during the spring semester of 2019-2020, from March to June 2020. The Didactics of Science Course included fifteen lectures on topics such as scientific literacy, history, and philosophy of science in science teaching, the role of experiment in science teaching and the inquiry-based teaching and learning model in addition to four associated laboratories during which pre-service teachers had the opportunity to design their own teaching scenarios. All participants were engaged to at least one lecture regarding NoS ideas in addition to an associated laboratory exercise regarding teaching NoS. During the lecture, emphasis was given to "Keys to Teaching the Nature of Science" (McComas, 2004) as a context for elaborating how science and scientists work. In the context of the associated lab, pre-service teachers were engaged to activities regarding the distinction between science and pseudo-science, the role of empirical evidence and the difference between observations and inference, the role of scientists' prior ideas in knowledge development and the interrelation between science and society.

The sample consisted of 296 fourth year university prospective primary teachers, 24 males and 272 females, who undertook the Didactics of Science Course and were selected due to convenient access. All participants designed a teaching scenario on Nature of Science as part of their final assessment (response rate 100%). They were asked to "imagine" the school year 2030-2031 and design a teaching scenario to familiarize twelve years old students with NoS aspects in the context of COVID-19 recent pandemic. As a result, 296 teaching scenarios were collected and analyzed according to their teaching goals.

This study follows a qualitative descriptive cross-sectional research approach. Qualitative content analysis method (Mayring, 2000) and descriptive statistics were used to quantify the findings and present a clearer picture of what pre-service primary teachers find important to teach about NoS understanding (Gay, Mills & Airasian, 2012).

RESULTS

First findings are available in Table 1. Most of the participants recognized as important aspects to teach in twelve years old students the role of empirical evidence in science (72%) and the idea that science has a subjective element (56%). Regarding the empirical character of science, participants' main argument was that during COVID-19 pandemic scientists had to wait until an adequate amount of evidence was gathered before the first findings regarding the modes of transmission were explained and modes of protection and treatment were developed. Regarding the subjective element of science, pre-service primary teachers argued that scientists had different opinion on the same topic, due to their prior beliefs and perspective. They referred to the example of experts' different opinions regarding whether children are super spreaders of COVID-19 or not. Moreover, 48% of pre-service teachers found important to teach that there are cultural and social influences in science. Most of them focused on the negative impact of the pandemic in every aspect of social life, such as the school lockdown and the measures of social restriction. Few of them referred to the controversial role of religious leaders towards the spread of pandemic, giving religious advice to a scientific problem, such as COVID-19 pandemic. Regarding the aspect that scientific knowledge is tentative, about half of the participants (46%) found it important to be taught, underlining that during the pandemic experts' instructions to citizens differed from day to day. Such instructions included diverging ideas, from "masks do not protect" to "masks are compulsory in all publicly accessible areas". Pre-service teachers argued that science is not dogmatic and scientific findings change in the light of new evidence and research. Participants argued that COVID-19 revealed that science is more complex than expected and recognized that it is the first time that science's complexity comes to surface.

Table 1: Pre-service primary teachers' priorities for teaching NoS.

Key aspects on teaching NoS (McComas, 2004)	**Pre-service primary teachers (%)**
Science demands and relies on empirical evidence	72
Science has a subjective element	56
There are historical, cultural, and social influences on science	48
Scientific knowledge is tentative but durable…	46
Science and technology impact each other, but they are not the same	32
Science and its methods cannot answer all questions	26
Knowledge production in science includes many common features and shared habits of mind … there is no single step-by step scientific method by which all science is done	20
Science is a highly creative endeavor	18
Laws and theories are related but distinct kinds of scientific knowledge	-

Regarding the relationship between science and technology, 32% of the pre-service teachers found important to introduce their students to this aspect. They argue that since COVID-19 outbreak, technological developments from different types of diagnostic tests and protective masks to innovative mRNA vaccine technology interact with science enabling the deepen explanation and prediction of COVID-19 related phenomena. Nearly one quarter of the participants (26%) included in their teaching goal the aspect of NoS according to which science and its methods cannot answer all questions. Although this NoS aspect refers to questions that are not scientific, such as "which kind of music do you like?", pre-service teachers used as examples the unanswered questions related to COVID-19 pandemic such as "why do some people with COVID-19 get sicker than others"? Regarding the role of scientific method in "science in the making", the 20% of pre-service teachers found it important to be included in their teaching goals. They argue that although scientific research against COVID-19 includes some common features, such as constructing hypotheses, providing evidence, experimentation and modelling, every scientist or research team apply its own specific procedures in developing scientific products, such as theories, explanations, or predictions. Pre-service teachers underlined that not all scientific inquiries regarding COVID-19 follow the same steps. Regarding the creativity of science, the 18% of the pre-service teachers found it important to be taught in the context of NoS teaching, supporting that crisis is a strong driver of creativity and innovation in science and beyond. For example, pre-service teachers referred to the innovative idea of mRNA vaccination technology and the 3-D printing face masks in order to meet the desperate need for protective masks during the pandemic. Finally, pre-service teachers did not propose the differences between laws and theories in science as teaching goal for NoS teaching in the context of COVID-19 crisis.

CONCLUSIONS - DISCUSSION

The research revealed that most pre-service primary teachers found COVID-19 pandemic a fruitful context to think and teach aspects of NoS. Their experience during the pandemic helped them recognize as important aspects of NoS the empirical character of science and its subjective element along with the tentativeness of science. Regarding the social and cultural influences on science, most of pre-service primary teachers emphasized on the interruption of social activities and only a few revealed concerns related to the position of the governments, the availability of the vaccine without restrictions by the pharmaceutical companies and the role of church to the spread of COVID-19.

Findings of the present study provoke some additional thoughts. The study took place in the beginning of the pandemic, from March to July 2020. World Health Organization Director-General Tedros Adhanom Ghebreyesus, referring to the pandemic, said, "We're not just fighting an epidemic; we're fighting an infodemic," (Barzilai & Chinn, 2020, p. 107). This infodemic calls attention to the importance of questioning the reliability of the information and its source: explanations from scientists, politicians, and healthcare providers in media; and speeches of several nonexperts on TVs as well as the rapid spread of information and misinformation in social media (Mugaloglou et al., 2022). This complex situation drove to scientists' mistrust, which gives rise to further pseudo-science scenarios. Research reveals that during the pandemic people could not cope with the tentative and subjective aspects of NoS, and this fact made a lot of people lose their trust in science. It is a positive finding of this research, that pre-service teachers designed NoS teaching scenarios based on the pandemic, focusing on the empirical, tentative and subjective NoS which is considered to be key-issues of NoS.

Moreover, almost half of pre-service teachers suggested teaching goals related to the socio-cultural aspects of NoS. This finding has increased importance if we take into consideration the fact that COVID-19 pandemic is a socio-scientific issue, which engages not only scientists and doctors, but also policy leaders, journalists and policy makers. Pre-service teachers that referred to this aspect avoided raising the issue of the relationship between science, politics and religion, maybe in order to keep equilibrium between science and policy making or because they find primary students too young to familiarize them with such issues.

Regarding future considerations, further analysis in pre-service primary teachers' teaching scenarios should shed light on the teaching approach, activities and resources they used in order to *teach* the above-mentioned aspects of NoS. It seems that aspects such as the empirical and tentative aspect of science seem to be more manageable for pre-service teachers related to aspects such as the politicization of science and churches' role during the pandemic, which seem to be more controversial. Maybe it is time for re-considering the role of science education in the light of modern socio-scientific issues in the post covid era (Dillon & Avraamidou, 2020) or in other words it is "time for action" (Hodson, 2003) in order science education to find its position in 21st century society.

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Part 7 / Strand 7
Discourse and Argumentation in Science Education

Editors: *Kalypso Iordanou & Maria Andrée*

ESERA 2021
Fostering scientific citizenship in an uncertain world
30 Aug - 3 Sep 2021
Organised by University of Minho, Braga, Portugal

Part 7. Discourse and Argumentation in Science Education

Understanding, supporting and promoting use of evidence and argumentation discourse in science education. Scientific practices related to knowledge evaluation and communication. Supporting the development of critical thinking. Discourse analysis. Talking and writing science in the classroom. Meaning making in science classrooms.

Part 7: Discourse and argumentation in science education

Editors: *Kalypso Iordanou & Maria Andrée*

Introduction

Strand 7 *Discourse and argumentation in science education* includes research on the understanding, supporting and promoting use of evidence and argumentation discourse in science education. The strand also includes research on scientific practices related to knowledge evaluation and communication, supporting the development of critical thinking, discourse analysis, and meaning-making in science classrooms. This E-proceeding includes eight contributions, all contributing to advancing the understanding of potential roles of argumentation and critical thinking in science education from primary school practices to undergraduate studies.

Most of the contributions to ESERA 2021 strand 7 zooms into how argumentation and conceptual learning unfold discursively in science classrooms. It is viewed from the perspectives of students and teachers in different stages of the educational system. (1) Dennis Diez and Claus Bolte from Germany investigate the concept of energy and the extent to which German Year 9 students make intra-subject (so-called vertical) linkage structures. Their work includes the development of a model for analysing and describing vertical linking knowledge. (2) Georgios Tsiftsis and Krystallia Halkia from Greece examine the parallel development of undergraduate students' argumentation skills and conceptual understanding of Newtonian Mechanics. They conducted a quantitative analysis displaying a statistically significant improvement in both students' argumentation skills and their conceptual understanding in three out of five problems. (3) Panagiotis Rigas, Katerina Salta, Katerina Paschalidou and Constantinos Methenitis from Greece focus on the processing of epistemic mental models that students relied upon to make their decisions when solving problems on solution formation and solubility. In particular, they focus on what heuristic reasoning high school students use to solve problems on solution formation and solubility. The study was based on interviews, and the results show that many students used more than one heuristic as part of their reasoning and decision-making while responding to the tasks. (4) Shungu Mupfawa, Marissa Rollnick, Kershree Pdayachee and Anastasia Buma from South Africa investigated teachers' talk while teaching basic genetics concepts. In particular, they focused on features of the use of language and context of use across teachers and what strategies teachers employed to foreground meanings of basic genetics terms. (5) Naykiavick Rangel, Marina Castells and Joaquín Gimenez from Venezuela and Spain conduct a multimodal-rhetorical-argumentative analysis of characteristics of physics lecturers' classes to find forms to visually represent the construction of explanatory stories, using schemes to describe story elements according to thesis, premises, arguments and its interactions and their relationship with multimodality. The study shows the complexity of teaching from argumentative-rhetorical and multimodal perspectives.

Another contribution to the strand sets out to explore argumentation, conceptualised as critical thinking, concerning the nature of science (NOS). (6) María Antonia Manassero-Mas and Ángel Vázquez-Alonso from Spain explore the relationships between critical thinking and NOS by selecting some variables from two assessment tools representing both constructs in order to compute their empirical correlations regarding a hypothesised mutual relationship between NOS beliefs and CRT skills. Their study shows significant relationships between thinking skills and NOS beliefs on science definitions.

Discourse, argumentation and conceptual science resources are also intertwined outside formal science education in ways which might be relevant for advancing formal science education practices. (7) Ana Sofia Afonso and Susana Afonso from Portugal and the UK, respectively, have explored scientists' voices in news media. In particular, their study explored astronomers' uses of metaphors in interviews with Portuguese newspapers from 2009 to 2021. In the study, they identified several conceptual metaphors, which evoked a network of concepts concerned with astronomical research. They further suggest that these conceptual metaphors may be useful for developing formal education on astronomy.

The final contribution to ESERA 2021 Strand 7 introduces the notion of chronotype for understanding science education discourses. (8) Vanessa Cappelle, Luiz Gustavo Franco and Danusa Munford from Brazil analysed classroom events to understand how students and their teacher construct space-time relationships in science lessons throughout the first three years of elementary school. The results indicated that space-time connections established by the participants became relevant resources in the group's history.

Overall, the papers of Strand 7 contribute to the flourishing area of discourse and argumentation in science education and show the central role of argumentation in promoting knowledge acquisition and reasoning in science education.

Analysis of Linking Knowledge within the Concept of Energy in Student Essays

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In the present study, we investigate the extent to which intra-subject (so-called vertical) linkage structures can be identified in essays of German Year 9 students on the basic concept of energy. In contrast to English-speaking countries, the natural sciences are taught in the differentiated subjects of biology, chemistry, and physics in Germany. Despite the differentiation of subjects, one hopes that by teaching interdisciplinary basic concepts alone, such as the concept of energy, similar linkage performances can be achieved, as one would expect from an integrated subject science. Existing models for analysing and describing vertical linking knowledge provide similar but not fully comparable results. Therefore, we must develop our own analysis tool. With this analysis tool, it is possible to examine the linkage of terms within the basic concept of energy in essays comprehensively. Our aim is to gain an empirical insight into linking knowledge of our students within the concept of energy in the sense of a first (normative) survey. This survey should enable future comparative studies both on a national and international level in which the effects of subject-integrated science teaching on students' linking performance can be investigated.

Keywords: Conceptual Understanding, Qualitative Methods, Interdisciplinarity

INTRODUCTION

In 2005, the secretariat of the permanent conference of the ministers of education of the federal states in Germany (KMK) introduced basic concepts into the standards for the intermediate school leaving certificate (KMK, 2005a-c). Basic concepts are intended to enable both more subject-inherent (so-called vertical) linkage and more cross-curricular (so-called horizontal) linkage in science teaching (Demuth et al, 2005). The concept of energy is of particular importance in this context, as it is the only basic concept that is used in all three science subjects in Germany: biology, chemistry, and physics. Although there are studies that examine German students' understanding of the concept of energy (e.g., Neumann et al., 2013), these focus only in a few cases and then only on selected aspects of the issue of linking knowledge (e.g., Podschuweit & Bernholt, 2020). Since it is now more than 15 years after the introduction of the basic concepts, an empirical investigation of the linking performance of German students within the concept of energy appears to be a desirable task.

THEORETICAL BACKGROUND

Theory-based considerations of constructivist learning theories (e.g., Jonassen, 1999) as well as the assumptions of cumulative learning (Gagné, 1965) support the importance of linking knowledge. In the literature there are different models which describe vertical linkage within conceptual knowledge.

Fischer, Glemnitz, Kauertz and Sumfleth (2007) developed the model of vertical linkage which is pervasively used in German science education research. For instance, Wadouh (2009) utilized it for the analysis of students' linking performance in videotaped biology lessons. The ESNaS competence models (ESNaS is the German acronym for: Evaluation der Standards für die Naturwissenschaften in der Sekundarstufe I, in English: Evaluation of the standards for science in the lower secondary level) utilize the model of vertical linkage in its final version (e.g., Kauertz et al., 2010). The model of vertical linkage contains five linkage levels in ESNaS competence models: *1 fact*, *2 facts*, *1 relation*, *2 relations* and *generic concept* (e.g., Kauertz et al., 2010, pp. 142-143). In that way, the model of vertical linkage takes qualitative as well as quantitative aspects of linkage into account.

Bernholt and Parchmann (2011) adapted the model of hierarchical complexity (Commons et al., 1998) to assess the complexity of students' knowledge in chemistry. In contrast to the model of vertical linkage mentioned above, the model of hierarchical complexity only considers qualitative aspects of linkage. This model differentiates between the linkage levels *everyday experiences*, *facts*, *processes*, *linear causality*, and *multivariate interdependencies* (Bernholt & Parchmann, 2011). This model is also pervasively used for the analysis of videotaped lessons (e.g., Podschuweit et al., 2016) and serves as a basis in different competence models (e.g. Woitkowski et al., 2017).

Woitkowski, Riese and Reinhold (2011) identified many overlaps but also differences comparing the category definitions of the model of vertical linkage (Fischer et al., 2007) and the adapted model of hierarchical complexity (Bernholt & Parchmann, 2011). Nehring, Päßler and Tiemann (2017) compared both models in practice. In this investigation they analysed teacher questions in chemistry lessons using both the model of vertical linkage and the model of hierarchical complexity. The results of the analysis with both models were only comparable up to 70 % (Nehring et al., 2017). Furthermore, it is particularly notable that the authors could not even relate a single *generic concept* to a *multivariate interdependency* (Nehring et al., 2017). That is one of the reasons why in our opinion, it is necessary to combine and to optimize both models to achieve an accurate description of the analysis dimension *vertical linkage level*. With the help of this combined and optimised approach, we would like to investigate the following research question:

In what way and to what extent do student statements concerning the basic concept of energy show vertical linkage structures?

METHODS

We planned to survey the entire 9th grade cohort of one secondary school in Berlin directly at the start of the school year to get an impression of the student's linking performances in the sense of a first evaluation. There are many ways to explore students' cognitive structures (e.g., Stewart, 1980). On the one hand, we wanted to survey a large number of students, which would not be possible with methods such as conducting interviews. On the other hand, the method we wanted to use should not require any special training, as it would be the case, for example, with the creation of concept maps (e.g., Novak, 1990). Therefore, we decided to ask the students to write essays on the basic concept of energy as the students know how to write essays from German lessons. Van Kirk (1979) asked students to write essays on biological topics and gave them a list of terms to support the writing process. Following van Kirk's idea (1979), we first looked into curricula of the science subject's biology, chemistry, and physics for the states of Berlin and Brandenburg (SenBJF, 2017a-c) in order to prepare a list of terms relevant to the concept of energy. We extracted 108 terms, which we presented to 107 science teachers, asking them to mark ten to fifteen of the most important terms for their lessons. The list of terms that we finally present to the students consists of 26 terms (Tab. 1). 15 terms are the "teachers' top 5 ratings" for each of the three science subjects. In addition, we have supplemented the list of 26 terms with these terms that appear in at least two of the three science curricula (Dietz et al., 2021).

Table 1. List of terms to support students in writing an essay on the basic concept of energy (Dietz et al., 2021).

endothermic	*kinetic energy*	*metabolism*	*energy forms*
system	*photosynthesis*	*reaction energy*	*work*
energy flow	*chemical energy*	*electric energy*	*nutrition*
chemical reaction	*energy transformation*	*particles*	*potential energy*
cell respiration	*activation energy*	*heat*	*light*
energy conservation	*mitochondrion*	*exothermic*	*motion*
	energy content	*temperature*	

To analyse the essays on the concept of energy, we chose Mayring's method of qualitative content analysis (2015). In this context, we decided to define and elaborate two dimensions of analysis: First the dimension of the *vertical linkage level* and second the dimension of *scientific correctness* (Fig. 1).

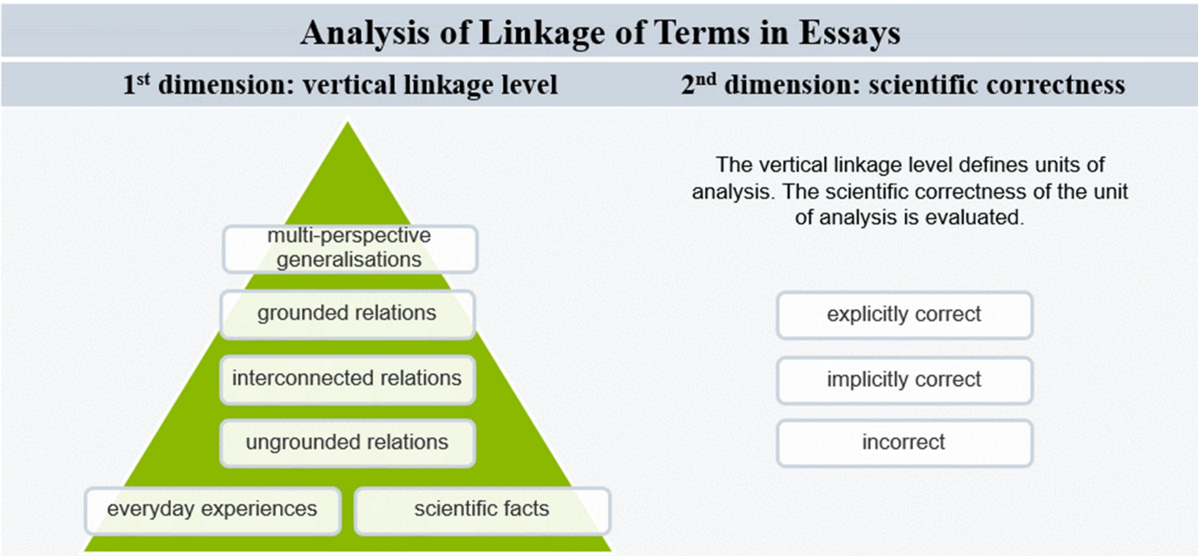

Figure 1. Category system for analysing the linkage of terms within the basic concept of energy.

For the analysis of the first dimension, the *vertical linkage level*, we have developed our own approach. This approach combines the strengths of the vertical linkage model (**MvL**) according to Fischer et al. (2007), the hierarchical complexity model (MHC) of Commons et al. (1998) and its adapted version for chemistry lessons (**MHC-C**) created by Bernholt, Parchmann and Commons (2009; Bernholt & Parchmann, 2011). Furthermore, it also takes into account the problems that Nehring, Päßler and Tiemann (2017) reported (see chapter 2). Consequently, our approach considers six categories distributed across five hierarchically arranged linkage levels (Fig. 1).

At the first vertical linkage level, we consider simple links between two terms using verbs such as "be" and "have". This includes naming objects or concepts, stating classifications, and describing properties. Depending on the (supposed) origin of the students' statements, like the MHC-C, we distinguish between the categories of *everyday experiences* and *scientific facts*. In contrast to the MHC-C, we do not arrange these two categories in a hierarchical order because for us only the simple way of linking is the decisive criterion for our first vertical linkage level.

To reach the second vertical linkage level, students must link at least two terms in a more complex way compared to the first vertical linkage level. By a more complex linkage we understand the formulation of causalities (if-then relationships), conditions, dependencies (e.g., the more - the more), or process descriptions between terms. These types of linking of terms are also considered in the MvL and the MHC-C. The MvL includes causalities, conditions, and dependencies in the category *relation*. The MHC-C distinguishes between the categories of *processes* and *linear causality* and emphasises the importance of justifying a causality. In our approach we combine the categories *relation* of the MvL and *processes* of the MHC-C and name this category *ungrounded relations*. We consider this combination necessary because the students' linguistic abilities should not be the only deciding factor in assessing the level of linkage. For instance, from the students' perspective, it hardly makes a difference whether chemical energy is converted into kinetic energy *during* cycling (which is a process description according to the MHC-C) or whether the transformation of the forms of energy takes place *through* cycling (which is to code as a relation according to the MvL).

At the third vertical linkage level, we take into account students' statements in which statements from the previous second linkage level are linked together. By linking these statements, however, we do not mean enumerations such as those considered sufficient in the original MvL to reach a higher linkage level (categories *several facts* or *2 facts* and *several unconnected relations* or *2 relations* according to the MvL of Fischer et al. (2007) respectively Kauertz et al. (2010)). Here we follow the reasoning of Commons et al. (1998, p. 240), who state that an arbitrary string of lower order actions cannot lead to a higher complexity level. In our opinion, it should make no difference whether, e.g., forms of energy are mentioned in the manner of an enumeration or listed individually at various points in an essay. The link between the terms "*form of energy*" and, for instance, "*chemical energy*" and "*electrical energy*" remains the same in both cases. However, according to Commons et al. (1998, p. 252), an increasing number of linking operations leads to a higher level of complexity. An additional linking operation represents relations that are linked with each other. In this way, for instance, causalities can be linked to form causal chains. Therefore, we name the category of this third vertical linkage level *interconnected relations*.

At the fourth vertical linkage level, we consider students' statements in which relations are justified by further relations. We refer to the corresponding category as *grounded relations*. The MHC-C also emphasises the importance of justifying connections and includes the category *linear causality* for this purpose.

Finally, due to the problems reported by Nehring, Päßler and Tiemann (2017) with the coding of the highest linkage level, we developed our own category definition independently of the MvL and MHC-C for the fifth vertical linkage level. This category, which we call *multi-*

perspective generalisations, includes blocks of statements in which students link subconcepts of the concept of energy and additionally explain this linkage in detail using at least one example. These subconcepts are *energy forms* and *sources*, *energy transformation*, *energy transfer*, *energy degradation*, *energy conservation*, and *entropy* (Duit, 1986; 2014; Neumann et al., 2013; Poggi et al., 2017).

In the second analysis dimension, we also consider the *scientific correctness* of the students' statements (Fig. 1). Since statements cannot always be labelled entirely correct or false, we have defined an additional category besides *explicitly correct* and *incorrect*, in which we include *implicitly correct* statements

As it is common for qualitative methods, we determined interrater reliabilities to ensure the appropriateness of our category definitions (e.g., Mayring, 2015). To determine these interrater reliabilities, we first conducted a coder training with a student assistant. Subsequently, units of analysis, which were determined a priori in the essays, were independently coded from 39 randomly chosen essays from a data set of a different study. Finally, we calculated Cohen's kappa values using the random correction procedure proposed by Brennan and Prediger (1981). For all of our codings we use the MAXQDA software (VERBI software, 2019).

RESULTS

Data collection and sample

At the beginning of the school year 2019/20, we asked a complete 9th grade cohort (average age 13.9 ± 0.4 years) of a secondary school in Berlin to write an essay on the topic of energy. We conducted the surveys during a German lesson (à 45 minutes) to avoid subject-related chains of association. In this way, we received 134 essays, of which only two had to be excluded from the analysis because the students did not work on the task. Using our analysis procedure (see chapter 3) we identified a total of 1,894 units of analysis in 132 essays (average length: 126 ± 75 words). Since 100 student statements were either repetitive or unclear in meaning, we excluded them from further analyses. Thus, we finally examined 1,794 units of analysis with respect to the analysis dimensions of *vertical linkage level* and *scientific correctness*.

Checking the coding procedure

Before we started examining the units of analysis in our study, we evaluated our coding procedure by determining the interrater reliabilities using a dataset from a different study (see Chapter 3). The results of the calculated Cohen's Kappa values of these analyses are presented in Table 2. For the analysis dimension *vertical linkage level*, a Cohen's kappa value of 0.84 and for the analysis dimension *scientific correctness*, a Cohen's kappa value of 0.81 was determined. According to Altman's (1999) interpretation, these are very good values for intercoder reliabilities for both analysis dimensions.

Table 2. Results of the test of interrater reliabilities for the analysis dimensions vertical linkage level and scientific correctness.

analysis dimension	Cohen's kappa κ
vertical linkage level	0.84
scientific correctness	0.81

Vertical linking knowledge and scientific correctness

Following our analysis procedure, we have to assign more than half of the students' statements to the first linkage level – *everyday experiences* or *scientific facts* (Fig. 2). In particular, the students describe the properties of energy and name different forms of energy. The second most common category is *ungrounded relations*. Students frequently formulate causalities, conditions, or process descriptions to the topics of nutrition and electrical energy. We only have to assign slightly more than 10% of all student statements to a high vertical linkage level. We have classified many statements from students in the category *interconnected relations*, in which energy transformation processes are described over several steps. The statements in this category are dominated by causal chains also in connection with the topics of nutrition and electrical energy.

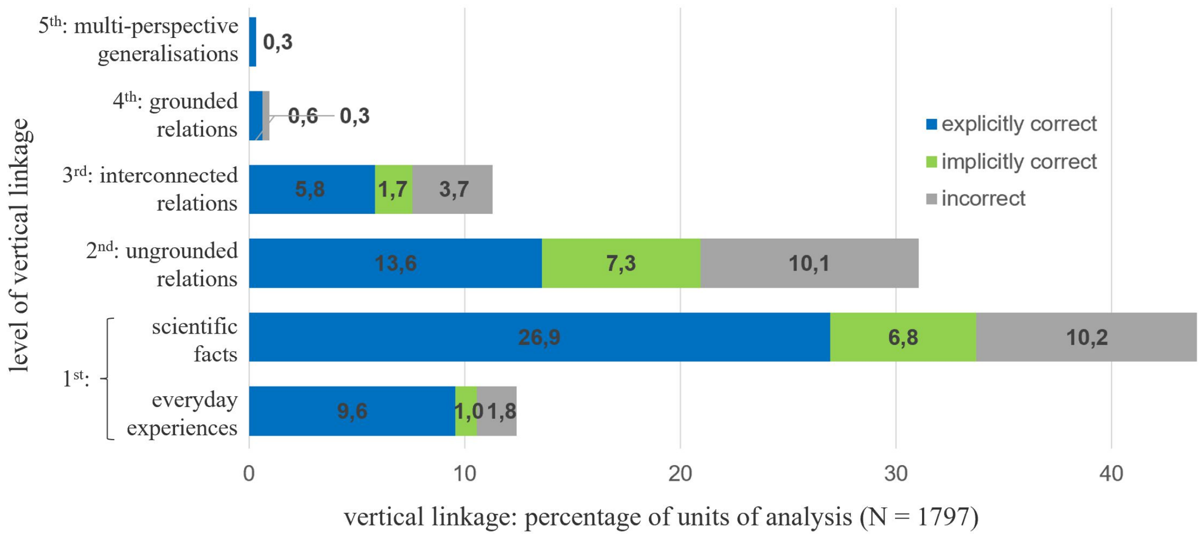

Figure 2. Results from the analysis concerning the analysis dimensions *vertical linkage level* and *scientific correctness.*

Regarding the second analysis dimension – the dimension of *scientific correctness* – we find that within each linkage level, the *explicitly correct* statements are in the majority. However, when all statements are considered, slightly more than a quarter of all statements on the concept of energy are to be rated as scientifically incorrect.

DISCUSSION OUTLOOK

The innovative analysis procedure presented here turned out to be qualified for examining the vertical linkage of terms associated with the concept of energy. The very good interrater reliability values that we found for both analysis dimensions confirm this finding (Tab. 2).

Our analyses show that students mainly formulate statements about the basic concept of energy at a low vertical linkage level (Fig. 2). On a positive note, most of the students' statements are explicitly or at least implicitly correct. In the next step, it will be interesting to examine the extent to which the identified linkage structures exhibit interdisciplinary characteristics. Therefore, we are currently expanding our research and include the analysis of the interdisciplinary (horizontal) linkage dimension into our research. In this way, we want to develop a holistic model for analysing the linkage of terms in essays, which we term as

MAVerBE (the German acronym for *Modell zur Analyse der Vernetzung von Begriffselementen in Essays*, in English: Model of the Analysis of the Linkage of Terms in Essays).

Furthermore, our next main objective will be to use this model MAVerBE to investigate the influence of the integrated science teaching approach at the secondary level (as is common in several European countries, the US, and Australia) on linking knowledge. To achieve this, we were able to convince the Berlin school examined in this study to change their teaching approach in the 7th and 8th grades from the traditional German subject-differentiated science teaching to the more internationally common integrated science teaching approach. At the beginning of the 2020/21 school year, we were already able to collect essays from 141 Year 9 students who received integrated science lessons at this school in grades 7 and 8. We are looking forward to reporting the results of this study soon.

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THE PARALLEL DEVELOPMENT OF UNDERGRADUATE STUDENTS' ARGUMENTATION SKILLS AND CONCEPTUAL UNDERSTANDING ON NEWTONIAN MECHANICS

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This research examines the parallel development of students' argumentation skills and conceptual understanding on Newtonian Mechanics. The sample consisted of seventeen undergraduate students (four groups made up of four to five participants). The research was based on students' group discussions on five Newton's Laws problems alternating with the researcher's interventions. Before and after this procedure, pre- and post-tests consisting of five open-ended questions on Newtonian Mechanics were answered individually. Students should justify their answers through their written arguments. To evaluate the arguments, a modified version of McNeill and Krajcik's model was applied. The quantitative analysis showed a statistically significant improvement in both students' argumentation skills and their conceptual understanding in three out of five problems.

Keywords: Reasoning, Conceptual Understanding, Physics.

INTRODUCTION

Argumentation is considered to be a significant process in science courses, as it helps students comprehend the scientific content, enrich their knowledge, and express their conceptions (Erduran, Simon, & Osborne, 2004; Osborne et al, 2019). Students, however, are rarely involved in the scientific argumentation process (Driver, Newton, & Osborne, 2000). This happens due to the following reasons:

- Students' insufficient prior knowledge regarding argumentation, as well as the content knowledge of the object to be studied (Driver, Newton, & Osborne, 2000; Taasoobshirazi & Hickey, 2005).
- Some teachers' difficulty in accepting that argumentation is an effective way for students to learn the scientific content (Cebrián-Robles, Mariscal, & Lopez, 2018; Sampson & Blanchard, 2012).
- Students' difficulty in improving their argumentative skills. Many teachers tried to apply argumentation techniques and methods to science lessons, mainly through explicit teaching of argumentation, but the expected results have rarely been confirmed (Ibraim & Justi, 2016).
- Students' struggle to judge and evaluate claims, arguments, and counterarguments, as well as to examine the validity of scientific explanations (Sampson & Clark, 2008).
- Students perceive argumentation to be a means of evaluation by their teachers, instead of an activity to construct knowledge jointly (Wang, 2020).

As Sampson and Clark (2009) support, collaboration is an effective motivation for students, as it contributes to the development of their argumentative skills in science courses. Moreover, collaborative discourse and argumentation in the classroom are significant and crucial, as they enhance students' conceptual understanding via the critical evaluation of all the aspects of arguments, especially evidence and explanations (Can & Saribas, 2019).

THEORETICAL FRAMEWORK

Instructional Context

Many studies reveal that argumentation played an important role in improving students' scientific knowledge (Bell & Linn, 2000; Hakyolu & Ogan-Bekiroglu, 2016). However, there are a few studies where argumentation did not contribute to the improvement of scientific knowledge and conceptual change, because, despite the high levels of structural argumentation recorded, arguments were based on alternative conceptions and not on the scientific knowledge (Shemwell & Furtak, 2010).

The instructional context of this research is Newtonian Mechanics. A small number of studies related to students' argumentation on topics concerning Newton's Laws have been conducted; most of them showed that students' involvement in problems, the solution of which demand the understanding of Newton's Laws' content knowledge, can motivate them to develop their arguments (Admoko, Hanifah, Suprapto, Hariyono, & Madlazim, 2021; Eskin & Ogan – Bekiroglou, 2013). In addition, asking students to develop arguments "for the opposite side" of an expressed position on a science topic, for example on Newton's First Law, is quite effective and contributes to better understanding of the relevant content knowledge and facilitates conceptual change (Nussbaum & Sinatra, 2003).

Argument's Evaluation Model

Several models of argument analysis have been developed. The Toulmin's (1958) argumentation analysis model was applied first. According to this model, the structural elements of the argument are the following: claims, data, warrants, qualifiers, backings, rebuttals.

In this work, a modified version of McNeill and Krajcik's (2008) model has been applied because, in comparison with Toulmin's model, it evaluates not only the overall structure but also the conceptual content of written arguments. In specific, the researcher modified the initial version by adding the structural element of the rebuttal, and by modifying the characterization of the level 1 rating of the claim and rebuttal by adding the characterization "partially accurate" (Table 1).

Table 1. McNeill and Krajcik's modified model.

Component	Level		
	0	1	2
Claim–A conclusion that answers the original question.	Does not make a claim, or makes an inaccurate claim.	Makes an accurate but incomplete claim, or a partially accurate claim.	Makes an accurate and complete claim.
Evidence–Scientific data that supports the claim. The data need to be appropriate and sufficient to support the claim.	Does not provide evidence, or only provides inappropriate evidence (Evidence that does not support the claim).	Provides appropriate but insufficient evidence to support the claim. May include some inappropriate evidence.	Provides appropriate and sufficient evidence to support the claim.

Reasoning–A justification that links the claim to the evidence. It shows why the data count as evidence by using appropriate and sufficient scientific principles.	Does not provide reasoning, or only provides reasoning that does not link the evidence to the claim.	Provides reasoning that links the claim to the evidence. Repeats the evidence and/or includes some but not sufficient scientific principles.	Provides reasoning that links the claim to the evidence. Includes appropriate and sufficient scientific principles.
Rebuttal–A statement that attempts to disprove the argument, as it contradicts the claim, the evidence, and the reasoning.	Does not make a rebuttal, or makes an inaccurate rebuttal.	Makes an accurate but incomplete rebuttal, or a partially accurate rebuttal.	Makes an accurate and complete rebuttal.

AIM AND RESEARCH QUESTION

The aim of this research is to explore the reciprocal contribution of argumentation and conceptual knowledge on Newtonian Mechanics through the following question: To what extent could undergraduate students develop their argumentative skills, overcome their alternative conceptions, and achieve a conceptual development through exercising collaborative argumentation on Newtonian Mechanics qualitative problems?

The main reason why Newtonian Mechanics was selected as the instructional context of this research is: As shown by many studies (see table 2), no matter how familiar with Newton's Laws students are, they express different points of view driven by their alternative conceptions, which offer a fertile ground for developing rebuttals and a strong argumentation between the members of a group.

RESEARCH METHOD AND DESIGN

Sample

The sample of this research consisted of seventeen undergraduate students (four groups made up of four to five persons) of the Department of Primary Education of the National and Kapodistrian University of Athens.

Research design

Intervention steps (3sections-phases, 11 steps): The present research is focused on an intervention that aims to check whether students' argumentation improves along with their conceptual content. The intervention consisted of three sections. The first section was introductory focusing on the presentation and analysis of the main structural elements of an argument by the researcher. In the second section, the students, in groups of four or five, had to discuss their ideas on each of the five Newtonian Mechanics problems selected (see table 2), while being videotaped.

Table 2. Newtonian Mechanics topics and respective alternative conceptions.

Topics	Alternative Conceptions
Factors which affect the kinetic friction– empirical law: «*The magnitude of the kinetic friction depends on the roughness of the surfaces and bears a constant ratio to the normal force between the two surfaces*».	The magnitude of kinetic friction depends on the surface area of the objects in contact (Besson, Borghi, De Ambrosis, & Mascheretti, 2010).
Newton's 1st Law: *Balance of a stationary object*.	On stationary objects no forces are exerted, or only the gravity is exerted. On objects which move at a constant velocity, a constant force must be exerted on them (Hestenes, Wells, & Swackhamer, 1992).
Newton's 2nd Law: *Free Fall.*	Heavier objects fall to the ground faster than lighter ones (Hestenes, Wells, & Swackhamer, 1992).
Newton's 2nd Law: *Vertical Shot Upwards.*	The force exerted on an object is integrated into it and is gradually reduced (Hestenes, Wells, & Swackhamer, 1992).
Newton's 3rd Law: *Comparison of forces between two objects with different masses*.	The force exerted by the heavier object on the lighter is greater than that exerted by the lighter on the heavier (Hestene, Wells, & Swackhamer, 1992).

In the third section, the researcher, having studied the recorded collaborative argumentation, comments on the quality of the arguments (the way they had been structured), as well as the students' scientific content knowledge and the way it could be improved. In total, the intervention consisted of 11 steps (table 3).

Table 3. Intervention Steps.

Steps	Description
1st	Presentation and analysis of the main structural elements of an argument by the researcher.
2nd	Students' discussion – collaborative argumentation on the 1st problem: Factors which affect kinetic friction.
3rd	Comments on the quality of students' arguments by the researcher.
4th	Students' discussion – collaborative argumentation on the 2nd problem: Balance of a stationary object: Newton's 1st Law.
5th	Comments on the quality of students' arguments by the researcher.
6th	Students' discussion – collaborative argumentation on the 3rd problem: Free Fall: Newton's 2nd Law.
7th	Comments on the quality of students' arguments by the researcher.
8th	Students' discussion – collaborative argumentation on the 4th problem: Vertical Shot Upwards: Newton's 2nd Law.
9th	Comments on the quality of students' arguments by the researcher.
10th	Students' discussion – collaborative argumentation on the 5th problem: Comparison of forces between Earth and Moon: Newton's 3rd Law.
11th	Comments on the quality of students' arguments by the researcher.

Research instrument: Two questionnaires consisting of five open-ended questions on Newtonian Mechanics problems were answered individually by the students. The first one was delivered before the intervention (pre-test) and the second one three weeks after the intervention (post-test). The post-test was different from the pre-test but referred to corresponding and equivalent problems. In all these tests, the students had to answer to the respective problems not only by offering their solutions but also by justifying them through their written arguments. Finally, it should be noted that the intervention was conducted through Skype due to the lockdown that was imposed because of the Covid-19 pandemic.

Research analysis

Students' pre- and post-tests were analyzed and evaluated, in terms of the adequacy of the argument's structural elements as well as their conceptual content, according to a modified version of McNeill & Krajcik's model (see table 1).

RESEARCH FINDINGS AND DISCUSSION

Two exterior independent raters evaluated the pre- and post-tests. The interrater reliability was measured through the Cohen's kappa (k) test: claim: **0.828**, data: **0.768**, reasoning: **0.737** and rebuttal: **0.747**. The statistical difference between pre- and post- results was measured through the Wilcoxon non-parametric test (table 4).

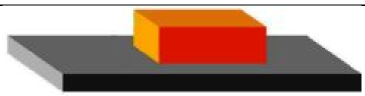
Table 4. Wilcoxon non-parametric test results.

Problems and respective structural elements	Asymp. Sig. (2-tailed)(p)	Mean (Pre-Test)	Mean(Post-Test)
Problem 1 – Claim	**0.003**	**0.71**	**1.76**
Problem 1 – Data	**0.001**	**0.53**	**1.71**
Problem 1 – Reasoning	**0.001**	**0.47**	**1.41**
Problem 1 – Rebuttal	**0.000**	**0.29**	**1.41**
Problem 2– Claim	**0.132**	**1.53**	**1.24**
Problem 2 – Data	0.564	1.18	1.29
Problem 2 – Reasoning	0.655	1.12	1.18
Problem 2 – Rebuttal	0.454	0.76	0.94
Problem 3 – Claim	0.059	1.59	2.00
Problem 3 – Data	**0.014**	**0.76**	**1.29**
Problem 3 – Reasoning	**0.026**	**0.88**	**1.47**
Problem 3 – Rebuttal	**0.035**	**0.53**	**0.94**
Problem 4 – Claim	**0.001**	**1.06**	**1.82**
Problem 4 – Data	**0.000**	**0.53**	**1.82**
Problem 4 – Reasoning	**0.003**	**0.29**	**1.24**
Problem 4 – Rebuttal	**0.002**	**0.24**	**1.29**
Problem 5 – Claim	0.317	1.94	1.82
Problem 5 – Data	0.130	1.24	1.59
Problem 5 – Reasoning	0.112	1.24	1.65
Problem 5 – Rebuttal	0.627	1.12	1.24

Three out of five topics (problems **1**, **3**, **4**) reveal statistically significant differences in students' arguments (**p<0.05**). In the majority of the problems, students achieved an improvement in both the structure of their arguments and their conceptual level. The fact that there was no such difference in problems 2 and 5 comparing with the other three problems was probably due to the strong alternative conceptions that emerged through the students' post-test answers.

In tables 5 and 6, we present two examples of students' answers to the pre- and post-tests on problems 1 and 2. In the first case there is an improvement in the argument from the pre- to post-test, while in the second case there is an alternative conception in the student's post-test answer.

Table 5. Problem 1 (Pre- and Post- test).

Problem 1: Pre-Test	**Problem 1: Post-Test**
 **Figure 1**  **Figure 2** We want to push a heavy, rectangular parallelepiped box which is leaning on the floor, in order to place it on the edge of the floor. As we do not know how to push it, so as to end up having the least resistance possible, we asked Giorgos and Nikos to help. Giorgos suggests that we push it with the side with the largest surface area touching the floor (figure 1), while Nikos disagrees and suggests that we push it with the side that has a smaller surface area than the first case (figure 2). The floor is not smooth and is the same in both cases. a) Do you agree with either of them and, if so, with whom and why? If not, write your own opinion. In any case, justify your answer with the appropriate argument(s). b) In case you agree with Giorgos while another student agrees with Nikos, what would your argument(s) be to disprove his / her point of view? The same goes the opposite way. c) If you disagree with both Giorgos and Nikos by supporting a different point of view, what would your argument(s) be to disprove each one of their opinions?	 A **Figure 3**  B **Figure 4** Antonis drags on the same non-smooth floor, with the same force, two tables of the same material; A and B. Table A has four legs and table B has six. Although table B has two more legs, its mass is distributed in such a way that it is equal to the mass of table A (they both have the same weight: in table A it is distributed into 4 legs, while in table B into 6 legs). Two students, Anna and Vassilis, discuss with each other which table ends up having the least resistance while sliding on the floor. Anna claims that Antonis drags table A (the one with 4 legs) more easily on the floor, while Vassilis claims that Antonis drags table B (the one with 6 legs) more easily on the floor. a) Do you agree with either of them and if so with whom and why? If not, write your own opinion. In any case, justify your answer with the appropriate argument(s). b) In case you agree with Anna while another student agrees with Vassilis, what would your argument(s) be to disprove his / her point of view? The same goes the opposite way. c) If you disagree with both Anna and Vassilis by supporting a different point of view, what would your argument(s) be to disprove each one of their opinions?
Student's No. 4 answer to pre-test's problem 1	**Student's No. 4 answer to post-test's problem 1**
I agree with Nikos; I believe that in order to end up having the least resistance possible, we must push the box with the side that has the smaller surface area. Since the surface area is small, the resistance will be small. Having a larger area will result to larger resistance, making it more difficult for the box to move.	*I do not agree with either of them. Since both tables have the same mass, Antonis does not drag either of the two more easily. The friction that is developed between table A and the non-smooth floor, as well as the one developed between table B and the same non-smooth floor, are equal. Friction is affected by the force exerted by one surface on another, so the greater the mass of a body, the greater the friction developed. Since the two tables have the same mass and Antonis drags them with the same force on the same non-smooth floor, he will drag them both just as easily. According to Newton's Third Law, when a body (Antonis) exerts a force on another (table), the*

	latter will exert an equal and opposite force on the former.

Table 6. Problem 2 (Pre- and Post- test).

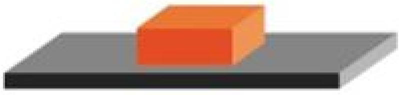
<table>
<tr><th>Problem 2: Pre-Test</th><th>Problem 2: Post-Test</th></tr>
<tr><td>
Figure 5
A box is lying on the floor. Is/Are force(s) exerted on the box? Yes or No?
a) For those who choose yes:
i. Draw it / them, compare their magnitudes (if there are more than one), and justify your point of view with the appropriate argument(s) (e.g. by which object each force is exerted, for what reason / based on which law each force has the specific magnitude, etc.).
ii. If someone chose no, what would your argument(s) be to disprove his / her point of view?
b) For those who choose no:
i. Justify your point of view with the appropriate argument(s).
ii. If someone chose yes, what would your argument(s) be to disprove his / her point of view?</td><td>

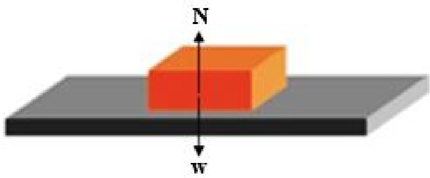
Figure 6
A child is constantly pushing a box on a non-smooth surface so that it moves at a constant velocity (figure 1).
Are forces exerted on the box? Yes or No?
a) For those who choose yes:
i. Draw it / them, compare their magnitudes (if there are more than one), and justify your point of view with the appropriate argument(s) (e.g. by which object each force is exerted, for what reason / based on which law each force has the specific magnitude, etc.).
ii. If someone chose no, what would your argument(s) be to disprove his / her point of view?
b) For those who choose no:
i. Justify your point of view with the appropriate argument(s).
ii. If someone chose yes, what would your argument(s) be to disprove his / her point of view?</td></tr>
<tr><th>Student's No. 3 answer to pre-test's problem 2</th><th>Student's No. 3 answer to post-test's problem 2</th></tr>
<tr><td>

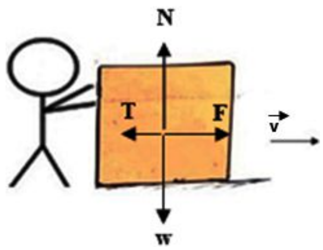
Figure 7
It is the weight exerted by the earth on every object placed on its surface, according to the law of gravity. N is the force exerted by the box on the surface on which it is placed.</td><td>

Figure 8
Forces are exerted on the box that the child pushes on a non-smooth surface. Initially, the weight is exerted downwards, with weight being a force exerted by the earth on all objects on its surface, according to the law of gravity. Also, since the box is in contact with the surface, according to Newton's Third Law of action and reaction, when two objects are in contact and one exerts a force on the other, the second will exert an equal force in the opposite direction of the first. Thus, the normal force N, which is equal to the weight and has opposite direction (upwards), is exerted by the surface on the box. Since the child constantly pushes the box, he / she exerts a force F to the right. It is also exerted by the force of friction to the left, in the opposite direction from the force F.</td></tr>
</table>

	It is the force that exists between two objects that slide or are about to slide. This movement is due to the roughness of the two surfaces that are in contact. ***The force F is greater than the friction*** *and, for this reason, the object is moving.*

In problem 2 of the pre-test, the object is stationary. In problem 2 of the post-test, the object moves. The fact that there is no conceptual development in students' responses to the post-test of the problem may be due to the fact that in the case of the object's movement, the alternative conceptions that students have are more resilient to change and require more time and effort to overcome.

CONCLUSIONS

According to the results, students' continuous engagement in the argumentation process and, more specifically, in collaborative argumentation, contributes to the development of their argumentative skills, as well as to the improvement of their conceptual level on most of Newton's Laws' problems. As Shemwell & Furtak (2010) point out, even after constant practice with argumentation, most students find it particularly difficult to fully overcome their alternative conceptions on some Newtonian Mechanics problems. For this reason, more interventions may be needed towards the improvement of the conceptual content of students' arguments. However, the present research reveals that expressing different views on these problems help students develop rebuttals and, thus, improve the quality of their arguments.

A limitation of this research was the fact that it was conducted via Skype due to Covid-19 pandemic. Therefore, it is recommended that the present research is conducted in person meetings and expanded to a larger and more representative sample.

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HEURISTIC REASONING EMPLOYED BY STUDENTS WHEN SOLVING SOLUTION CHEMISTRY PROBLEMS

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Based on the heuristic-analytic theory of reasoning, this study aims to characterize and better understand the heuristics, as well as identify the analytic processing of epistemic mental models that students relied upon to make their decisions when solving problems on solution formation and solubility. To achieve this, a qualitative methodology was implemented. Forty-seven 11th-grade students from two different public-school units in Attica voluntarily participated in the study. Data sources included written responses on a worksheet and semi-structured individual interviews. Data analysis was based on theoretical frameworks: dual processes in reasoning and judgment (Evans, 2006) and heuristics (Talanquer, 2014). Results indicated that explicit and implicit features of each task triggered the frequent use of the following heuristics: one-reason decision making, rigidity, fluency, and recognition. Most of the interviewees made use of their prior knowledge to generate mental models that were then employed to make decisions. Despite leading students astray on occasions, the processing of mental models allowed most interviewees to shift towards more effective cue selection strategies and/or make correct predictions. Our findings suggest that a more attentive analysis of heuristic reasoning is of central importance for chemistry education.

Keywords: Decision Making, Problem Solving, Reasoning.

INTRODUCTION

Theoretical Framework

Dual-process theories of cognition have become increasingly popular among researchers in the psychology of thinking and reasoning and are currently being applied in the field of judgment and decision making (Evans, 2006). The heuristic-analytic theory of reasoning was first proposed by Evans (1984, 1989) as a two-stage sequential model consisting of two cognitive processes: heuristic processes, which involve selective representations of problem content, and analytic processes, which derived judgments or conclusions from these representations. Evans et al. (2003) offered a revised extension of the original heuristic-analytic theory that incorporates three principles of hypothetical thinking. The singularity principle derives from the consideration that mental models are constructed one at a time, due to limited analytic processing capacity. The relevance principle refers to the pervasive influence of prior knowledge and belief in the construction of this model. Finally, in the analytic system, the most plausible or relevant model is evaluated with reference to the current goals (satisficing principle) and is accepted if satisfactory. In cases where default representations are translated into responses concerning the instructions given, judgment is determined predominantly by heuristic processes. In other cases, inferences are a product of analytic thinking being actively involved in the inhibition of responses cued by the heuristic system.

The heuristic-analytic theory of reasoning is considered as a robust tool that can be used to account for cognitive biases in reasoning tasks, as well as interpret, in a mechanistic fashion, inconsistencies in the responses given by students who develop a "first-impression" mental model. (Kryjevskaia et al. 2014, Todd & Gigerenzer 2000) Studies in chemistry education provide evidence that many of the judgment errors that students make are the result of cognitive processes that are inherently human (Maeyer & Talanquer 2010, 2013, McClary & Talanquer 2011, Taber 2009). According to Talanquer (2014), research in judgment and decision making in personal or social contexts provides insight into how students reason under conditions of limited time and knowledge, like those faced in chemistry courses. Besides, pervasive shortcut reasoning strategies that reduce the information processing load (heuristics), play a central role in the classroom with major implications for chemistry education. To facilitate reflection on teaching and learning issues, Talanquer (2014) analyzes ten heuristics that work in tandem or conjunction when chemistry students engage in judgment and decision making (Table 1).

Table 1. Ten heuristics described by Talanquer (2014).

Fundamental Associative Processes
1. Associative Activation uses linked constructs in the mind to fill in information, quickly and automatically, in situations that resemble past observations or experiences, arising cognitive biases when some aspects of the information are systematically overweighted while others are underweighed or neglected.
2. Processing Fluency refers to the subjective experience of the ease or difficulty with which a cognitive task is accomplished.
3. Attribute Substitution can be described as the judgment of a target attribute that automatically triggers the evaluation of associated attributes in the mind.
Inductive Judgments
4. One-Reason Decision Making refers to people's tendency to reduce the number of factors analyzed when making judgments and decisions, simplifying reasoning by using one single cue or factor to provide a plausible answer.
5. Surface Similarity relates to people's assumptions that objects or events that resemble each other on first appearances are members of the same category, and thus they share similar properties, behaviors, and inner structures.
6. Recognition uses the identification of an entity as a decision cue, particularly when there is a strong association between the recognized object (e.g., alcohol) and the judged property (e.g. selecting the substance soluble in water).
7. Generalization refers to humans' tendency to overgeneralize learned patterns and rules, using their knowledge on few cases to make hasty conclusions without considering all the variables that may be involved.
8. Rigidity is a cognitive process that is mainly expressed by two cognitive tendencies: (a) people's tendency to adopt strategies or solutions during problem solving that have worked for them in the past without taking the current conditions into consideration; and (b) the cognitive bias, which guides individuals to use objects only in the way and contexts in which they have traditionally used them, failing to make use of such tools in flexible and creative ways in new situations.
Affective Judgments
9. Overconfidence refers to people's confidence in their judgments and decisions, or in their understanding of a subject that systematically exceeds their actual accuracy.
10. Affect is related to the use of readily available affective impressions to make decisions, as people's judgments and decisions are influenced by what they perceive, or their feelings evoked.

The first category of fundamental associative processes includes three relevant heuristics that often work in tandem supporting all other types of heuristic reasoning. For this reason, it is difficult to present concrete examples of one of these three processes without including the other two. The four heuristics involved in inductive judgments are closely related to each other supporting inductive reasoning. Similarly, the last two heuristics (overconfidence and affect) are related to each other, involving affective judgments. (Morewedge & Kahneman 2010, Talanquer 2014)

Importance and Aim

Although heuristic strategies are highly productive for experts in order to make quick and efficient decisions, as they have learned to use them properly in their field of expertise, the application of heuristics for novice learners can result in reasoning biases that may be difficult to avoid (Talanquer 2014). Therefore, becoming aware of these issues can help instructors better support student learning and avoid creating conditions that reinforce or inadvertently reward Type I reasoning. Based on Talanquer's categorization (2014), we attempted to recognize and characterize the intuitive heuristics used by high school students, when solving problems on solution formation, and solubility. Also, applying the heuristic-analytic theory of reasoning, we aim at interpreting inconsistencies in student reasoning approaches to chemistry problems. "The emerging body of evidence that suggests that student conceptual and reasoning competence demonstrated on one task often fails to be exhibited on another" (Evans, 2006), served as the motivation for this study. If the development of critical skills is a critical outcome of chemistry instruction (Talanquer, 2014), the direction of our efforts toward a careful examination of student reasoning approaches is imperative. An important step in research on student reasoning is the development of methodologies that identify the factors that appear to prevent correct reasoning approaches and conceptual understanding. Based on the aforementioned rationale, the specific research question that has guided this study is: *What heuristic reasoning do high school students use to solve problems on solution formation and solubility?*

METHOD

Research Method and Design

To answer the research question, a qualitative method research study was conducted based on data collected using both a worksheet of five problems and individual semi-structured interviews. This research design was expected to help us increase the validity of the results, as well as the meaningfulness of the findings (Calik et al., 2005). Participants included only 11th-grade students. From a total of forty-seven students from two different public-school units (both general and experimental) in Attica, six students volunteered to participate in the interviews conducted. To investigate the reasoning strategies used, students were asked to think aloud retrospectively, shortly after completing the worksheet, so that their thinking would not be disturbed, while engaged in the tasks. Based on our knowledge of common shortcut reasoning strategies (Talanquer, 2014), our goal was for the problems to include cues that might trigger the application of heuristic reasoning (familiar substances, both implicit and explicit differences, and similarities).

RESULTS

Our analysis of the worksheet and interview data indicated that many study participants relied frequently on one or more of the following heuristics to make their decisions: *one-reason decision making (ORDM), rigidity, fluency*, and *recognition*. As revealed in the semi-structured interviews given, the majority of students applied different combinations of heuristics to form their representations, which were rarely properly evaluated by analytical thinking, nonetheless. In general, each student used one to two heuristics to solve each problem with the largest percentage attributed to ORDM, rigidity, and fluency depending on the question. To facilitate the presentation, interpretation, and discussion of our results, students' answers to one of the five tasks in the research instrument (solution formation inquiry with visual access to information on the molecular formula; Task 1 in Figure 1) will be used as a primary reference to introduce our major claims.

Which of the following mixtures are solutions?

A. Gasoline (C_6H_{14}) and water (H_2O)
B. Gasoline (C_6H_{14}) and alcohol (C_2H_5OH)
C. Water (H_2O) and alcohol (C_2H_5OH)

Give the reasoning for your answer.

Figure 1. Task 1: Solution formation.

Analysis of the first task

The analysis of students' answers to task 1 as summarized in Table 2, indicates that the heuristic most used in our sample was ORDM. When applying ORDM, students reduce the amount of information kept in the working memory, following simple search termination rules, and finally use one single differentiating cue to make their decision (Todd & Gigerenzer, 2000).

However, as reflected in the following interview excerpts, the majority of students relied on different cues that enabled them to choose between options: "A solution is a mixture containing water" (S12, choice A, C), "A solution is a mixture of a substance with water, not a mixture of two substances" (S24, choice A, C), "Gasoline has color and water does not. When mixed, gasoline and water form a solution" (S39, choice A), "$H_2O + C_6H_{14} \rightarrow C_6H_{13}OH_{(l)} + H_2\uparrow$, so it can't be option A. $C_6H_{14} + C_2H_5OH \rightarrow C_6H_{13}OH_{(l)} + 3H_2\uparrow$, so it can't be option B. $H_2O + C_2H_5OH \rightarrow$ do not react", (S10, choice C). Although less frequently, students' recognition or familiarity with the substances or the substances' known properties was commonly mentioned as a justification for their choices. For example, as part of his reasoning strategy, student S3 first applied the recognition heuristic: "I knew in general that water and alcohol dissolve… For example, alcoholic beverages contain both water and alcohol". In an attempt to confirm the heuristic answer, he made use of superficial similarity, following an arbitrary rule nonetheless: "I thought… I looked at the molecular formulas and tried to find a correlation between what I knew and what was given to me… so I found that both contained oxygen atoms, while the second did not… So, I thought that for them to dissolve, two molecules cannot both have carbon atoms… so one of them had to be water… Then I thought the other should also have oxygen atoms, so that they can dissolve… "join" one another…". In the end, he seemed overly confident in constructing an argument, in support of the answer given (final choice C): "I basically knew the answer, I just wanted to find a way to justify it".

Table 2. Main heuristics applied by students in Task 1.

Choice	Sum	Heuristics	Frequency
A. Gasoline and water	19	**One-reason decision making**	**5**
		Surface similarity	2
B. Gasoline and alcohol	15	**Reduction**	**4**
		One-reason decision making	1
C. Water and alcohol	28	**Recognition**	**4**
		One-reason decision making	4
		Surface similarity	3
None of above	1	**Associative Activation**	**1**

DISCUSSION & CONCLUSIONS

Results from the total tasks analysis indicated that explicit and implicit features of each task triggered the frequent use of the heuristics: ORDM, rigidity, fluency, and recognition. Particularly for the ORDM in chemistry, where many judgments about the properties and changes of matter depend on the simultaneous consideration of several variables, the students' tendency to simplify reasoning by focusing on one single variable and neglecting others is a pervasive problem. (Talanquer 2014) Novice chemistry students are known to use the rigidity heuristic during the problem solving, applying learned algorithms in rather inflexible ways instead of focusing on more productive strategies. (Salta & Tzougraki 2011, Talanquer 2014) Students processed more fluently the choices that include cues that are easier to notice and process in each task, particularly if such features can be somehow associated with targeted variables in the task (Oppenheimer 2008). The recognition heuristic uses a recognized entity as a decision cue, particularly when there is a strong association between the recognized object (e.g., alcohol) and the judged quality (e.g., selecting the substance soluble in water). Results from this study suggest that students frequently use recognized substances as anchors in making decisions. Human reasoning is complex, resulting in the integration of multiple cognitive processes, as various of them often work in tandem or conjunction when people engage in judgment and decision making. (Morewedge & Kahneman 2010) Thus, many students used more than one heuristics as part of their reasoning and decision making while responding to the tasks. Most of the interviewees made use of their prior knowledge to generate mental models that were then employed to make decisions. Despite leading students astray on occasions, the processing of mental models allowed most interviewees to shift towards more effective cue selection strategies and/or make correct predictions.

Heuristic reasoning, as being fast and frugal, cannot be avoided. Moreover, it is considered to play an important role in human reasoning and is rather useful when used appropriately. Nevertheless, problems arise when individuals fail to recognize their inadequacy in particular contexts, accepting the first quick answers derived from heuristic reasoning automatically. Therefore, recognizing, and understanding the different heuristics used by students is essential to help them control and change their default reasoning approaches, resulting in their being led to more efficient use of this type of cognitive resources (Talanquer, 2014). Given that people seem to think heuristically by default (Evans, 2006), one possible path to educational intervention seems to be the explicit training in metacognitive intercession, monitor, and control. Research has shown that the cultivation of metacognitive skills serves as a regulatory factor in the conflict between intuitive and analytical responses (Alter et al., 2007).

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TEACHER TALK: AN ANALYSIS OF DISCOURSE IN BASIC GENETICS

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Genetics is considered one of the most difficult topics in high school biology and teacher's use of language is considered one of the key factors contributing to this challenge. This study investigated the teachers' talk that foregrounded meanings of basic genetics terminology when teaching basic genetics concepts. This was done by analysing classroom Discourse (language and context of its use) during the teaching of genetics to grade 12 learners. Four grade 12 life sciences teachers from three public schools in a South African city were observed and video-recorded while teaching genetics concepts. A follow-up interview with each teacher was conducted to obtain clarity on Discourse-related issues arising from the classroom observations. The classroom observation videos and interview transcripts were analysed using a framework developed from Gee's Theory of Discourse/discourse. The analysis shows some common features of use of language and context of use across teachers, especially with regard to the teaching of basic genetics terminology. Teachers employed the following strategies to foreground meanings of basic genetics terms; labelling, explaining, differentiating, selecting, constructing, deconstructing, mnemonics, rationalizing and pronunciation. This analysis provides important pointers to future professional development support for teachers of genetics.

Keywords: Teacher talk, Discourse and Genetics

INTRODUCTION

South Africa has consistently ranked last or close to the bottom when it comes to worldwide studies on the quality of mathematics and science education (World Economic Forum, 2017). This performance portrays a negative picture about the quality of learners produced by South African teachers in these subjects. The South African Department of Basic Education (DBE, 2018) attests to this as it argues that the quality of passes in life sciences in the grade 12 final examination is low. Though there are many teacher-related factors influencing the low performance (e.g., Kriek & Grayson, 2009), a prominent factor is that the language used by teachers is usually not the learners' home language (Ferreira, 2011). In addition, it is not the teacher's home language. Various researchers have highlighted the importance of language in science education (e.g., Mortimer & Scott, 2003). Specifically in their study on basic gentics concepts, Buma and Nyamupangedengu (2020) reported that language proficiency challenges associated with the learning of pertinent genetics terminologies could be addressed when teacher talk is characterised by learner participation stimulating talk-related instructional strategies. They further revealed that such strategies employed by the teacher could include; open-ended questions, explanations and representations that indicate teacher talk attracting sense-making learner contributions in the classroom discourse.

As a result, teachers have been identified as key players in helping learners to master the language of science characterised by unique terms and a certain style of talking (Thörne, Gericke & Hagberg, 2013). This study focused on teachers' Discourse when teaching genetics concepts by analysing teacher talk. In addition to being component of the grade 12 Life Science assessment, genetics is considered to be one of the most difficult topics as evidenced by poor performance in the grade 12 examination (DBE, 2018). The importance of genetics in society coupled with the abovementioned learners' poor performance in genetics thus motivated us to focus on this topic. This study took place in South Africa, a multilingual country with twelve official languages where English is considered to be the language of commerce and science (Lehohla, 2016) and is primarily the language of learning and teaching. The analytical tool adopted for this study is informed by Gee's Theory of Discourse/discourse and its foundation is demonstrated by the difference between Discourse and discourse as indicated using the lower-case 'd' and upper-case 'D'. Discourse with a capital 'D' is "…a socially accepted association among ways of using language, other symbolic expressions, and artefacts, of thinking, feeling, believing, valuing and acting that can be used to identify oneself as a member of a socially meaningful group or social network" (Gee, 1996: 131). Discourse analysis goes beyond analysis of use of language as it considers other factors such as context. The following research question guided this study: How does teachers' talk foreground meanings of basic genetics terminology during genetics teaching?

METHOD

Design

This study adopted a qualitative case study research approach, using naturalistic methods which allowed close observation of teachers and provided detailed accounts of their practice.

Participants

This study's sample consisted of four teachers teaching grade 12 during the time of study, who were selected purposively from three public secondary schools in a South African city. All four teachers (Mrs Dee, Mr Zindi, Mrs Letsiba and Mr Xulu (pseudonym) are English Second Language speakers and had at least two years of teaching experience.

Data collection

Teachers were observed three times each while being video-recorded as they taught basic genetics to grade twelve learners.

Data analysis

All videos were transcribed verbatim, cleaned and captured electronically. To answer the research question that guided this study, analysis was conducted using the analytical framework presented in Figure 1 below. This framework was primarily informed by Gee's Theory of Discourse (Gee, 1996) which emphasises that language cannot be separated from its context of use. Therefore, Gee's Big 'D' tool was used for analysis in this study. In this study Big 'D' refers to language together with context as shown in the analytical framework. However, to analyse the language part of Discourse, the ALDIS Framework proposed by Seah and Silver (2018) was integrated into the analytical framework as shown in Figure 1. The ALDIS

Framework was integrated into the analytical framework because Gee's theory fell short in terms of analysing the science language. Moreover, Gee's studies did not focus on science.

Therefore, relevant utterances foregrounding meanings of basic genetics terminology were identified thematically. In fact, analysis was conducted in three phases using ATLAS.ti software. The first phase invloved use of the ALDIS Framework component of the analytical framework to capture the functional strategies engaged by teachers to foreground meanings of the genetics. In fact, nine categories adopted from Seah and Silver (2018) were used as codes but allowing new codes to emerge from the data. The second phase involved the identification of contexts in which teachers foregrounded meanings of genetic terms using context categories presented in the analytical framework as codes.

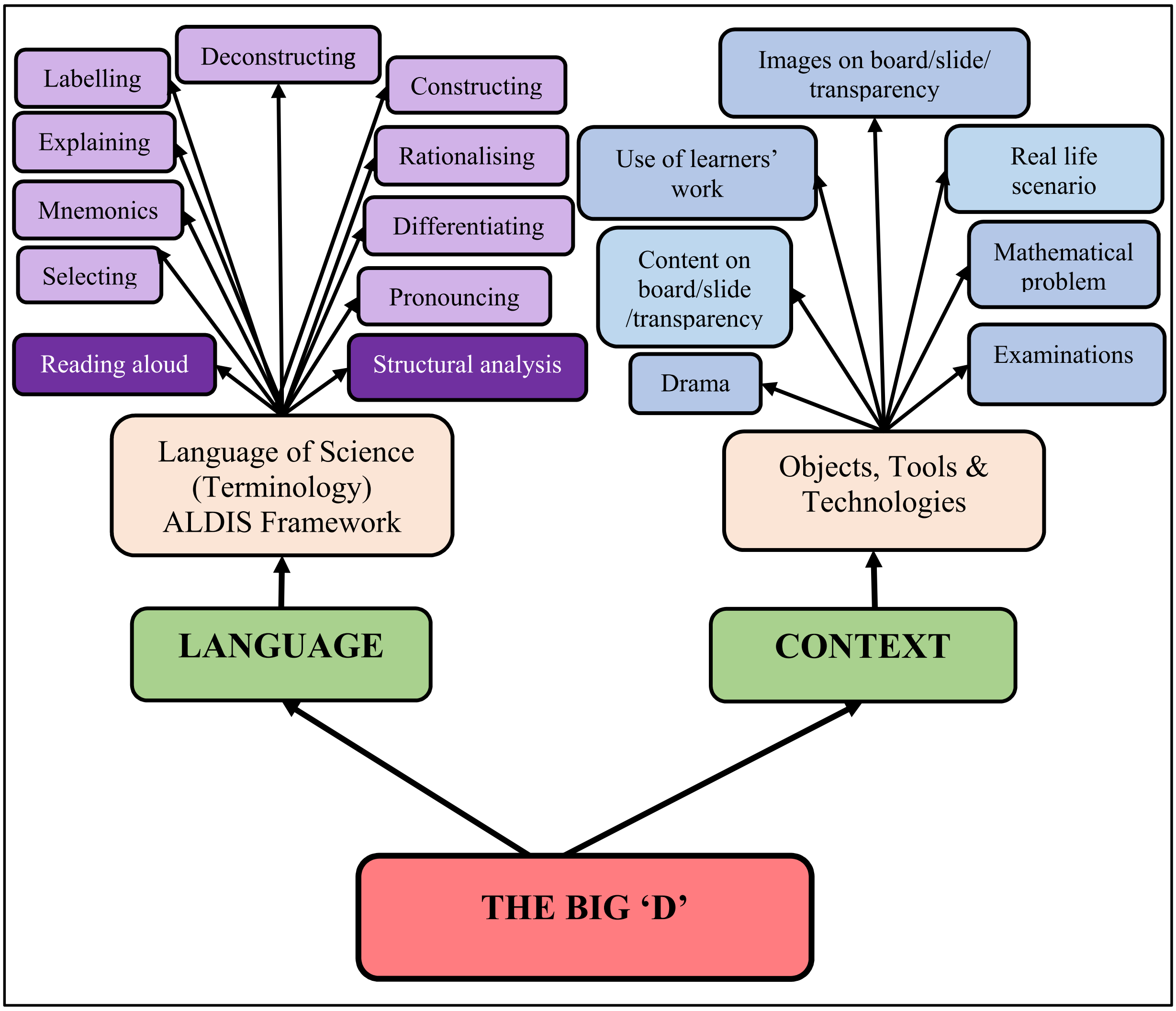

Figure 1. Analytical framework used for this study, Adapted from Gee (1996) and Seah and Silver (2018).

RESULTS

Several means of providing learners with support for understanding genetics terminology were uncovered during our analysis. Examples of coding categories used for analysis in this study and findings are presented in Table 1 below. Findings from this study are consistent with Seah and Silver (2018) who uncovered nine functional strategies (labelling, explaining, diferentiating, selecting, constucting, deconstructing, mnemonics, ratioanisating and pronouncing). Nonetheless, this study uncovered two more strategies viz., reading aloud and stuctural analysis. These are presented in a darker shade of purple on the analytical framework in Figure 1. The most dominant functional strategies engaged by the participant teachers to assist learners through the meanings of genetic terms are labelling and explaining. This study revealed that language cannot be seperated from the context of its use (shown in Table 1) as highlighted by Gee (1996). In this study, participant teachers foregounded meanings of words in different contexts viz., use of drama, content or images on the board/slide/transparency, learners work, real life scenarios, mathematical problem and examinations. Though all teachers focused on meanings of words, particularly in the context of examinations, each one was unique in the way that they foregrounded meanings of genetics terms in their specific contexts. Mrs Letsiba's is the only participant that engaged the reading aloud functional strategy to assist learners through meanings of genetics terms. In addition, her practice was associated with a focus on meanings of genetics terms in the context of drama. Mrs Dee's parctice was unique in the sense that she is the only participant that engaged structural analysis and mnemonics to assist learners with meanings of genetics terms. Mr Zindi was the only teacher that explained meanings of terms in the context of using a mathematical problem and learners' work while Mr Xulu is the only teacher that enganged the pronounciation strategy to foreground meanings of genetic terms.

Table 1. Examples of coding categories and findings as derived from Gee (1996) and the ALDIS Framework (Seah & Silver, 2018).

Functional Strategy for science language	Description	Example	Context of use
Labelling	Introducing or emphasising a linguisticitem as representing a particular object, concept, or process	Mr Zindi: We call them homologous chromosomes and [reading from his paper] what is the special word that we use to the cells-- for the cells-- for the cells that we find in the body…ehm…that is the body cells, what are they called? [Moving along the isle and points to a learner] Hanley…	Contextualization cues-movement-refer to interview
Explaining	Ascribing particular meaning to a linguistic item	Mrs Letsiba: …so, the aneuploidy…Molatello read that for us quickly…the aneuploidy L8: [Reading from the textbook] In aneuploidy one gamete receives two copies of the same chromosome while the other gamete receives no copy. Mrs Letsiba: I want you to underline that, one ehh…gamete will receive ehh…two ehh…copies of the same ehh…chromosome…	Using textbook and a learner reads Learners asked to underline key words in the textbook.
Differentiating	Distinguishing two or more linguistic items in terms of their meaning or form	Mrs Dee : …Okay, (now writing on the white board '*mitosis vs meiosis'*) first of all… am actually going to DO... something like this…because in grade 10, we sort of introduced very briefly, meiosis…	Connects this to grade 10. Context-content written on the board.
Selecting	Adopting particular linguistic item (among others)	Mrs Letsiba: ...So that ehh… it becomes so simple, that even in your exam paper you are a given a diagram of metaphase 2 or metaphase 1, then you are able to identify.	Connecting instruction with examinations
Constructing	Addressing the language difficulty	Mr Zindi: There could an increase in the number of chromosomes, in the parent cell hanti... Is that possible? How? What happens--?	Content written on the board.

Deconstructing	Explicating the parts and features of a pre-existing text	Mr Xulu: …ahh-- em…this is homozygous… homozygous...that's a mistake [correcting what's on the transparency]. Heterozygous means they are not the same. So, this homozygous tall neh...THIS IS HOMOZYGOU:S TALL are we following?	Content written on transparency
Mnemonics	Providing ways for remembering	Mrs Durand: …Okay, remember you have got to know this in the order, that's why I'm using the acronym IPMAT. PROPHASE, METAPHASE and ANAPHASE and TELOPHASE…	Content written on the board
Rationalising [labels,word choice]	Justifying with reason the origin or choice of a linguistic item	Ls: Brown Mr Xulu: …because we say this one will mask the effects of this neh.... Right so all of them will be having brown ehh…eyes.	Content written on transparency
Pronunciation	Importance of correct pronunciation-	Mr Xulu: …This MEIOSIS but not MIOSIS [emphasisng pronunciation] this is meiosis okay.	Link to examinations

DISCUSSION AND CONCLUSION

In this study, the strategies employed by teachers to assist learners to understand the genetics concepts and achieve shared understandings of terms (Seah & Sliver, 2018) included addressing difficulty of terms by labelling, explaining, differentiating and selecting. Labelling and explaining were the dominant strategies engaged by teachers to help learners through meanings of genetics terms. This finding can encourage teachers to use the unfamiliar strategies when teaching genetics to motivate learners more into the topic. Findings from this study indicate that the teachers focused on the meanings of words, particularly in the context of examinations rather than a deep conceptual relationship between the meanings of words as reported in the study by Buma and Nyamupangedengu (2020) who investigated the use of teacher talk in the teaching of basic genetics concepts. It is argued that teacher talk that promotes depth in conceptual understanding that also create links between the many genetics terminologies could be the kind of professional development needed by life sciences teachers. In this study, each teacher's practice was shown to be unique in terms of functional strategies and the context in which terms were forgrounded. An awareness of the strategies and various contexts uncovered in this study may encourage teachers to try new and unfamiliar strategies in their teaching of genetics. Perhaps this may motivate learners into the topic genetics which is considered to be difficult (DBE, 2018) and improve learner performance.

ACKNOWLEGMENTS

We are grateful to the teachers and learners who participated in this study.

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ARGUMENTATIVE AND MULTIMODAL VIEW OF AN EXPLANATORY STORY ABOUT ELECTRIC CHARGE IN SCIENCE CLASSROOM.

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Qualitative research, case-based study focused on specific pedagogical knowledge of Physics lecturers. It is part of a larger doctoral study. The aim is to identify the multimodal-rhetorical-argumentative characteristics of physics lecturers' classes and to find forms to visually represent the construction of explanatory stories, using schemes to describe elements of story according to thesis, premises, arguments and its interactions and their relationship with multimodality. The starting point of study are the "teaching units", built from the discourse analysis of physics lecturers' explanations in an engineering school and presented didactically as a story. Topic is electrostatic introduction to electric charge. The theoretical frame is structured mainly on argumentation theory by Perelman, and multimodality in science classrooms. This study shows up the complexity of teaching performance, as well the graphic-descriptive techniques that represents of the lecturer performance from argumentative-rhetorical and multimodal perspective. It offers theoretical frame, resources and didactic tools that together may be potential generators for the design of teacher training activities in similar contexts.

Keywords: Explanation Construction, Classroom Discourse, Physics Teaching.

INTRODUCTION

The multimodal discourse analysis in the science classroom together with resources and didactical tools for the design of teaching activities, contributes with ideas toward teaching praxis improvement. In this study tables and diagrams are elaborated to present the way how the science story is developed by means of description of didactic-rhetorical-argumentative-multimodal elements. Didactic tools and techniques were developed for the discursive analysis focused on the lecturer, which combination are potential generators of elements to be applied for the preparation of educational activities for the physics lecturer improvement of teaching in this or similar contexts.

Aims from argumentative and multimodal rhetorical perspective are characterize and plot the trajectory of physics explanatory story in science classroom, according to the multimodal-rhetorical-argumentative elements (thesis, premises, arguments interaction and communicative modes), and represent segments of the explanatory story in a schematic way, such as that which describe the interaction of arguments and their sequentially.

THEORETICAL FRAMEWORK

Science classroom explanations, represents a dynamic action of lecturer/teacher, which combines within a descriptive narrative, reasoning to convince or persuade (rhetorical argumentative perspective) with various didactic strategies and multimodal action, with the objective to facilitate the meaning construction in the teaching learning process. The doctoral work (Rangel, 2021) explores the lenses with which the explanation is viewed, and with each one of them carry out activities to discover and characterize how the teacher develops the story; providing an analytical framework represented in the *figure 1* as a four-sided pyramid, that points three dimensions (or lens used by researcher) to describe the construction of the explanation:

1- communicative socio- didactical;

2- rhetorical-argumentative;

3- multimodality.

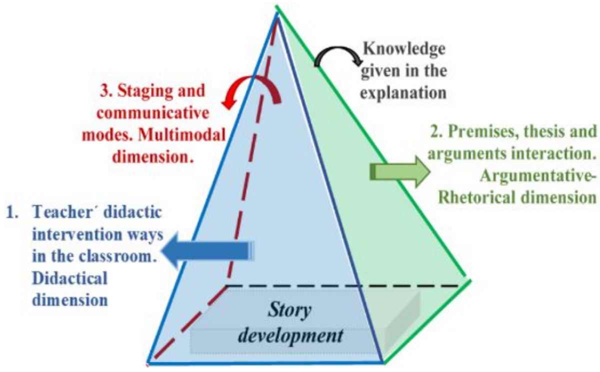

Figure 1. The story explanatory gaze, represented in a pyramidal lens.

At a higher level there is a fourth dimension, which closes the reflection carried out by the researcher, with a **graphic construction of story**, seen from one of the previous lenses.

The knowledge given in the explanation is content in the **teaching units**, that represents "the structure of scientific content for instruction" designed for real classes and focused on the teacher action, and that materializes the story development, for research.

The rhetorical-argumentative perspective

The argumentation theory of Perelman and Olbrechts-Tyteca (2000/1958) aims the study of discursive techniques that allows the adhesion of public's minds to the thesis presented for their acceptance. In this theory many rhetorical aspects are mixed with the argumentative ones. This theory says that in any discourse there are three fundamental elements: *thesis*, *premises,* and *arguments*. A fourth aspect is also highlighted in Perelman's theory, which is *arguments interaction*. Perelman highlights the *presence* which is necessary to give to the premises in order to increase its rhetorical or convincing value. There are other aspects such as presentation and discourse form. To achieve the audience's adherence, the discourse must be based on agreements with this, to modify the attitudes of their components, so it is important to start creating *communion* to convince and persuade about the *thesis* being defended (Cros, 2003).

The multimodality in the classroom.

In their research, Kress, Jewitt, Ogborn & Tsatsarelis (2001) show the rhetorical functions of objects that mediate action in the classroom, to give "*presence*" to the scientific entity, with this the students can see new characteristics and qualities that are useful in their conceptual construction. Among several ***multimodal presence*** resources are a) the demonstration of imaginary, using gestures or mimicry action with the body, and b) the demonstration using physical objects. Physics phenomena can be explained in the classroom through demonstrations with everyday objects, and also, they can be represented with imaginary objects, relying on the mind recreation of the students for the evocation of known events or easily understood facts; this type of justification will be called ***argument by demonstration*** (argument not considered in Peralman & Olbrecht-Tyteca, 1958) due to the rhetoric involved and the search for attention with representation with objects, real or imaginary.

METHOD

Research is qualitative, case based. The experience is supported in *the "teaching units*", built from the discourse analysis of physics lecturers' explanations in an engineering school and presented didactically as a story. The experience is carried out in an engineering faculty from video recordings of a physics lecturer 's discourse (called Montse). The topic is about Electrostatic introduction to electric charge. The electrical charge is built, like a story built from other stories, taking sequential pieces in time, and arranged according to the contents in five parts, the first three by Montse, the fourth by Pere and the fifth Laura's. Montse's story spans fifteen episodes [A01_M, A15_M], it includes introduction to electric charge story, the demonstration of charge transfer phenomena and properties of electric charge. The fourth and fifth parts (Pere, Laura) are not included in this paper.

The graph representation of explanatory story. Tools were designed to give graphic support to these initials analyses, aiming to obtain several objects (tables, diagram, or graph) that describes the trajectory of explanatory story.

ANALYSIS OF LECTURER PERFORMANCE

The types of representation of the analysis carried out are shown below, taking episodes from the first part of story. Starting with *the teaching unit* described above and shows in *Table 1*.

Table 1. The Didactic Unit, example. Introduction of electric charge topic Episode [A05_M].

10:27 Aside from that, when one is sitting (*bends the body a little*) and moves (*moves to the right, imitating the movement*) to get out from the car, one grazes moves (*touches their clothes towards down, pointing to the friction*) ... **her body and her clothes** (*she moves her hands, rubbing her torso and palm together*) **she brushes against the leather or the skin of the car seat ...** (*she touches her clothes again*)

then a **static charge is also created, and that charge goes to the ground** (*gesture: from head to toe*) **if one is not well insulated** (*pointing down*) but if one has shoes (*indicates with the finger index and thumb*) which isolates you from the ground ... **then you touch anything else connected to ground** (*she goes to the door and touch the metal frame*) **and !Pah!,** (*gesture: a semicircle with index of the other hand, pointing downwards*) **one goes to earth**; is like that, as this load leave.

This electric charge goes to earth (*hand gesture in a semicircle down*) one is a good conductor. **The human body** (*she goes forward*) (gesture "I") **is a good conductor** ... (*goes back to the slate and then go to the left*) it has its **resistance**, but it conducts the current ... that's why **you have to be careful ... where they put their little hand** (*points with the index to the side*) but that's what happens **and surely some of you have had experiences of this type ...**

The analysis Grid. The *Table 2* shows an example separating into three columns a) intervention content, b) thesis, premises and arguments, and c) way of presenting the discourse and function.

Table 2. Argumentative analysis of A05_M episode: "the human body is a good conductor".

<table>
<tr><td colspan="3">Thesis 2 Superior: The electrical charge phenomenon of materials is a fact that is always present in everyday life. (Comes from previous episodes). Source: Rangel (2021)</td></tr>
<tr><th>A05_M: Montse Intervention</th><th>Thesis, Premises and Arguments</th><th>Presentation Form and function</th></tr>
<tr>
<td>10:27 ... apart from that when one is sitting (bends the body a little) and moves (moves to the right, imitating the movement) to get off the car ("get out of the car") ... one grazes moves (touches her clothes down, pointing to the friction)… her body and her clothes (moves her hands, rubbing the torso and palm together) she brushes against the leather or the skin of the car seat (she touches her clothes again) (P26) … [T14]… then a static charge is also created and that charge goes to the ground (gesture: from head to toe) if one is not well insulated… (pointing down) [P26] but if you have shoes (you indicate with your index finger and thumb) that isolate you from the ground… [P27]

then you touch anything else grounded (he goes to the door and touches the metal frame) and pah! (gesture of a semicircle with the index of the other hand, pointing downwards) [T15] one goes to the ground ... that way the load one has goes to the ground ... [P28] (gesture with the hand in a semicircle towards down) one is a good conductor ...

the human body (comes forward) (I gesture) is a good conductor ... (goes back to the blackboard and then to the left) [P29] he has his resistance, but he conducts electricity ... that's why you have to be careful ... where they put their hand [T16] (points with the index to the side) but that is what happens and surely some of you have had experiences of this type [P30]</td>
<td>Thesis 14: The human body is charged by contact and friction of clothing with the material of the car seat.
Premise 26: "one in the car, when moving, rubs his clothes with the seat" (load by rubbing (fact, already elaborated previously)
Argument by Illustration with gestures and mimicry

Thesis 15: The charge in the isolated human body, when touching another conductive body is discharged and a current is felt, ¡pah!
Thesis 16: You must be careful with what you play due to the downloads that we can receive.
Premise 27: "a static charge is created, and that charge goes to ground if one is not isolated" (true),
Premise 28 (recent): "if one is isolated, that load, when one touches anything connected to ground, the load goes there (fact)
Premise 29: The human body is a good conductor, it has the resistance of it, but it conducts the current. (fact)
Premise 30: Surely you have had experiences of this type (presumption)
General thesis 17: "Some bodies (conductors) can be easily discharged when touching with another conductive body not isolated from the ground and thus produce electric shock (in the person who touches them)"
Visual argument by illustration with gestures and mimicry (complete the previous one)</td>
<td>Lecturer Representation with gestures and mimicry

Give presence to rubbing between clothing and seat with mimicry

It gives presence to the load in the body, with the gesture around its body.

Give presence to the electric touch with the onomatopoeia pah!</td>
</tr>
</table>

Tree diagram analysis, with the order of premises/thesis, shows a hierarchy scheme and draws the story trajectory that corresponds to the segment [A01_M, A05_M] (*figure 2*).

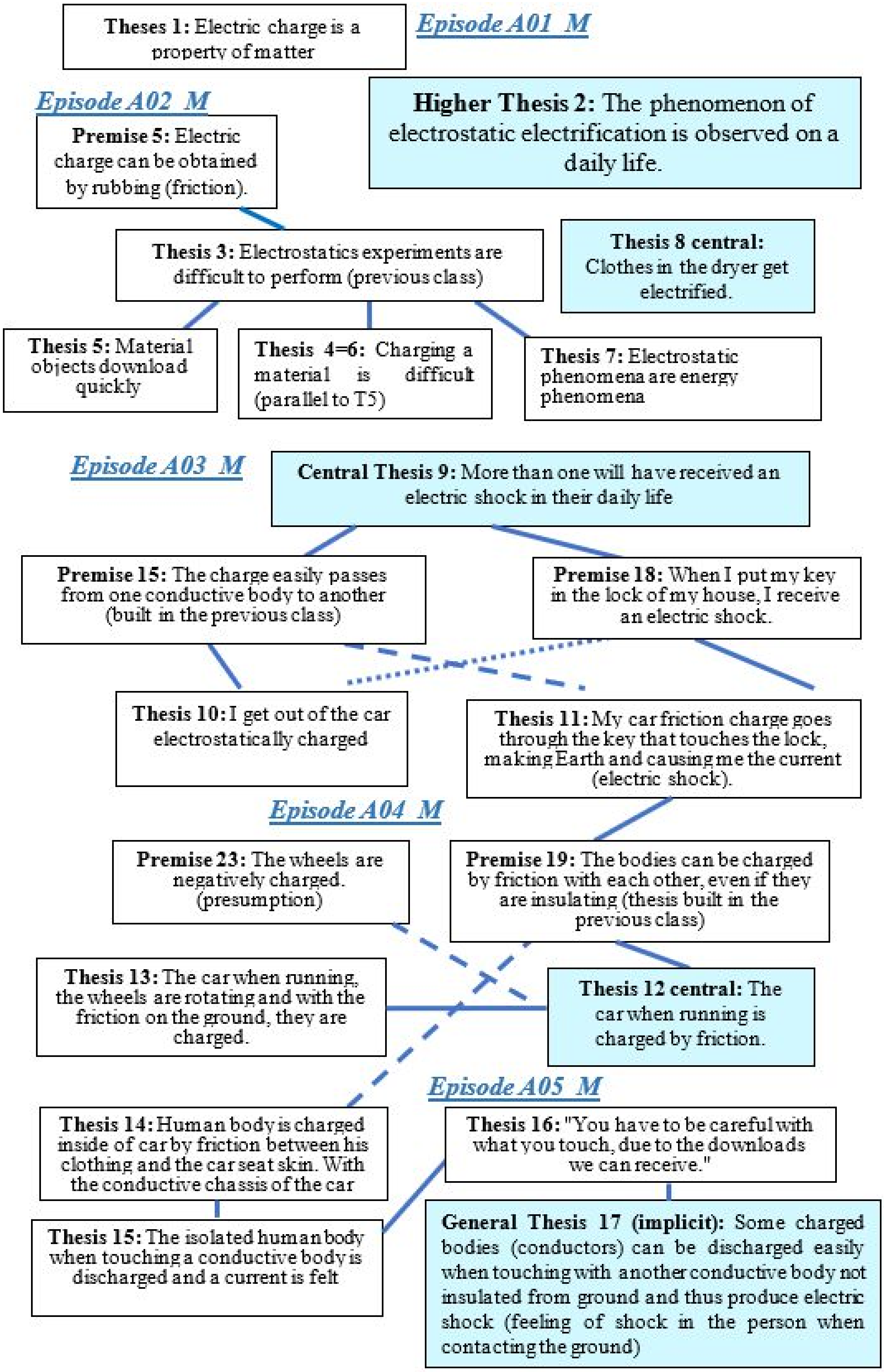

Figure 2. Tree Diagram schematic of Premises-Thesis in Montse's explanation. Episodes [A01_M, A05_M].

The arguments interaction plotting, outstanding main arguments. The *figure 3* show argumentative trajectory story corresponds to the segment [A01_M, A05_M].

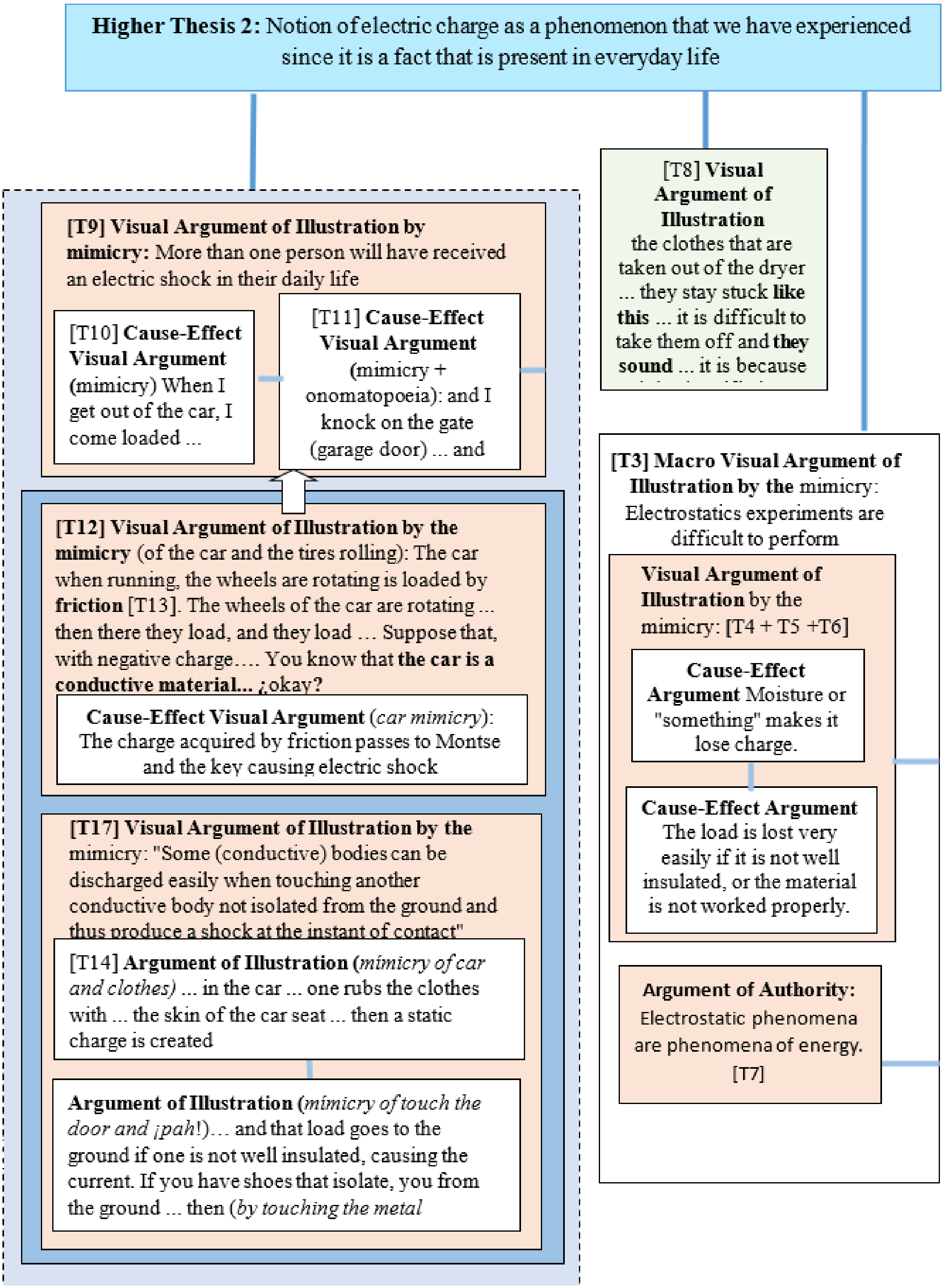

Figure 3. The arguments' interaction in the explanation of electric charge Episodes [A01_M, A05_M].

Multimodal board.

The "Modal Board" tool offers an analytical platform, designed (Rangel, 2021) to characterize the communicative modes (verbal, gestural, writing mode, drawing mode, representation mode and interaction) and that responds: How is the teacher's interaction with the environment, to achieve the construction of explanatory story? It is made up of a descriptive table, in whose header is the description of the story, below identify teachers, their explanations segment, and macro arguments that characterizes. In the first column are the communicative modes, which were assigned colours to locate them visually and detect interactions. With this board it is possible to verify by visualization the relationship between the arguments and multimodality, through the pairing between analyses. Each ~~columns~~ represents episodes of one-minute of story. The *Table 3* shows the first part of story divided in fifteen episodes.

Table 3. Multimodal board of "electric charge" story. Segment [A01_M, A05_M].

Multimodal board of Montse Story: Electric charge																
	Lecturer	MONTSE					MONTSE				MONTSE					
	Electric charge:	Introduction					Characteristics				phenomenon transfer					
	Argument	Illustration					Quasi logic				Demonstration					
	Episode	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15
Representation	ROG_{mimExp}															
	ROG_{Exp}															
	ROG_{skin}															
	ROG_{rod}															
	ROG_{door}															
	$ROIG_{electricity}$		Drying	Touch	Car	Car										
D	$Imagen_{book}$															
Coupli	V→D															
	R→ E															
	V→E															
W	E															
	ET_{itle}															
Gestures	GA					2x							3x	5x	3x	3x
	GN	2x	6x	6x	4x	6x		2x			2x	2x			4x	4x
	Gno															
	GF_{tone}															
Questions	PR															
	PF				4x											
	PG															
	Pr						2x								2x	
V	Speech															
	Episodes	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15
	ARGUMENT	Illustration					Quasilogical				Demonstration					

ROG: Representation using objects and gesture (skin or rod plastic piece)
ROIG: Representation using imaginary objects and gestures (car - mimicry)
D1: Drawings
V →D: Verbal - Drawing

R →E: Represented - Written Coupling
V →E: Verbal - Written
E : Writing on slate
ETittle: Writing Titles
GA: Pointing gesture
GN: Narrative gesture
GNo: Onomatopoeic gesture
GF: Facial gesture marked

PR: Question -Response
PF: Feedback-type question,
PG: Guiding question, whose answer serves as a scaffolding to obtain more complex answers
Pr: Rhetorical question,

THE ILLUSTRATION ARGUMENT AND MULTIMODALITY

Montse's story was classified in three macro-arguments: a) Visual Illustration for introduction and audience engagement to electric charge, b) Quasi-logical to present its characteristics in an orderly manner, and c) Visual Demonstration using the representation with physical objects to show the charge transfer phenomena.

Visual illustration macro-argument [A01_M, A05_M]

Headed by Superior Thesis 2 [T2]: The phenomenon of electric charge with electrostatic electrification is a fact that is observed in everyday life. The interaction of arguments is shown in *figure 3*, headed by [T2] and formed by a structure of three illustrations in parallel [T3], [T8] and [T9], accompanied by mimicry, which converge to reinforce [T2].

Illustration [T3]: Electrostatics experiments are difficult to perform [A02_M]. It is a combined structure formed by two structures in parallel: a) a simple [T7] argument from authority: Electrostatic phenomena are energy phenomena; and b) a causal macro argument of succession through mimicry composed of two arguments in series (cause 1: Moisture or "something" causes charge to be lost), and (cause 2: charge is easily lost if it is not well insulated or if it is not works well with the material).

Illustration [T8]: The clothes in the dryer become electrified. [A02_M] Montse performs a mimic representation with an imaginary object (ROIG) of the dryer, when she takes the clothes out of the centrifuge and her gestures (six times GN) that help to represent and make "visible" what happens to the clothes" it is stuck", "it is difficult to take it off and it sounds".

Illustration [T9]: More than one will have had a jolt in his daily life [A03_M]. It is a composite structure, formed by three visual illustration macro arguments. Illustration 3a: [T10], [T11] in series. A chain (series) of two cause-effect arguments Montse performs a representation with imaginary objects (ROIG) mimicry of electrifying: with the index finger touching something; get out of the car, be loaded through the rubbing of clothes, and touch the gate with the key and Pah! Feel the rush. Illustration 3b: [T12] The car when running is charged by friction. [A04_M] and reinforced by the thesis [T13]. Argument by cause and effect: Verbal description accompanied by narrative gestures (4x GN) and a dynamic using the rhetorical question (Pr) and the feedback question (4xPF) to verify understanding. Montse makes a representation with an imaginary object (ROIG) mimicking the car and explaining how the tires are loaded. Illustration 3c: [T17]: Some bodies (conductors) can be easily discharged when touching another conductive body not isolated from the ground and thus produce shocks (in the person who touches them) [A05_M]. Narrative description and gestures (6xGN) and then with the 2xGA door) with mime and onomatopoeia. Formed by a chain of two visual illustration arguments, using representations with an imaginary object.

Quasi-logical macro-argument [A06_M, A09_M]. Headed by Thesis 21 Major: The characteristics of electric charge: There are two types of charge, the charge is conserved, the charge is quantized. Is observed the use of Authority argument: because the lecturer says so. However, it is made up of three parallel arguments. Using the Visual argument for Identification and Definition, it gives presence by nominalization by writing each characteristic in an enumerated way, as she explains them. [T18, T19 y T20]. Adding: Quasi-logical argument of

Part in the Whole: It is the basis of the building of physics. Argument by Metaphor: It is the basis of the building of physics. She uses the continuous rhetorical question to seek student participation: "What does this mean? What does it mean that it is quantized?"

Demonstration with Physical Objects macro-argument [A10_M, A15_M]. Formed by two argumentative structures. *Demonstration argument using physical objects performed in silence* [A10_M, A11_M] to formulate [T22] Principal: Materials are neutral in nature and are electrified by friction. demonstration with representation with objects. Constructed from the implicit [T25]: The charge is transferred, so a body can be charged. Montse approaches the charged bar (rubbed with skin) to one of polystyrene piece. It is noted that the anime is attracted. but when the bar and the anime touch, they separate. This Experimental Demonstration is previously anticipated by two arguments: a Transitive Quasilogical [T23] (a→b, b→c then a→c) and a Visual Illustration [T24], by representation of the imaginary, the mime both used to motivate and prepare the audience to Experimental Demonstration to show (*figure 4*).

Figure 4. Episode shows electrical charge transfer. Demonstration with objects [A11_M].

The Causal macro argument of V*isual* Succession is the second structure [A12_M, A15_M], which is supported by the previous one to complete the initial blackboard presentation and develop the main thesis [T21]. Formed by Causal arguments linked to the Demonstration macro argument through Gestures and Object representation [T26 ...T30]. One of them [T29]: The bodies are charged by friction, when rubbing the bodies, energy is supplied to them, causing the electrons of last layer to come out, leaving the material with an excess or deficiency of electrons.

RESULTS

In this study has been presented an argumentative and multimodal analysis, about how the teacher develops the scientific story, trying to understand, how the teacher pedagogical content knowledge emerges and dynamizes the audience, building the story. There is an effort to give presence, visibility to the concept, capturing the audience's attention in that initial story based on the imaginary recreation, to then return to the formal part of describing the properties of electric charge, relying on the writing on the blackboard. It is interesting Montse action who, without losing her formality respect of scientific content, never stops taking account and verifying that the audience is closed to her while evolution the story.

The graph representation of story: From the study to characterize the lecturer performance, the search is proposed to present the graphic interpretation of argumentative analysis carried out, which in some way gives an account of trajectory traced by explanatory story, and that can serve as an example of possible activities that show the reflective process of the researcher or the novel lecturer.

Types of arguments: The following Association arguments were observed: a) Quasi logical arguments: the logical (Identity, Definition and Transitivity arguments); b) Arguments that Establish the Structure of Reality, specifically, identified for the particular case (Illustration, Demonstration); and c) Arguments based on Structure of Reality: Causal argument of Succession, and the argument from Authority, based on a relationship of Coexistence.

FINAL DISCUSSION

Discourse Analysis and the Training of teachers. We have seen the usefulness of Perelman's theory of argumentation, in allowing us to obtain information about the explanations of physics lecturer, obtaining data on the argumentative and rhetorical characteristics of the same. On the other hand, we obtained graphical ways to describes the story development, information based on how the arguments and the communicative modes involved in the Lecturer's discourse contribute to the creation of scientific meanings.

This research is repeatable in other similar teaching contexts. The analytical framework is great, it has taken a lot of work. It has not been easy. And working with peers, good results have been seen and the reflection process necessary to carry out the activities was verified, with different levels of theoretical or practical difficulty. The processes are recursive, very complete, and attractive

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NATURE OF SCIENCE AND CRITICAL THINKING SKILLS: AN EMPIRICAL ANALYSIS OF THEIR RELATIONSHIPS

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The label 21st century skills has been coined to depict a set of innovative skills that may allow citizens to better live and work in the demanding context of 21st century knowledge societies. Thus, general education and Science & Technology Education (STE) are challenged to teach these skills, which usually are labelled as critical thinking, problem solving, creative thinking and the like. On the other hand, nature of science (NOS) is a perennial component of scientific literacy that embodies knowledge and skills on scientific practice, which currently involves engineering and technological practices too. Further, some scholars claim that students' critical thinking skills are key to effective learning NOS issues. This communication elaborates this previous claim searching for the empirical relationship between thinking skills and NOS knowledge. The methodology assesses students' thinking skills (causal explanation, decision-making, parts-all relationships, sequence and logical reasoning) and NOS epistemic beliefs on science conceptualization of a Spanish 8-grade students who attend twelve different schools. The empirical correlations between thinking skills and epistemic knowledge are computed and partially confirm the hypothesized relationship, yet the results are far from simple. The majority of correlations between the skills and the items expressing adequate beliefs about science are significant and positive; on the other hand, the majority of correlations with items depicting misinformed beliefs on science appear non-significant and somewhat negative. The linear regression analysis from NOS beliefs on thinking skills confirms the significant and positive predictive power of one adequate item, while all the remaining items are non-significant. Some interpretations and consequences of these results for research and for teaching scientific literacy, nature of science, and critical thinking skills are discussed.

Keywords: critical thinking skills; scientific thinking; educational assessment

INTRODUCTION

Since years several international documents and reports are pointing out to an innovative aim for general education, the so-called 21st century skills, which involve a set of skills to better live and work in the demanding context of knowledge societies. Many prestigious researchers, experts and organizations advocated 21st century skills for education, such as the European Union (Council Recommendation on Key Competences for Lifelong Learning, 2015), the Organisation for Economic Cooperation and Development (OECD, Global Competency, 2016), the partnership for 21st century on deep learning (P21 framework), the World Economic Forum (Education 4.0 initiative), the UNESCO (Principles for Learning in the Twenty-first Century, 2014), as well as many individual educational experts and researchers (Fullan & Scott, 2014).

The different depictions of 21st century skills invariably include critical thinking skills (CRT) as a common, transversal and cross-curricular competence for learning. For instance, the European Commission of Education (European Union, 2014) proposes the development of some transversal skills, namely critical thinking, creativity, initiative, problem-solving, risk assessment, decision-making, communication, and constructive management of emotions, in order to achieve the key educational competencies.

The research on critical thinking

The CRT construct has been developed in the psychological research, which is a rich, complex, controversial and terminologically bewildering field. To start with the complexities, CRT scholars do not even agree a common definition for CRT; for instance, Ennis' (1996) definition of CRT as, reasonable reflective thinking focused on deciding what to believe or do, and his extensive conception based on its constitutive skills, provide a full theoretical framework for CRT (Ennis, 2019). Of course, other scholars propose different definitions and skills (i.e., APA, 1990; Fisher, 2009).

In fact, many researchers, especially those concerned with the development of CRT assessments, usually handle an extensive definition of CRT, that is, defining CRT by enumerating the set of higher-order thinking skills that conform CRT, which obviously differ from one another. For instance, the Halpern Critical Thinking Assessment on Everyday Situations Test assesses the skills problem solving, verbal reasoning, probability and uncertainty, hypothesis-testing, and analysis of arguments and decision making (Halpern, 2010). Watson and Glaser (2002) test assesses deduction, recognition of assumptions, interpretation, inference, and evaluation of arguments, and the California Critical Thinking Skills Test assesses analysis, evaluation, inference, deduction and induction (Facione et al., 1998).

The CRT field needs some kind of systematization, and the previously mentioned Ennis' extensive conception and APA statement are conspicuous examples. Further, on the basis of CRT literature and CRT assessment tools, the authors have proposed a four-dimension taxonomy for critical thinking skills, which in turn develops in multiple categories, subcategories and skills. Critical thinking is the foundational concept (the highest level of the taxonomy), and creativity, reasoning and argumentation, complex processes (problem solving and decision making) and evaluation and judgement are the four basic dimensions of CRT. Overall, the taxonomy contributes to put some order across the complex field of CRT skills (Fisher, 2021; Manassero-Mas & Vázquez-Alonso, 2019b).

Beyond the differences, it seems quite obvious that all CRT skills mentioned above display a clear content identity with the skills that are put into play in scientific practice. This justifies researching the relationship with the second concept involved in this study (nature of science).

The nature of science and the scientific thinking skills

Nature of science (NOS) is a perennial and acknowledged component of scientific literacy that embodies interdisciplinary knowledge, skills and attitudes about the scientific practice. According to recent conceptualizations NOS spread across epistemic and social dimensions (Erduran & Dagher, 2014; Manassero-Mas & Vázquez-Alonso, 2019a). Teaching and learning NOS effectively to students has also settled NOS as an extant, contentious and controversial field of science education research. Beyond hindrances and controversies, there is also a wide agreement that NOS knowledge represent a relevant component of scientific literacy and, as such, NOS should be taught through explicit and reflective methods. Explicit means planned and purposeful teaching, which is opposed to implicit; reflective means using thinking to clear

NOS ideas in order to achieve understanding, which is opposed to rote learning and uncritical acceptation of ideas (Cofré et al., 2019; Deng et al., 2011; García-Carmona et al. 2011).

NOS science education research has contributed to highlight the controversies when deciding the representative NOS contents to be taught to students in science curricula and to identify the many difficulties students cope to understand NOS. These difficulties refer to the inability to differentiate facts and explanations and to properly coordinate evidence, justifications, arguments and conclusions, the introduction of opinions, inferences and personal reinterpretations, the usual jump to conclusions as self-evident, the lack of attention to the contrary evidence and the lack of elementary epistemic meta-knowledge and self-regulation, among many others (García-Mila & Andersen, 2008; McDonald & McRobbie, 2012; Simonneaux, 2014).

Both, the cognitive character of the students' difficulties to learn NOS and the need of reflective teaching and learning are theoretically connecting NOS and CRT fields. Thus, some science education researchers are currently advocating that NOS learning needs CRT skills to critically achieve its learning aims. Conversely, NOS learning may also contribute to the development of CRT skills, given that NOS learning put into play scientific thinking skills to achieve adequate understanding. All in all, this literature is suggesting that both, NOS and CRT skills may hold a mutual relationship (Allchin & Zemplén, 2020, among others).

Further, both directions of this intuitive relationship between CRT and NOS learning are fruitful ways to scientific literacy and learning. However, the empirical research about this relationship is scarce and somewhat incomplete, as the operationalisation of both constructs, CRT and NOS, is quite mystified across studies, as the selected variables for the constructs in play not always adequately represent the NOS and CRT constructs (i.e., Yang et al., 2019). Summing up, this study aims to empirically explore this hypothesized relationship between CRT and NOS, by selecting some variables that represent both constructs, in order to compute their empirical correlations that may evaluate the support to the theoretical claim on the mutual relationship between NOS beliefs and CRT skills.

METHODOLOGY

In order to empirically check the NOS–CRT relationship, two assessment tools were developed. The 36-item Thinking Challenges Test assesses five thinking skills (causal explanation, decision-making, parts-all relationships, sequence and logical reasoning) that are appropriate for the young participant students. All test items are designed free of culture, as their contents are not related nor anchored in any curricular knowledge or school subject. Half items were borrowed from standardised CRT tools and display a verbal format, while half items were designed by the authors through figurative formats. Correct answers score one-point, incorrect answers zero points, and any correction for random answers was applied; scores for the skills and the total test score were computed by adding the correct scores of their constituent items.

A simple scenario on science definition has been borrowed from the item-pool "Views on Science-Technology-Society" to operationalize NOS knowledge in order to be affordable for the young participant students (Aikenhead & Ryan, 1992). The scenario presents nine sentences, each conveying a different definition of science and the students rate their agreement on each sentence on a 9-point Likert scale (1-9). The nine definitions involve two adequate items conveying an informed view of science, two naïve items conveying an uninformed view of science and five plausible items conveying a partially informed view. The combination of heterogeneous items is psychometrically recommended to avoid the acquiescence bias, which overestimate agreements when only positive items are displayed; however, heterogeneity underestimates the internal consistency of scales (Solís-Salazar, 2015). Further, heterogeneity also requires a scaling procedure through experts for calibrating the sentences and a coherent scoring rubric to transform the students' direct answers (1-9) into an index (-1 to +1) that evaluates the value of students' ratings, according to experts' current NOS views (i.e., the rubric states a proportional reversion for the students' ratings to naïve sentences).

The NOS and CRT assessment tools were answered by a convenience sample of 347 grade-8 Spanish students (48.5% females; mean age 13.32 years), who attend twelve Spanish schools placed in different social contexts. Their teachers led the applications of the two tools to students within their classrooms, as a part of their regular learning and assessing activities.

The database was processed with SPSS 25 and the Factor program (Baglin, 2014) through polychoric correlations for ordinal variables that allow computation of the expected a posteriori (EAP) reliability score. The links between thinking and NOS are explored through the computation of correlation indexes among the variables drawn from the Thinking Challenges Test and the indices of the nine sentences of the NOS scenario on science definitions.

RESULTS

The descriptive statistic for the direct agreement ratings of the NOS sentences on the 1-9 Likert scale showed an overall acquiescence bias to agreement, as all sentences reach average scores over 5.7, which is the minimum mean score (it is not displayed in the table due to lack of space). Thus, this result backs the use of a mix of adequate, plausible and naïve sentences, according to experts' recommendations to counter the acquiescence bias of students' responses.

The average indices displayed positive scores for the two adequate sentences, and mainly negative means for the naïve and plausible sentences. The overall weighted average index for the whole sample across all sentences is close to zero (+0.019), yet slightly positive, which means that students' overall epistemic conception on science definition is not significantly informed. Most students agreed with the Adequate phrases (expressing informed beliefs about science), and the average Adequate indices have got the highest positive index (+0.202). In contrast, the average indices of Naïve sentences (expressing uninformed views on science) have got the lowest negative mean score (-0.116). The Plausible sentences (expressing partially informed beliefs, neither adequate nor naive) obtained close-to-zero and negative average indices, which mean students' beliefs on these sentences are far from informed (-0.030). Overall, students present slightly informed views on Adequate sentences, close-to-zero average indices scores for Plausible phrases and slightly uninformed views for Naïve statements.

The descriptive statistics of the six critical thinking variables shows that most of their mean scores place quite close to the midpoint of their score range. Overall, these results indicate that the CRT test displays a medium difficulty for students, and it is neither easy nor difficult. Thus, the test can be considered an acceptable tool to assess thinking for these young takers of this CRT test (lower half of table 1).

Table 1. Descriptive statistics of the study variables: scientific beliefs on the definition of science (nature of science) and critical thinking skills (n = 347).

Instruments		Min.	Max.	M	SD
Nature of science sentences	Categories				
A. a study of fields such as biology, chemistry and physics.	Plausible	-1	1	0.152	0.622
B. a body of knowledge, such as principles, laws and theories, which explain the world around us (matter, energy and life).	Adequate	-1	1	0.291	0.558
C. exploring the unknown and discovering new things about our world and universe and how they work.	Plausible	-1	1	-0.135	0.678
D. carrying out experiments to solve problems of interest about the world around us.	Plausible	-1	1	-0.023	0.685
E. inventing or designing things (for example, artificial hearts, computers, space vehicles).	Naïve	-1	1	-0.255	0.583
F. finding and using knowledge to make this world a better place to live in (for example, curing diseases, solving pollution and improving agriculture).	Plausible	-1	1	-0.220	0.717
G. an organization of people (called scientists) who have ideas and techniques for discovering new knowledge.	Plausible	-1	1	-0.038	0.675
H. an inquiry process and its knowledge outcomes.	Adequate	-1	1	0.213	0.499
I. No one can define science	Naïve	-1	1	0.023	0.668
Critical thinking skills	Formats				
Explain	Verbal	0	8	4.792	1.652
Sequence	Figurative	0	5	2.732	1.308
Parts All	Figurative	0	14	6.991	3.330
Decision	Verbal	0	6	2.374	1.405
Logical Reasoning	Verbal	0	3	1.147	0.835
Total		1	36	18.037	5.830

The expected a posteriori (EAP) reliability index for direct scores is good for the whole NOS scale (0.828) in spite of their constitution with informed (adequate), uninformed (naïve) and partially informed (plausible) sentences that lower the reliability index. The EAP reliability indices of CRT test are excellent for the scales sequence (0.940) and parts-all (0.851), which are made of figurative items, and for the whole test - total - (0.932); the EAP reliability is good for the scales explain (0.785) and decision (0.670), and poor for the logical reasoning scale (0.265), probably due to its low number of items (3), which points out to enlarge the scale.

Correlations between thinking skills and nature of science

The Pearson correlation coefficients between CRT skills and NOS sentences have been computed to evaluate the hypothesized relationship between thinking skills and NOS beliefs (table 1). The results reveal a complex pattern of the NOS-CRT relationships; on the one hand, the correlation indices between all CRT skills and NOS adequate phrases indices are positive and statistically significant; on the other hand, most correlation indices of CRT skills with non-informed NOS phrases (naïve and plausible) tend to be statistically non-significant (close to zero, either positive or negative), yet few of them (9) are statistically significant (eight negative, one positive).

The close analysis of the whole correlation table among CRT and NOS variables shows that all correlations between adequate phrases and the six CRT skills (including the total thinking score for the whole test) are positive and most (67%) are statistically significant. The majority (58%) of the correlations between naive phrases and CRT skills are non-significant, a minority are significant and negative (32%), and only one is significant and positive. The big majority (87%) of the correlations between plausible phrases and CRT skills are non-significant, and only a minority are significant and negative (13%).

Table 2. Pearson correlation coefficients between critical thinking skill variables and scientific beliefs on the definition of science sentences (non-significant correlation indices are omitted for easier reading).

Nature of science sentences	Critical Thinking skills					
(Category of the sentence)	Explain	Sequence	Parts All	Decision	Logical Reasoning	Total
A. a study of fields such as... (P)						-.114*
B. a body of knowledge... (A)	.157**	.239**	.277**	.125*		.300**
C. exploring the unknown... (P)						
D. carrying out experiments... (P)						
E. inventing or designing things... (N)		-.141**	-.212**	-.163**		-.219**
F. finding and using knowledge… (P)		-.135*			-.137*	-.121*
G. an organization of people... (P)						
H. an inquiry process and its... (A)			.132*		.124*	.139**
I. No one can define science. (N)		.123*			-.125*	

** Significant correlation at level 0.01 (bilateral). * Idem at level 0.05 (bilateral).

Thus, the pattern of the relationships between NOS beliefs and CRT skills emerging from the correlation matrix is complex, as it displays quite diverse specific traits. The most relevant conclusion is that the relationship pattern deeply depends on the category of the NOS belief into consideration, either informed (adequate sentences), partially informed (plausible sentences) or uninformed (naïve sentences).

The second relevant conclusion shows that the adequate phrases display a robust significant and positive correlation pattern for the huge majority of skills.

The third relevant trait shows a correlation pattern for the naïve and plausible phrases with a majority of non-significant correlation indices (76%), which is still stronger for the plausible sentences (87%) than for naïve sentences (50%). Besides, the correlation pattern of the scarce significant correlation indices for the naïve and plausible phrases (21%) tend to be negative, which is still stronger for the naïve sentences (42%). Approximately, the strength of the correlation indices displays a decreasing model from adequate to naïve sentences.

Linear regression analysis

The regression analysis is a correlational statistical procedure that allows comparing the predictive power of a set of predictors on a dependent variable. A linear regression analysis was performed, where the nine independent NOS variables play the role of predictors on the thinking skills, which act as the dependent variables (the logical reasoning skill has not been studied because of its low reliability index). Collinearity tests were negative for all RA through tolerance, variance inflation factor and condition index statistics. The regression analysis tests the relative strength of the NOS variables to predict the variance of the CRT skills.

The results (table 3) show that the adequate variable (B sentence) achieved the greatest significant predictive power on CRT skills, as all its standardized beta coefficients are statistically significant and positive for the regression equations of all thinking skills. On the contrary, plausible and naïve sentences had much lower predictive power on CRT skills, as almost all their sentences display non-significant standardized regression coefficients.

Only two exceptions to the previous result are displayed for the E naïve sentence, which achieves significant, yet negative, standardized coefficients as the predictor of parts-all and total thinking skills. Overall, this exception represents a tiny proportion in regard of all the remaining non-significant variables (two significant cases out of forty possible cases).

Table 3. Standardized coefficients (Beta) for the statistical regression analysis of the predictors (nature of science sentences) on the dependent variables (thinking skills).

Predictors	Dependent Variables (thinking skills)				
Nature of science sentences	Explain	Sequence	Parts All	Decision	Total
A. a study of fields such as biology… (P)	-0.051	-0.048	-0.077	0.074	-0.073
B. a body of knowledge, such as principles... (A)	0.173**	0.218***	0.208***	0.137**	0.249***
C. exploring the unknown and discovering... (P)	-0.019	0.03	0.002	0.004	0.011
D. carrying out experiments to solve... (P)	-0.05	-0.008	-0.028	-0.03	-0.034
E. inventing or designing things... (N)	-0.036	-0.077	-0.148**	0.074	-0.139*
F. finding and using knowledge... (P)	0.044	-0.026	-0.005	0.013	-0.019
G. an organization of people... (P)	0.105	0.097	0.065	0.018	0.1
H. an inquiry process and its knowledge... (A)	-0.055	0.024	0.01	0.066	0.028
I. No one can define science. (N)	-0.066	0.019	0.061	0.084	-0.017
Explained Variance (%)	4.7	7.9	10.3	3.8	12.5

* Significant standardized coefficient at level .05; ** Idem at level .01; *** Idem at level .001

Further, the total thinking variable shares the largest proportion of the common variance with its predictors (12.5%) followed by the parts-all skill (10.3%). Both rates represent a relevant amount of common variance between predictors and skills.

All in all, the results of the regression analysis, which directly contrasts the predictive power of the NOS sentences, shows that the B adequate sentence displays the highest predictive power on thinking skills. It is also noteworthy that the second adequate sentence (H) has not got significant predictive power on thinking skills.

CONCLUSIONS

The empirical findings show significant relationships between thinking skills and NOS beliefs on science definitions. However, the correlation pattern depends on the category of NOS beliefs. Adequate beliefs display a significant and positive correlation pattern, most plausible beliefs display non-significant correlation pattern, and naïve beliefs display a weaker non-significant and somewhat negative correlation pattern.

The findings about the positive, significant correlation pattern of NOS adequate beliefs confirms the initial launched hypothesis about a positive relationship between CRT skills and NOS beliefs. Further, the findings of the regression analysis about the predictive power of the NOS sentences on CRT skills pinpoint that the B adequate sentence leads the highest significant and positive predictive power on all thinking skills, while the other adequate sentence (H) display non-significant standardized regression coefficients.

On the other hand, the unexpected non-significant and slightly negative NOS-CRT relationships for plausible and naïve sentences, casts doubt that this result may be an undesirable effect of the acquiescence bias. Further, it connects with some criticisms on the marginalization of the uninformed NOS beliefs (plausible or naïve) on NOS teaching, which has been mainly focused on adequate NOS beliefs and usually forgets misinformed beliefs. Thus, these results point out to advocate more balanced attention to teach all NOS beliefs, and especially the misinformed beliefs, in order to attain effective NOS learning (McComas, 1996).

Further, this study contributes to clarify the literature on NOS-CRT relationships by adding data where both parts of the comparison variables neatly correspond to NOS (beliefs on science definitions) and CRT skills, which not always has been the case in previous mystified research (i.e., Yang et al., 2019).

However, further attention is needed to enlarge the empirical support for the relationship NOS-CRT, whether to confirm or to explore these complex patterns and trends. On the one hand, diverse and wider samples should be tested. On the other hand, the scope of the assessment tools of NOS beliefs and CRT skills should be widening. For instance, new NOS issues, such as further epistemological and social aspects of science should be explored to make NOS knowledge more comprehensive and representative of the NOS conceptualization (Erduran & Dagher, 2014; Manassero-Mas & Vázquez-Alonso, 2019a). Similar recommendations apply for including new skills to enlarge the scope of the CRT tool; particularly, increasing the number of items of the logical reasoning scale is required to improve the reliability of this scale. Finally, the quantitative methods might be complemented with qualitative methods (such as students' interviews, drawings and the like) to enlarge the methodological empirical support Erduran & Kaya, 2018).

The prospective of this study refers to the role of science education in the promotion of critical thinking skills through NOS knowledge, and vice versa, the promotion of understanding NOS through the mastery of CRT skills, along the multiple socio-scientific issues and skills, as this study focuses on the epistemic knowledge drawn from science education and NOS research. In parallel to science education, general education research has elaborated the epistemic knowledge (EK) construct (Hofer & Pintrich, 1997). EK opens further prospective research developments for NOS understanding and CRT skills. On the one hand, the study of the relationship NOS-EK may shed light for convergent epistemic teaching and learning, both in science education and in general education. On the other hand, the importance of CRT skills for NOS, and vice versa, may help the impact of teaching NOS-EK issues (Erduran & Kaya, 2018; Ford & Yore, 2014; McDonald & McRobbie, 2012; Simonneaux, 2014). This joint NOS-EK prospective elaboration may also lend new answers on two innovative aspects: the mutual connections between CRT skills and NOS-EK issues, and additionally, the EK assessment tools that may also contribute to advance the evaluation of CRT skills and NOS.

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CONCEPTUAL METAPHORS IN ASTRONOMERS' DISCOURSES

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Newspapers play an important role in communicating breakthroughs in science. Science news reports often present episodic coverage of discoveries, neglecting processes of inquiry. However, when scientists have a voice in newspapers (e.g., news in the form of interviews to scientists), they have an opportunity to clarify journalists' interventions, to redirect the conversation to aspects of scientific research or to persuade readers of the value of science. What is communicated is framed by the language employed, namely conceptual metaphors that may shape readers' understanding of the message and affect issue viewpoint. Focusing on astronomers' interviews to Portuguese newspapers, this study analyses the conceptual metaphors in these interviews, through the perspective of Conceptual Metaphor Theory, and discusses their potential use for science education.

Keywords: Social Media, Metaphors, Nature of scientific inquiry

INTRODUCTION

Newspapers (online or print) play an important role in keeping readers up with scientific developments and in alerting them to issues of personal, social, and economic importance. Like all journalistic accounts, science news reports tend to be episodic in nature, short, inclined towards headline-grabbing, and tend to feature sensational stories (Dunwoody, 2008; Stamm, Clark & Eblacas, 2000). Furthermore, little space is devoted to discussing the process of inquiry (Dunwoody, 2008). This factual coverage is problematic for some scientists and a source of tension between them and journalists (Dunwoody, 2008). Scientists often believe that this factual coverage does not provide an image of science as a knowledge production system and often relegates the scientific message and its relevance. On the other hand, journalists are aware that lay audiences may just be interested in the main facts, presented in understandable words and accompanied by a personal or dramatic story about a discovery (Madsen & West, 2003).

While there is dissonance between what scientists consider relevant in science and what is conveyed to readers, some journalistic formats give voice to scientists. Interviews to scientists, for example, provide an opportunity for scientists to clarify journalists' interventions, to redirect the conversation to aspects of scientific research or to persuade readers of the value of science.

Reading newspapers is often a solitary experience, through which the reader is informed about a certain topic, but not educated (Stocklmayer, 2013). When that information is about breakthroughs in science, extra care is necessary in the dissemination through written text, as, without interaction, the complexity of ideas and scientific jargon is not always easy to be understood by lay audiences. Conceptual metaphors play a key role in making the text more accessible, concrete, and in affecting readers' viewpoint. Some metaphors are coined as analogies, i.e., they are novel metaphors deliberately constructed to convey complex concepts, but many others are not used consciously by speakers. Due to its high frequency of use, they become conventionalized (conventional metaphors) and embedded in everyday language use (e.g., to construct a theory, to attack an idea, etc. (Lakoff & Johnson, 1980, p. 54)).

Metaphors are, therefore, more than aesthetic devices, they are a structuring element of thought (Lakoff & Johnson, 1980; Richard, 1936; Kövecses, 2010), i.e., metaphors are the organizing principles of concepts which structure what and "how people think and imagine in everyday life" (Gibbs, 1994, p.145). One evidence for the metaphorical nature of thought is the ubiquity of metaphorical expressions in everyday language.

The conceptual structure is organized according to a unidirectional cross-mapping between conceptual domains (from the source to the target or metaphorical domain). Basic physical experiences, i.e., interactions between human sensorimotor system with the surrounding environment, structure abstract concepts metaphorically (Lakoff & Johnson, 1980). Conceptual metaphors, therefore, play an important role in understanding because they are capable of attributing new meanings to abstract experiences which can only be fully comprehended through familiar entities and experiences (Lakoff & Johnson, 1980).

In Astronomy observations are mainly made of numbers, which are then converted into visual representations. This conversion entails the use of a set of rules for encoding the information, which is not transparent for the lay public and can lead to misinterpretations (e.g., it is not easy to discern 4D Spacetime universe) (Sandu & Cheung, 2018). Furthermore, as in any scientific area, explaining astronomical ideas requires the use of jargon, whose meaning is unknown by lay audiences. Despite these challenges for communication, astronomy often catches a wide spectrum of readers, in part because the extreme distances and times trigger readers' imagination. Furthermore, astronomy offers a conceptual framework for understanding the world, triggers public questioning, supports the reconceptualization of our representation of the universe and invites emotional involvement in topics like cosmology, exoplanets and the possibility of extraterrestrial life (Madsen & West, 2003). Hence, it is without surprise that metaphors are frequently employed in media, namely news reports (Madsen, 2003).

Focusing on astronomers' interviews to Portuguese newspapers, this study analyses the conceptual metaphors in these interviews, through the perspective of Conceptual Metaphor Theory, and discusses their potential use for science education.

METHODOLOGY

We identified 15 interviews to Portuguese astronomers found in three Portuguese daily newspapers and one in a weekly newspaper, from 2009 (the international year of Astronomy) until 2021. All were freely available online. These interviews have different foci, e.g., they focus on the life and work of the interviewed astronomer, the astronomer' contribution for a particular discovery or for the advance of astronomy, and astronomers' discussion on particular astronomical event. The analysis of the corpus is still running due its length. For this paper, we will present the metaphors found in the discourse of two Portuguese astronomers, leaders of research groups. The analysis of the astronomers' discourse was carried out on the original Portuguese data (not the corresponding English translation) and encompassed an identification of the conceptual metaphors, including analogies, which emerged in scientists' speech. We took an inductive approach following Cameron (2007) and followed similar steps to the ones in metaphor analysis employed by Niebert and Gropengiesser (2015). To identify the metaphors, we identified key words related to astronomical concepts in each astronomers' discourse, e.g., 'black hole', 'planet', 'star', 'astronomy', etc. We considered the construction (i.e., the immediate linguistic context) in which they occurred, e.g., existence of prepositions co-occurring with the lexical item which could shed light on image schemas, existence of quantifiers or other nouns (such as crest of waves, prison, etc.) which entered an 'X is Y' identification structure. Finally, if the "contextual meaning constrast[ed] with the basic meaning [of the located lexical items] but could be understood in comparison with it" (Pragglejaz Group, 2007, p. 3), the meaning of the lexical unit was considered to be metaphorical. Once this was done, we identified the function of the metaphors employed, having in consideration the context of their use. The metaphors are presented in capital letters, and in the format, TARGET IS SOURCE (Lakoff & Johnson, 1980).

FINDINGS

The analysis of the astronomers' discourses allows the identification of several conceptual metaphors, which evoke a network of concepts. Many of these metaphors are concerned with astronomical research and elicit metaphorical frames[6]. These frames are networks of concepts structured metaphorically. For instance, the strategy frame in the political arena is metaphorical, as it is structured via the military tactics and conflict frames (Brugman, Burgers & Steen, 2017). The metaphorical frame may contain, as its elements, linguistic metaphors but may also contain other lexical items which, not being metaphors themselves, are also part of the metaphorical frame. In this paper, we will present the linguistic metaphors only. The metaphors astronomers produce in this context, in which amusement of audience is also a factor (Madsen, 2003), convey, to a certain extent, somewhat simplified assumptions and expectations about the research world in which the astronomer interacts with and through the angle the astronomer selected to look at that research.

One topic emerging from the interviews related to research environment ~~such as~~ is funding which is verbalised through a metaphorical frame structured via the SURF frame. Examples of conceptual metaphors are: RESEARCH AREA IS THE SEA/WIND; THE RESEARCHER IS A SURFER; FUNDED RESEARCH IS GOOD SURFING, and MONEY IS STABILITY present in (1).

> (1)"We lack an autonomous funding agency independent from whoever is in government […] If we have **stability**, we will have far more possibilities of keeping on the **crest of the wave** in this area".

The source domain is the gestalt "force of nature", in this case the perception of balance in the presence of several natural agents (i.e., sea, wind) and the overcoming of adversity. Hence, natural agents (financial support) act, constrain and unfold the course of events (research). Furthermore, grounded in these metaphors are the context and environment in which surfing takes place. Surfing (research) is a promising pleasant experience with associated risks (concerning financial support) that surfers (astronomers) accept to take. Readers hold a network of concepts and embodiment experience on "force of nature" and can build a "storyworlds"

[6] For a general sense of frame, please see Fillmore (1982).

(i.e., the cognitive models created by the perception of the interlinked metaphors), which can touch them emotionally (Fuchs, 2015). This financial funding lens to present astronomical research was expected to some extent, since the cost of astronomical research is one of the highest in all the sciences (Abt, 2003).

Another metaphorical frame is structured via the RACE frame, in which competition and cooperation are elements of. Metaphors such as RESEARCH IS A RACE can be seen in (2).

(2)"[…] I began to participate in **this race**. But they are always team discoveries. The job is too big for one person only."

Research is also conceptualised metaphorically via the WAR frame, of which DISCOVERIES ARE TARGETS is an example. This frame which is related to the CONFLICT frame is supported by other elements which are not metaphorical such as 'scrutiny' and 'controversy'. A breakthrough in science is conceptualised metaphorically as movement ACTION IS SELF-PROPELLED. Example (3) illustrates these metaphors.

(3)We were at the beginning, each new planet was a **target** of big scrutiny by peers and, sometimes, of big controversy. Each discovery was a giant **step**.

Note that in examples (2) and (3), the use of 'giant' and 'big' is also metaphorical (BIG IS IMPORTANT/SIGNIFICANT). Importance is metaphorically expressed via size.

From another interview, readers become aware that creativity is also an aspect of scientific practice: via conceptual metaphors, astronomers can invent terminology to give a name to astronomical phenomena. That is the case of the term black hole, which emerged from the conceptual metaphor A BLACK HOLE IS A TINY PRISON. This conceptual metaphor is connected to other conceptual metaphors, namely A COMPLETELY COLLAPED STAR IS A PRISON; LIGHT/MATTER ARE SOLDIERS; ENCLOSED LIGHT/MATTER ARE SQUEEZED SOLDIERS, and articulated in a story (see example (4)). As explained in the interview, the local slang in India for a tiny prison was black hole, a dark cubicle where soldiers squeezed into and died. The model of a Black hole can be read narratively and enhance understanding of the events. The text from which the conceptual metaphors were identified is:

(4)"[…] a **completely collapsed star** was a phenomenon identical to a **tiny prison** in Calcutta, India, known as a **black hole** in local slang, where around 1750 a hundred English **soldiers** died when **squeezed** into this cubicle".

CONCLUSION

Findings suggest that conceptual metaphors are employed in science news, echoing other studies (e.g., Madsen, 2003). The few interviews analysed revealed that conceptual metaphors are employed to convey aspects of astronomical research. Hence, this format of science news can have a role in science education to support students' understanding aspects of astronomical research. However, teachers need to have in consideration that what is reported does not represent the complexity and diversity of the real astronomical research. Rather, it is a simplified version (as they need to catch lay audiences) on how the astronomer conceptualizes the lived experiences. These conceptual metaphors, in turn, support the building of narratives, which, once understood, are likely to become memorable (Fuchs, 2015).

While these interviews were not created to be used as resources in formal education, they may promote an understanding of aspects of astronomical research. The advantage of using scientists' interviews from newspapers is that the text is comprehensible by lay audiences, the aspects of scientific inquiry are presented through the voice of researchers, and hence encapsulate a diversity of feelings and dimensions related to science in the making. To take full advantage of these conceptual metaphors and of the frames they evoke in formal education, teachers need to become capable of identifying them. As Daane et al. (2018) mentioned, while teachers are often unaware of conceptual metaphors, engaging teachers with conventional metaphors allowed them to perceive their value in teaching abstract concepts. However, once they are identified, care is needed in using them in the classroom, as inappropriate matches will result in wrong inferences (Harrison & Treagust, 1993). In addition, metaphors need to be discussed explicitly within the astronomical context. For example, the metaphor BIG is SIGNIFICANT, referring to the amount of work of astronomers' teams, highlights the idea that in astronomy the data is noisy, sparse, and gathered by remote sensing technologies as the objects of study cannot be visited. Consequently, data interpretation is time consuming and high demanding (Madsen & West, 2003). Finally, it would be important to select interviews in which different aspects of astronomical research are conveyed, so that they can support students' building of a holistic vision of research (see e.g., Erduran & Dagher, 2014).

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SPACE-TEMPORAL RELATIONSHIPS IN SCIENCE LESSONS: BUILDING LONG-TERM LEARNING OPPORTUNITIES

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In this paper, we analysed classroom events to understand how students and their teacher construct space-time relationships in science lessons throughout the first three years of elementary school. The study is informed by ethnography in education and the analyses are based on Microethnography. The notion of chronotope guided a qualitative perspective of time. The results indicated that space-time connections, established by the participants, have become relevant resources in the history of the group. Such resources contextualised and guided the engagement in inquiry practices over time, which was intertwined with an increase in the level of the students' epistemic agency.

Keywords: Classroom Discourse, Inquiry-oriented learning, Elementary School

INTRODUCTION

Many researchers acknowledge the key role of the temporal dimension to educational processes (Mercier et al., 2005). Teachers and students use what is discussed and what happens in the classroom as a resource for learning over time (Mercer, 2008; Bloome et al., 2009).

Past and future events constitute the history of science lessons and are intertwined through the interactions between classroom participants (Kelly & Green, 2019). Science learning, in this perspective, takes place in discursive events, within the same event and throughout events at different time scales (Lemke, 2001; Kelly, 2021).

There are theoretical and methodological challenges to adopt temporal analysis in science education research (Mercer, 2008). For instance, it is essential to develop understandings of time as a theoretical category in the classroom discourse analysis (Molenaar, 2014). Moreover, there are methodological challenges of mapping temporal relationships in the learning process (Kelly, 2021). Theoretical constructs and methodological procedures are deeply integrated when it comes to analyse time and learning (Grigorenko, Beierle & Bloome, 2014).

To explore these issues, we analysed space-time relationships anchored by the notion of chronotope from Bakhtin (1981/1935). The author used the term “chronotope” to describe, in literature, how heroes move through time and space in a novel. Bloome and Katz (1997) proposed that this construct could be applied to the classroom everyday life, because, similarly to what occurs in novels, there is a cultural conception of how people move individually/collectively through time and space.

Based on these assumptions, we analysed three temporally distant events over three years in the same classroom. Despite the temporal distance between each of the events, we observed connections established by the science teacher and students, based on evocation of collective memories. A collective memory is a “narrative about past events publicly recognized by members of a collective and to which members respond” (Grigorenko et al., 2014, p. 65). This type of construct was important for our analysis, as it makes it possible to identify spaciotemporal relationships established by the participants throughout their daily history. By evoking collective memories, classroom members jointly assume responsibility for events in the past related to the topics being studied in the present (Bloome et al., 2009).

Connections established by the participants themselves offer an interesting methodological tool for researchers interested in analysing science lessons over time (e.g., Grigorenko et al., 2014). In this study we investigated: How did a class discursively construct spatiotemporal relationships over the first years of Elementary School in science lessons? How did these relationships foster the construction of science learning opportunities in this classroom?

METHOD

The study took place in a public lottery school in a big city in Brazil. Our research team conducted participant observation (Spradley, 1980) in science lessons with records in field notes and video, over the first three first years of elementary school. Complementary data sources included students' artefacts and interviews with participants. Throughout the three years (2012-2014), students participated in scientific inquiry units (e.g., Pedaste et al., 2015; NRC, 2012) (Table 1).

Table 1 – Inquiry Units over the first three years of elementary school.

Year	Semester	Nº classes	Subject matter
2012	1º	13	Plant growth and diversity
	2º	9	The biology of the stick bug
2013	1º	21	The biology of the cricket
	2º	10	Mixtures and characteristics of chemical substances
2014	1º	23	Animal behaviour: parental care
	2º	21	Animal behaviour: reproduction

The analyses involved macroscopic and microscopic transcriptions, with an increasing level of detail (Castanheira et al., 2001). We selected events (Bloome et al., 2005) in which the participants themselves established space-time relationships with the evocation of collective memories (Bloome et al., 2009) over the three years. Based on macroscopic analysis, we selected events from the "Stick Bug" Unit, which happened between October and November 2012 comprising nine lessons. The activities involved taking care of three stick bugs, and making observations about their behaviour, morphology, growth, sexual dimorphism, camouflage (Figure 1).

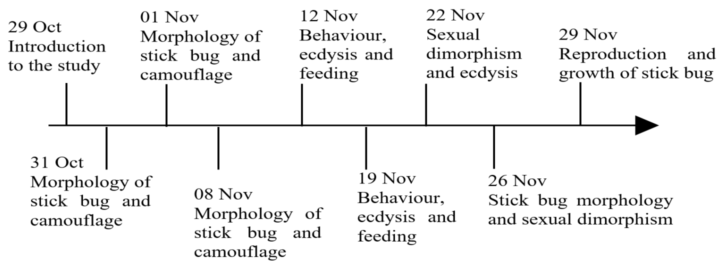

Figure 1 – Time line of stick bug unit.

Events from this unit were chosen as a telling case (Mitchell, 1984) because they make more visible how the group constructed space-time relationships. This was the first time the teacher was the main responsible for planning and conducting inquiry activities. Thus, we chose a set of events in this Unit as anchor events (Bloome et al., 2009; Castanheira et al., 2001), as they provide us a window into the group's everyday life chronotopes. The way the participants moved through time-space was constructed through the interactions experienced in this classroom. Roles, obligations, rules and expectations for participation in classroom activities have been renegotiated. After the telling case was delimited, we identified collective memories that the participants evoked related to the stick bug Unit in different events of the 2nd and 3rd year. In this paper, we focus on space-temporal relationships between events from the stick bug's unit and crickets' unit. In 2nd grade, students discussed feeding and oviposition, establishing relationships between these two insects. Moreover, participants evoked collective memories experienced during the stick bug lessons in order to solve problems.

The notion of chronotope (Bakhtin, 1981) oriented our analysis of social roles, expectations, norms of engagement and the positioning of group participants in certain daily practices in the classroom. We characterised chronotopes performed by the participants, considering: i) the verbal tense of the talk (past, present, future), ii) the main agent of the actions (me, you, us, she/he); and iii) instructional contexts (stick bug's or cricket's unit, or overlapping of both).

RESULTS

In the second grade, five months after the Stick bug Unit ended, the class had started a new unit on the Biology of Crickets. In the tenth class (April 10), the children were discussing the teacher's question: "How does the cricket poop?". In this event, we identified participants' collective memories regarding the stick bug. We organised this event in three interactional units (Charts 1, 2 and 3), according to directions of participants' conversations[7].

Chart 1 – Interactional Unity 1

Line	Speaker	Message unity	TIME			AGENT				CONTEXT	FRAMES
			Past	Present	Future	Me	You	Us	She/he		
01	Teacher	In stick bug↓	■					■		Stick bug	
03		We observed I	■					■			

[7] Symbols used in the chart: ↑ (rising intonation); ↓ (falling intonation); vowel+ (long vowel); *Non-verbal behaviour in italics;* I (pause), ▲ (increased volume).

04		The food I I I	■					■			
05		And we saw the poop I	■					■			
06		Right at the beginning I I I	■					■			
07		Someone saw the poop I	■				■			Crickets	
08		Inside the terrarium ↑	■				■				
09	**Vinícius**	I+	●			●				**Crickets**	
10	**Teacher**	Ô+ Mariana I	■				■			**Crickets**	
11		Tell us I	■				■				
12		What did you observe I	■				■				
13	**Mariana**	I saw ↓	●			●				**Crickets**	
14		When I got there ↓	●			●					
15		To observe ↓	●			●					
16		I saw ↓	●			●					
17		A lot ↓	●			●					
18		Of little poops ↓	●			●					
19		On the floor↓	●			●					

In the first interactional unit of this event, the teacher used the expression "in the stick bug" (L01) to refer to the space-time in which the class had shared knowledge of the biology of this insect in the 1st year. The collective narrative about the observations of the past (L03-06) was marked by the use of the first-person plural and verbs in the past (observed, saw). Still referring to the past, the teacher established relationships (L07-08) between the stick bug poop and the cricket poop. The children recognized the proposal and Mariana reported her observation in the first person singular and using verbs in the past (L13-19).

Chart 2 – Interactional Unity 2.

Line	Speaker	Message unity	TIME			AGENT				CONTEXT	FRAMES
			Past	Present	Future	Me	You	Us	She/he		
45	**Teacher**	What is the difference ▲		■			■			**Stick bug x Crickets**	
46		Between the stick bug's poop ▲		■			■				
47		And the crickets's poop▲↑		■			■				
48	**Maurício**	It is because-									
49	**Teacher**	Go there on the board for me▲		■			■			**Stick bug x Crickets**	
50		Put the difference ▲		■			■				
51	**Nara**	I know the difference I		●		●				**Stick bug x Crickets**	

52		Observe if it has poop ▲		■			■			**Crickets**	
53	**Teacher**	We observed a lo+t ǀ	■					■		**Stick bug**	
54		The stick bug’s poop ǀǀǀ	■					■			
55		Why is that happening ↑		■					■		
56		With that food ǀ		■					■		
57		That he is eating↑ ǀǀǀ		■					■		
58		Teacher ▲▲		●					●		
59		It is because ▲▲		●					●		
60		The crickets’ poop ▲▲		●					●		
61	**Maurício**	Is+▲▲		●					●	**Crickets**	
62		Is+▲▲		●					●		
63		Small▲▲		●					●		
64		And+▲▲		●					●		
65	**Mariana**	Is flat ▲▲		●					●		
66	**Maurício**	It is ǀ		●					●		
67		Draw ▲ *dividing the board in half and writing down: the stick bug’s poop*		■			■			**Stick bug x Crickets**	
68		Stick bug’s bug ▲		■			■				
69	**Teacher**	That we observed a lot ▲	■					■		**Stick bug**	
70		And crickets’ poop ▲ *writing on the other side of the board: crickets’ poop*		■			■			**Crickets**	
71		Or grasshopper ▲		■			■				

In the second unit, the teacher continued to evoke collective memories. The relationship she proposed was recognized by Maurício, who started to interact with her and presented the differences between the cricket poop and the stick bug poop. The teacher asked him to observe the cricket's poop and to represent these differences by drawing on the board (L49-50). While Maurício was watching the crickets, Karina pointed out that the group “observed a lo+t ǀ the stick bug’s poop” (L53-54), evoking the past and including the peers in the conversation. After observing the crickets, Maurício reported back to the teacher, with Mariana's collaboration, pointing out that the cricket's poop is “small and flat” (L59-65). Repeating the orientation for him to draw, the teacher went to the board, dividing it into two parts - poop from the “stick bug” and poop from the “cricket/grasshopper” (L74-78). Again, Karina used verbs in the past to continue emphasising that the group “observed the stick bug poop a lot” (L68-69).

Chart 3 – Interactional Unity 3.

Line	Speaker	Message unity	TIME Past	TIME Present	TIME Future	AGENT Me	AGENT You	AGENT Us	AGENT She/he	CONTEXT	FRAMES
94	Teacher	Stick bug ǀ	■					■		Stick bug	
95		Stick bug's poop ǀ	■					■			
96		We mistook ǀ	■					■			
97		Stick bug's poop ǀ	■					■			
98		With what↑	■					■			
99	Breno	With their eggs ▲▲	●					●			
100	Teacher	With eg-↑	■					■			
101	Students	Eggs *together*	●					●			
102	Teacher	Why↑	■					■			
103	Vinicius	Because the eggs ǀ	●					●			
104		Was black ǀ	●					●			
105	Breno	Because the eggs ǀ	●					●			
106		Are very similar ǀ	●					●			
107	Teacher	Yes ǀ		■					■	Stick bug x Crickets	
108		And if there is an egg ǀ		■					■		
109		in that thing too ↑		■					■		
110		Go look there ǀ		■				■			

In the third interaction unit, the teacher (re)constructed the group's collective memories associated with another moment in the cycle of stick bug activities, when children confused eggs with poop. Again, her talk was situated in the past and included the entire group in the interaction (L94-98). Breno and Vinícius acknowledged the proposal and presented their responses, also located in the past, pointing out the similarities between eggs and the poop of the stick bug (L99-106). Agreeing with the students' response, the teacher proposed another relationship by supposing that, similarly to what they observed with the stick bug, there would be eggs inside the crickets' aquarium (L107-110). Chart 4 summarizes these results.

Chart 4 – Space-temporal relationships between the events stick bug cycle and cricket's cycle.

InteractionalUnit	Lines	TIME Past	TIME Present	TIME Future	AGENT Me	AGENT You	AGENT Us	AGENT She/he	CONTEXT Stick bug Unit	CONTEXT Stick bug X Crickets	CONTEXT Crickets Unit
1	01-06	X					X		X		

	07-08	X				X					X
	09	X			X						X
	10-12	X				X					X
	13-19	X			X						X
	45-50		X			X				X	
	51		X		X					X	
	52		X			X					X
	53-54	X					X		X		
2	55-66		X					X			X
	67-68		X			X				X	
	69	X					X			X	
	70-71		X			X				X	
	94-106	X					X		X		
3	107-109		X					X		X	
	110		X			X				X	

Chart 4 evidences the analysis indicated how temporal flow (past «-» present) was intertwined with changes in the main agent of participants' actions. The stick bug's unit was associated with "us" (L01-06, 53-54, 94-106, in green in Chart 2), during the crickets' unit.

When proposing relationships between both units, the teacher considered memories of the stick insect as shared by the group. Students' engagement and the main agent of the actions, reiterated throughout the event, supported her assumption. The changes in agents ("me", "we","you" and "she/he") indicate that the teacher was not the main agent of the actions, as observed in 1st grade interactions. The group considered the past narrative as collective experience, and these memories guided children's engagement in knowledge-building practices.

The group was starting discussions about crickets' feeding and oviposition habits. The memories about investigations with the stick bugs about feeding and oviposition were used as an interpretive framework for studying a new insect. Thus, space-time relationships contextualised and guided participation in more sophisticated inquiry practices over time.

DISCUSSION AND CONCLUSIONS

Our results reiterate the role of temporal connections as an important resource for science learning. In this paper, we contribute to science education field by using an interpretative framework of time as chronotope. Thus, we provided analyses that considered a more qualitative dimension of time. People experience time in different ways and connections established in the history of a classroom can be useful for understanding their own ways of doing science.

Regarding the scholarly implications of the study, it contributes to current research that indicates the way students socially constructed temporal connections for learning and how their epistemic agency in science lessons was fostered through these connections. The analysis evidenced a process of change of the main agent of the actions: from the teacher (1st grade) to the collective (2nd – 3rd grade) over time. Redistributing epistemic agency (Ko & Krist, 2019) is an important goal for science education in the 21st century. Our results indicate how this process was intertwined with the construction of time in this classroom. Moreover, it was a continuous endeavour that involved vertical coordination of curricula, across years over schooling, as suggested by Kelly (2013).

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Part 8 / Strand 8

Scientific Literacy and Socio-scientific Issues

Editors: *Antti Laherto & Eliza Rybska*

Part 8. Scientific Literacy and Socio-scientific Issues

Teaching about scientific literacy, science and citizenship education, science and media education, information literacy, informal reasoning and critical thinking, decision making, debates on socio-scientific issues (SSI), discourse communities, social dimension of science and techno-scientific practices, public engagement in science, schools', students' and teachers' engagement in socio-scientific issues.

Strand 8. Scientific Literacy and Socio-scientific Issues

Strand Chairs: *Antti Laherto & Eliza Rybska*

Introduction

Since the previous ESERA conference in Bologna in 2019, the world has changed in ways that nobody could expect. The risen crises have had and continue to have a deep influence on societies and educational systems and approaches. In the field of science education, probably the most immediate and apparent consequences apply to research and practice on our strand, "Scientific Literacy and Socio-Scientific Issues".

For years, the most central and wide-ranging socio-scientific issue for science classrooms has been the ecological crises caused by climate change. Nothing has rendered the climate emergency less acute now – on the contrary, the latest report by the Intergovernmental Panel on Climate Change (IPCC) highlighted that the phase of global warming is even faster than anticipated and the need for action more urgent than ever. Yet, in the spring of 2020, another concern took over the public discourse and schools: the pandemic caused by the novel coronavirus. Since then, the issues related to restricting the spreading of the virus, the clinical picture of the disease caused by the virus, and the pros and cons of the vaccine have constituted socio-scientific issues that no citizen can avoid facing. Aspects of scientific understanding, scientific argumentation and scientific literacy play substantial roles in these discourses, making them highly relevant to science education.

In February 2022, the pandemic stepped aside from the headlines in Europe. Russia's shocking, unjustified and brutal attack on Ukraine has caused immense suffering and anxiety. It also impacts the scope and way of thinking about socio-scientific issues. Some questions came back to us with a more significant impact, while others are new. Socio-scientific issues directly related to science education include, for example, the need to break Europe's dependency on Russian fossil fuels and find new solutions to energy production.

All these grand challenges Europe is facing in the 2020s give rise to considerations in science classrooms. What is green, responsible and sustainable energy? What does it mean to be a responsible citizen? Why are anti-vaccination movements more vigorous when we observe so many people in hospitals? Can the Anthropocene serve as a framework for science education curricula? The spectrum of questions pertaining to socio-scientific problems seems to be broadening. Addressing them in education calls for interdisciplinary approaches and explicit consideration of moral and ethical questions and values.

The twelve papers from Strand 8 in this e-proceedings capture the diversity of topics and research approaches related to socio-scientific issues. Both new and already established orientations are manifested in the following papers.

Giulia Tasquier and colleagues organised a symposium in ESERA 2021 presenting several EU-funded projects employing the concept of *open schooling* to facilitate an educational change in these challenging times. After this symposium paper, the following consists of three papers addressing science teachers' needs to support reasoning in complex socio-scientific issues. To that end, *Tom Konrad Anton* and *Christiane S. Reiners* focus on evidence-based reasoning of socio-scientific issues, *Marcus Kohnen* and *David Rott* on critical thinking, and *Jose Manuel Hierrezuelo-Osorio* and *Antonio Joaquín Franco-Mariscal* on students' emotions about socio-scientific issues. Studies on school interventions addressing socio-scientific approaches and decision-making are reported by *Miki Sakamoto* and colleagues, and *Maria Tsapali* and *Michelle Ellefson*. *Larissa Nascimento* and colleagues studied the development of biodiversity values among pre-service science teachers. *Stephanie Teeter* and *Jason Painter* explored the potential of a scientist-teacher partnership, and *Mengyao Li* examined the connection between science capital and science career intentions. Different visual methods of instruction were studied by *António Almeida* and *Rafael Sumozas,* as well as *Luiz Augusto Rezende-Filho* and colleagues. In the final two papers, *Mientje Lüsse* and colleagues report a study on a citizen science project, while *Eleonora Barelli* and *Olivia Levrini* explore the power of agent-based simulations in building analogies. We thank all authors for these contributions!

OPEN SCHOOLING IN THE (POST-)PANDEMIC WORLD: SYNTHESIS AND SYNERGIES FROM CURRENT EU-PROJECTS

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The pace of change in society, from technological innovation to global interconnectedness, has been fundamentally altering the way people live, work and learn. The increasing level of complex societal challenges of the 21st century renders urgent the need to integrate the knowledge and expertise of different societal actors, and to develop meaningful, inclusive and sustainable ways of connecting schools, universities, enterprises, civil society, governments and local communities using more innovative and open methodologies. In this scenery, from 2015, the open schooling idea started to enter the EU political horizon as a re-orientation of the role of the school and. Within the "Science with and for Society" pillar of the Horizon2020 EU Programme, the EC called for the development of new approaches to science teaching and learning, based on an open schooling approach. This symposium was orchestrated to put together different perspectives and approaches coming from four Horizon2020 projects that are developing open schooling ideas for re-imagining how school science can be rethought for steering the change in these challenging times.

Keywords: Open Schooling, Scientific Literacy, Science with and for Society

INTRODUCTION

Nowadays, even more than in earlier periods, the educational world is facing the urgency of formidable challenges (UNESCO, 2020). Indeed, in front of the increasing level of complex challenges facing society, like the pandemic and/or climate crisis, it is moving for finding innovative strategies to prepare individuals and communities to act and react to those societal changes and to be actively responsive in knowledge-based decision-making processes. Already in 2015, two reports, one from UNESCO and the other one from the EC, started to warn that complex changes and challenges in the today's world require to better understand science and technology in order to participate in knowledge-based decision-making. In particular, the EC (2015) report stated that, in order to address this issue, ways of expanding science education beyond traditional school models must be created and explored. Contextually, the report introduced for the first time the concept of 'open schooling', which is calling for a re-orientation of the role of schools. Particularly, open schooling implies that schools cooperate with other organisations to achieve community well-being and change the way science comes into the classroom. 'Openness' refers to the idea that schools have to become flexible structures, open to society and able to make a difference in the world (EU, 2015). The open schooling idea started to enter the EU political horizon related to the re-orienting the role of the school and, within the "Science with and for Society" pillar of the Horizon2020 EU Programme (WP2016-2017), the EC called for the development of new approaches to science teaching and learning, based on an open schooling approach, in which science learning processes are strongly linked to the students' participation in real-life science challenges in society, authentic research and innovation circles of inquiry.

Many open schooling practices emerging in the last years demonstrated that open schooling could have a lot of potential by representing a place where schools (in cooperation with other stakeholders) become agents of social change and community wellbeing. It offers a promising, albeit challenging, solution that requires a research-based, practice-oriented coordination to foster and support the necessary transformational action (Penuel, 2017). What are the main achievements reached out in the last years of EU funded projects on open schooling? What are the main impacts at an Institutional level? How can open schooling contribute to reimagining school science in today's world?

Within this framework, this symposium was orchestrated to put together perspectives and approaches coming from four Horizon2020 projects (all funded and started in 2019) implementing open schooling and discuss how they are re-imagining school science in answering to these challenging times.

SEAS project

To tackle the combined and interlinked challenges of human-made climate change, biodiversity loss and unsustainable consumption, society faces the need for rapid and deliberate transformation on a scale never before attempted (IPBES 2019). Education has a critical role in the struggles for a transition to an equitable and sustainable future. For science education, the challenge is to foster citizens with scientific literacies for applying and adapting scientific knowledge and methods to real-life challenges, often socio-scientfic issues, for critical and informed decision making and action for change (European Union 2015, Hodson 2003, Sadler et.al 2017). What will be important is to create and explore ways of expanding science education beyond traditional schooling models, which shall provide young and adult learners opportunities to engage in authentic science inquiry across formal, non-formal, and informal settings. It is also a matter of reflecting on the usefulness and relevance of science, thereby connecting science to beliefs, values and interests in the fostering of capacities for transformative action. Open schooling initiatives, where schools in cooperation with other stakeholders become agents of social change and community well-being, offer a promising but also challenging solution.

Throughout the process of the open-schooling approach, the H2020 project *Science Education for Action and Engagement towards Sustainability* (SEAS; https://www.seas.uio.no) project is experimenting with and developing tools for science education that explore solutions to sustainability issues, in collaboration with schools and actors in the local community. We consider tools as resources that influence practice and the ability of purpose-driven practice to engage with pre-determined ambitions. There are different types of tools, including textual objects (e.g., templates and instructions), methods (e.g., for inquiry) and tools for supporting collaboration. Tools both construe and enable practices as cultural resources serving to coordinate actions in specific ways and mediate the way collaborating partners experience and make sense of their objects (e.g., teaching for sustainability) (Jornet & Jahreie 2013).

The ambition is not only to increase scientific literacy among students, but for all actors to experiment with co-creating solutions for sustainability through how we engage in the process. Rather than treating people as "objects to be changed" in the name of sustainability, transformative change requires students, as well as teachers and people in the local community, to experience and understand how they can be agents of change. Our research question is: What role does tools take in efforts towards transformative change in the SEAS open schooling local networks?

To ensure that the SEAS' tools and collaborative methods continue serving the participants' and researchers' emerging needs throughout the challenges' implementation, a range of data sources are assessed by the local networks, including questionnaires, interviews, and ethnographic observations of learning trajectories across contexts. These assessments lead to context specific knowledge that are used for further development of the local networks' practices, tools, and for cross-network analysis and the development of models of scientific literacies, teaching and learning, and open schooling cooperation.

A key didactical tool, LORET, represents a methodology for co-creating locally relevant themes and curricula for open schooling, for providing shared reference points for pathways of emerging learning trajectories, and for facilitating and expanding collaboration with partners outside school. It offers teacher teams a step-by-step procedure to explore and plan teaching that is engaging with and aims at developing and responding to local sustainability challenges.

cCHALLENGE is a reflexive and experimental process for transformative learning, focusing on the relationship between individual change, collective change and system change. The method is based on the heuristic the Three Sphere of Transformation (O'Brien & Sygna, 2013), and invites students and teachers to explore how change happens through changing a habit for 30 days. The change experiments allow them to notice their influence on others by sharing their stories, and to explore their own role in changing unsustainable systems and cultures.

LORET is inviting students, teachers, researchers and communities to explore the status of objects of concern and inquiry in the process of finding solutions. In this sense it is opening practices and cultures to their entanglement and non-closure. By pointing out the surplus of the object of inquiry the tool can be seen as to have a potential for transformative change and agency, and open up beyond the immediate objects and practices without implying a transformational state at which process is to arrive (no harmonizing synthesis).

cCHALLENGE is inviting students to break a pattern and explore when change is easy and when it is difficult, thus getting a glimpse of the systemic and cultural causes of problems. The students are practicing what they learn in their own lives, questioning what is, challenging the status quo, willing to look inward and act outward. The tool opens for insights into how participants construe the challenge they are confronting, and, for the teacher, students' needs for further support.

These aspects of the tools discussed are tightly connected to key aspects of open schooling: The need for enabling cooperation and negotiation of diverse perspectives and knowledge domains across institutions and settings, the need for teachers to develop interdisciplinary curriculum plans that support students learning trajectories and their use of knowledge for action, and for students to be able to engage in inquiry in real-life problems that tend to be ill-defined and complex.

SEAS findings suggest that tools can have a potential for transformative change by opening for inquiry beyond the immediate object and by opening practices and cultures to their entanglement and non-closure, and for students to break a pattern and explore and link what they were doing in their own life to societal structures, culture and deeper dimensions of change such as values and worldviews.

PHERECLOS project

The establishment of Local Education Clusters (LECs) or micro networks is the core of the Horizon 2020 project *Partnerships for Pathways to Higher Education and Science Engagement in Regional Clusters* (PHERECLOS; https://www.phereclos.eu) to explore permeable systems between formal and non-formal education and to foster Open Schooling (OS) culture. Within the project LECs are established in six pilot regions and diverse educational ecosystems around Europe and beyond. This is based on experiences from almost 20 years of Children's University programs that engagement and understanding of science, arts and humanities is a key to social inclusion and the acquisition of fundamental competencies – often described as the 21st century skills. Giving science a face through direct contact – even online, enabling reflected perspectives and also addressing the unknown as prerequisite of scientific research shall foster the inherent critical mind and the ability to assess information of children and young people (Gary & Dworsky, 2013).

PHERECLOS highlights the learnings from the piloting work in the LECs and aims to use these experiences to catalyse access to higher education, particularly for STEAM-related careers, providing benefits in a wider societal context. Young people should accumulate important experiences to raise their Science Capital (Godec, King &Archer, 2017) as key to active citizenship and critical thinking from the earliest age on.

A main challenge of PHERECLOS lies in the heterogeneous approaches to OS, STEAM Engagement and Science Capital realised in various LECs. All LECs excel through specific aims, partner institutions, and planned activities. To compare them with respect to structure and implementation processes, it is necessary to establish a shared vision how to implement educational innovations in existing structures. This is a prerequisite for deriving success factors and challenges not only for the specific LEC programs but also for OS initiatives in general. Knowledge and tools from Implementation Science (e.g. the Hexagon Tool, Implementation Plan) were used to address this demand. Templates for documenting the LECs' structure and activities in a uniform way were developed.

The main objective of the current study was to conduct a formative evaluation of the implementation of the LECs. We were mainly interested in the following questions regarding the implementation of Open Schooling (OS):

- How is the OS approach applied in the LECs? How can these approaches be described on the basis of the Hexagon Tool (Blase, Kiser & Van Dyke, 2013) at the beginning of the project?
- How do the OS approaches prove themselves in practice? What are lessons learned after one year of implementation?
- How can the Hexagon Tool be used for project reflection and steering?

For answering these research questions, LEC Templates (completed by the LECs in May-September 2020) were developed based on the Hexagon Tool, consisting of three parts: A template for the *general LEC description*. This template collects information about the aims, organizations, and activities of the LECs. One focus lies in connecting the specific aims of the LEC to the overall aims of PHERECLOS. The second template assesses the *innovation indicators*. These specify the extent to which the program demonstrates evidence, supports for implementation, and usability across a range of contexts. With the third template, *system indicators*, i.e., the extent to which a program matches the implementing site, are assessed.

Furthermore, an implementation checklist was developed to keep an overview of the implementation process and the relevant indicators, which should be filled in every half year. Similar to the templates this checklist is completed by the LEC leads: It is again based on the Hexagon tool, but in addition, implementation fidelity is also recorded, as well as successes, challenges and support needs. The results of the checklist analysis are available to the PHERECLOS consortium for discussion. They are intended to stimulate the reflection process and to identify support needs and possibilities to ensure the best outcomes of the LECs.

For answering our research questions, document analyses were carried out (templates), the checklists with closed and open questions were evaluated at three different points in time and related to another.

The results showed that the LEC templates are a useful tool to describe the various OS approaches and support the LEC's work plan design. The checklist results pinpointed topics, which could be helpful for further development of the LECs. It became clear during the second survey that the different system indicators, in contrast to the project start, are described very well. The innovation indicators provided a very good description of innovation in the second survey, but evidence for the effectiveness of the LECs related to OS, STEAM Engagement and Science Capital was still lacking. The second survey showed that implementation teams were established with stakeholders from different organisations and different perspectives. However, it was still open for some LECs how to establish and maintain coordination and communication and how to measure outcomes. These topics will be addressed in workshops and through individual consultations by our implementation experts that are part of the PHERECLOS consortium.

All in all, it can be said that the developed templates –based on knowledge from Implementation Science- have proven their worth in describing the approaches of the LECs and that the

Checklist seems to be a good instrument for the further development and steering of the LECs. Thus, Implementation Science knowledge and tools can be helpful in supporting successful implementation of OS projects.

OSHub project

The pace of change in society - from technological innovation to global interconnectedness - has been fundamentally altering the way people live, work and learn. Moreover, the societal challenges of the 21st century render urgent the need to integrate the knowledge and expertise of different societal actors, and to develop meaningful, inclusive and sustainable ways of connecting schools, universities, enterprises, civil society, governments and local communities using more innovative and open methodologies. The *Open Science Hub* (OSHub; https://opensciencehub.net) Network, a consortium of nine European partners funded by Horizon2020 EU Science & Innovation program, supports schools and local stakeholders to use research and innovation as a tool to tackle local relevant challenges and contribute to sustainable community development. Particularly, OSHubs support schools and local stakeholders to use research and innovation as a tool to tackle local relevant challenges and contribute to sustainable community development, by engaging in real-life projects that meet societal needs. Importantly, OSHubs are being established in communities that traditionally do not engage with research and innovation due to various barriers - geographical location, socio-economic status, or ethnic minority group background.

After 10 months since the beginning of the project, all local teams have started their OSHubs, as can be seen in the OSHub.Network website - under the respective Local OSHubs pages. Most particularly, OSHubs have partnered with local schools (Partner Schools section) as well as relevant community stakeholders (Local Management Board section). The Management Board consists of a group of representatives from different local stakeholder groups (schools, families, research institutes, enterprises, industry, civil and wider society) that will be involved in all key processes and decisions of the local OSHubs. In addition, OSHubs have identified preliminary challenges (Challenge and Mission section) and defined initial ideas for the open schooling projects that are being co-created in collaboration between the local OSHub teams, schools and local stakeholders. As can be seen in the website, the institutions that belong to the OSHub Management Board, the identified challenges and the open schooling projects in each OSHub are quite diverse, reflecting the different local ecosystems, but also the different nature of the OSHub host institutions (ranging from universities, to SMEs, cultural, scientific and educational institutions and municipalities), each of them with their institutional assets and networks.

In the long run, we envision OSHubs as education brokers that support schools incorporating open schooling in their daily life practices, vision and organizational structure, leading to sustainable quality of education in unison with their needs, context and local communities. In order for this to happen, it is pivotal to define shared goals with schools, aligned with their needs and priorities. Indeed, a clear observation from the last months of the pandemic, was that the OSHubs that were responding to the actual needs of schools, were the ones less affected professionally by the effects of the pandemic, and that in some cases increased their activity. As such, although, due to the pandemic, the following months are surrounded by uncertainty, we believe that schools will, unfortunately, need more support from external partners, and as such it will be a relevant time period to test the OSHub model in each location.

PULCHRA project

The Horizon2020 project *Science in the City: Building Participatory Urban Learning Community Hubs through Research and Innovation* (PULCHRA; https://pulchra-schools.eu) explores the open schooling concept in the theme "Cities as urban ecosystems" in view of creating new partnerships in local communities to foster science education for all citizens. Schools, in cooperation with other stakeholders become agent of community well-being, taken that the theme explored encompasses the natural environment, the built environment and the socio-economic environment in cities.

The overarching aim of PULCHRA project is to facilitate support actions that engage learners in meaningful real-life problem-solving situations starting as of the beginning of the second year of the project and continuing during the second and third years, within education, workplace and other learning environments. The target groups are mainly students in the age range from 12 to 18 years old, i.e., the next generation of science literate citizens, and secondary citizens, including students' parents, interested in science events. Teachers are a critical part of the Science Teams as developed within the PULCHRA project, in particular with respect to motivating students and coordinating projects. The project has given weight to engage teachers and provide them the required scientific and technical support.

An innovative part of the PULCHRA project is that participatory and activating challenges are rolled out as City Challenges supporting partnerships in local communities (schools, agents of formal and non-formal education, enterprises, industry, local administrations, NGOs, civic groups, etc.). City Challenges are supported by the City Challenges Platform acting as a hub for open schooling through the interaction among stakeholders, the communication of the schools' projects, the provision of educational material, the facilitation of twinnings and mentorships, etc.

The PULCHRA project has already demonstrated the direct links between sciences and the understanding of cities as urban ecosystems. Young students realize their potential to actively participate and contribute to science. Based upon the own experience of active participation, the students learn how science works and built the self-confidence of being able to become a scientist, even if this notion is not the norm in the own social stratum.

In the 6th month of the implementation of the PULCHRA project, the vast majority of partner countries-imposed restriction measures – also with respect to schools' operation and activities – due to the pandemic. PULCHRA had to readjust its work program, adjust its activities (Workshops, open meetings with the stakeholders, etc.) to virtual meetings and events and develop contingency plans in close collaboration with the European Commission.

At present, all partners have deployed their activities, the project has been media launched at the European and national levels, the educational material has been developed, and most importantly a network of 52 schools has been developed. The signs as to the potential of the project are positive, yet the assessment on the compliance of the project to its objectives is to be done at the conclusion of its 2nd year of operation. Valuable conclusions have resulted in terms of the capacity of students to undertake science challenges linked to the urban environment, the importance of open schooling and the potential of schools to adapt to unpredicted situations such as the pandemic while at the same time promote the project.

An obvious finding of the PULCHRA project is the potential of open schooling for science education. Despite the varying educational systems of the member States which participate in the project, it was possible to develop common grounds for science education and develop a solid network able to exchange best practices and cooperate towards innovation (EC, 2019).

In addition, the architecture of the project namely to form Science Teams in the schools, to develop City Challenges in six themes, to activate the Science Reporters for the communication of the project to the local communities and the stakeholders and to develop the City Challenges Platform as the "meeting point" of all school projects as well as of the stakeholders with the schools has been proven successful.

Corrective measures need to be applied so as the project to take note of the variations in the educational systems of European countries as far as open schooling is concerned, as well as to comply with the overloaded school programs. Furthermore, the project needs to organize its replication model in view of its expansion to other schools and/or countries.

CONCLUSIONS AND OPEN ISSUES

The four presented projects showcased four complex different point of departures, pathways and approaches in which each project address the gap between science and society and how each of them positioned for making science education more responsive to changes in society.

Despite the profound differences, the projects still presented many synergies, like the idea of co-developing scientific knowledge together with different stakeholders as well as placing the learning process within a democratic dialogue, capable of fostering transformative engagement. In this sense, the presentation of the four point out not only the need of a multidimensional interaction among different stakeholders but also toward a strong re-definition of perspectives. Beyond these needs, all the projects highlighted, from their particular perspectives, that we really need to focus on beginning to closely assess opportunities for improving schools and the education system; we need open-mindedness, social responsibility and a collective power for imagining and designing spaces to stimulate the intelligence and curiosity of girls and boys within the context of school science.

Open schooling offers unequalled opportunities for looking for boundary crossing opportunities (inside, outside, inside-out, outside-in) and triggering deep cultural transformation in bridging school science and society.

To what extent we can dive into transformation? We wish to conclude by taking into serious account a provocative suggestion made by the discussant of this symposium "*Daring to be disruptive, to go against what is expected or considered 'normal' – toward transition pathways*".

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ON THE WAY TO EVIDENCE-BASED REASONING OF SOCIOSCIENTIFIC ISSUES

IN SCIENCE TEACHER EDUCATION

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A central implication of scientific literacy is the ability of students to participate in discourses and decision-making processes concerning societal challenges, such as climate change, on basis of their acquired scientific knowledge. In order to provide them with the corresponding competences it is necessary that teachers themselves are enabled to participate in matters of social importance and this entails acquiring corresponding subject-matter knowledge as well as the ability to evaluate varies sources of data and information. The topic 'limit values of pollutants in the air and their implications' is one possibility to focus on subject-matter knowledge for the development of social challenges. A preliminary study has revealed that preservice chemistry teachers not only lack appropriate knowledge but furthermore have difficulties in dealing with data and information sources to assess societal challenges raised by pollutants in the air. To address these deficiencies a course was designed which aims at knowledge acquisition and possibilities to put this into practice. Within the framework of knowledge acquisition, students were instructed in subject-matter knowledge and limit value knowledge as well as how to deal with data and information sources.

A piloted open questionnaire in a pre-post design and reflection questions were used to assess the outcome of the course. Fifteen preservice chemistry teachers took part in this study, which was carried out as an online course due to the pandemic. The results show that the deficiencies of the necessary content knowledge as well as the handling of data and information sources could be reduced. In a next step, the results will be validated with problem centred interviews and with regard to the dimension of action orientation preservice chemistry teachers' abilities to transform the societal challenges and their implications into teaching practice will be considered.

Keywords: Initial Teacher Education (Pre service), Scientific Literacy, Socioscientific Issues

INTRODUCTION

The Smart Chemistry Teachers Cologne (SChemTeC) project, which was funded by the City of Cologne as part of SmartCity Cologne GO, aimed to guide preservice chemistry teachers to acquire subject-specific knowledge about sustainable, responsible and smart design of the city of Cologne and to transform it into teaching practice. A smart city needs people who are able to shape their living space in a well-founded way, but who are also capable of developing new approaches in such a sustainable way that city life, the environment and the quality of life of present and future generations are preserved and even improved (Möhlendick & Kreitsch, 2018).

CONTRIBUTION OF SCIENTIFIC LITERACY TO PARTICIPATION

One of the central aims of science education is to provide students with a scientific literacy that enables to identify questions and to draw evidence-based conclusions in order to understand and help make decisions about the natural world and the changes made to it through human activity, and to participate in making decisions in this regard (OECD, 1999, p. 60; OECD, 2017,

p. 20). Some of these changes made to the natural world by human activities lead to societal challenges (Sekretariat der Ständigen Konferenz der Kultusminister der Länder in der Bundesrepublik Deutschland, 2020, p. 11; National Research Council, 2012, p. 212; National Research Council, 2013, p. 109), such as anthropogenic climate change or air pollution. This is because air, as a mixture of atmospheric gases, surrounds the entire earth, and consequently moves across national boundaries, and air pollution therefore affects people and environment globally. In terms of climate change and mitigation of its consequences, compliance with established limit values, such as those from the Paris Climate Agreement (Vereinte Nationen, 2016), is of particular importance. Due to their consequences for human health, the social debate about limit values of nitrogen oxides, which has led to controversial discussions (Menthe & Hüffner, 2019; Nationale Akademie der Wissenschaften Leopoldina, 2019), is similarly well-known.

In science it is up to the teachers to promote scientific literacy and they themselves must become scientific literates who are able to participate in socially relevant discourses (Zeidler, 2014). The idea of scientific literacy implies as a necessary condition presupposing that both a solid content knowledge of problem analysis (Höttecke & Allchin, 2020, p. 643) and competences to evaluate different sources of data and information in order to make fact-based decisions and to deal with evidence adequately (Archila, Molina, Danies, de Mejia & Restrepo, 2021; Sharon & Baram-Tsabari, 2020).

Consequently, skills for applying the acquired chemical expertise and knowledge about limit values must be given in order to recognize scientific questions from the living world and to be able to draw conclusions with the help of various data and information sources. In addition, the ability to transform the corresponding problem into teaching practice must be given as a sufficient condition. Although the project addresses both conditions, the following contribution is limited to the necessary condition.

THEMATIZATION OF RISKS USING THE EXAMPLE OF LIMIT VALUES

The challenges associated with emissions of the oxides of carbon and nitrogen pose ubiquitous risks to humans, animals and the environment (Pietrocola, Rodrigues, Bercot & Schnorr, 2021, p. 3). According to Beck's thesis of risk society (Beck, 2016, p. 26), these are caused by humans and are associated with new technologies and products. In dealing with these risks, (natural) scientific knowledge has a special significance, because for the most part these risks cannot be perceived through the sensory organs but become visible and interpretable by means of the instruments of science (experiments, models, theories) (Beck, 2016, p. 35). Therefore, in order to participate in appropriate decision-making processes, people, most of whom are scientific laypersons, must have confidence in science, be able to comprehend scientific findings and be able to evaluate certain risks (Pietrocola, Rodrigues, Bercot & Schnorr, 2021, p. 21; Hansen & Hammann, 2017, p. 749).

One way to address these risks is through limit values, which are often used in health and environmental policy (Bächi, 2012; Böhm, 2012; Dieter, 2009; Wicenec, 2000). Compliance with limit values is monitored institutionally and in a standardized manner and sanctions are imposed if they are exceeded, so that they have a regulating function, i.e., a limiting function, as well as an informing function about potential hazards and about sanctions in the case of exceedance (Bächi, 2012, p. 119; Wicenec, 2000, p. 2). Limit values are set by politicians in an interdisciplinary and staged process of consideration and are passed in the form of legal texts whereby a field of tension, e.g., between natural sciences, law and politics, arises (Böhm, 2012, p. 59; Wiedemann, 1998). Corresponding discourses about limit values can be considered as Socioscientific Issues because according to Hancock, Friedrichsen, Kinslow and Sadler (2019) – they fulfill the following characteristics: they are "current, controversial, relevant to students, have connections to science content, and allow for open discussion among learners" (Hancock, Friedrichsen, Kinslow, & Sadler, 2019, p. 643). In order to grasp the complex concept of limit value in a more purposeful way and to make it fruitful for this study, the following working definition was formulated:

Limit values are measures in the form of fixed pollution limits that are intended to protect the life-support systems of soil, water and air for humans, animals and plants from substances that affect them, that harm them and that endanger their existence, with the aim of preserving and safeguarding them, as well as reducing the corresponding risks.

In chemistry teacher training, discourses about limit values and their implications can be used in the sense of the principle of exemplariness to create the above-mentioned prerequisites for participation in societal challenges.

RESEARCH QUESTION OF THE STUDY AND STRUCTURE OF THE COURSE SCHEMTEC

Within the framework of a preliminary study, questionnaires had revealed that prospective chemistry teachers on the one hand do not have the necessary content knowledge to adequately understand and problematize social challenges associated with the oxides of carbon and nitrogen as pollutants in the air. And on the other hand, they are uncertain in dealing with data and information sources. These deficiencies were the starting point for the conception of this project and led to the following research question: To what extent can the designed course SChemTeC reduce the deficiencies of preservice chemistry teachers with regard to the prerequisites for participation in discourses about societal challenges of pollutants in the air? Within the dimension of knowledge acquisition, not only the necessary technical basics of pollutants in air were taught on the basis of the oxides of carbon and nitrogen, but also different implications and positions within the corresponding discourses. They were instructed to use and reflect on a wide variety of data and information sources in order to reduce uncertainties.

Thematically, knowledge acquisition started with reading and discussing of media reports, followed by a presentation and discussion of projects in Cologne, such as the climate road or e-buses of the Cologne public transport company. Furthermore, the participants discussed consequences of the so-called "Cologne Lights", a music and firework event near the Rhine, and possible alternatives. Based on this context-based introduction, factual analyses on the topic of climate change and air pollution were prepared in groups dealing with formation, release, mode of action and consequences of the oxides of carbon and nitrogen.

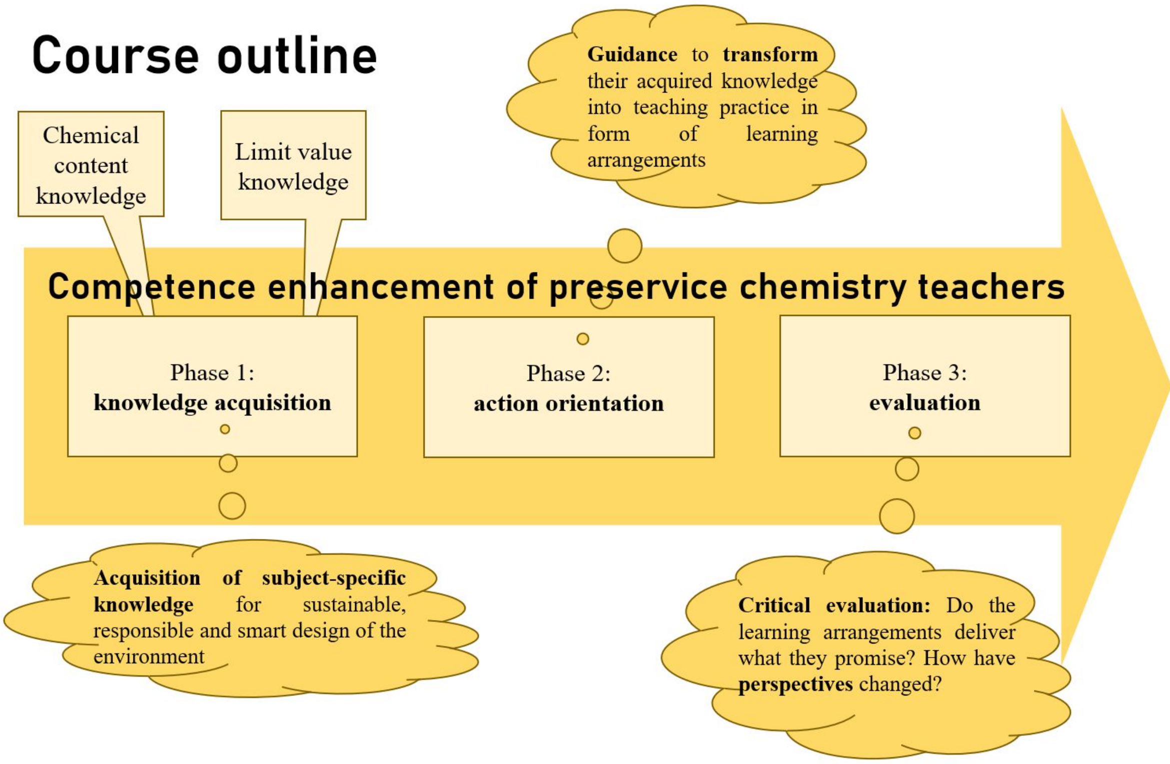

Figure 18. Course outline of SChemTeC.

These factual analyses were optimized based on feedback from the students during their presentations. They first dealt theoretically with the concept of limit values and then explored the city of Cologne with the intention of finding out place (where?), content (what?) and methods (how?) of the measurement. In the course, various methods for determining air quality were reflected together. The knowledge acquisition phase concluded with a guiding question-based reflection. This was followed by the phases of action orientation, in which the preservice chemistry teachers were guided to transform their acquired knowledge into learning arrangements, and evaluation, in which they reflected on these arrangements.

RESEARCH METHODOLOGY

Fifteen preservice chemistry teachers from all types of schools at the beginning of their Master program or at the end of their Bachelor program participated in the study; due to the pandemic, these courses took place online and run eleven weeks with four hours per week. For the survey, different instruments were used in a between-methods triangulation (Flick, 2018). An open-ended questionnaire in a pre-post design elicited the students' chemical expertise as well as their knowledge of limit values in general and that of the limit values of the so-called pollutants in the air. The questionnaire was piloted as part of the preliminary study and developed accordingly. For further data collection, preservice chemistry teachers documented in reflection tasks their further developments and the challenges they saw regarding the handling of data and information sources. At the end of the course, problem-centered interviews (Witzel & Reiter, 2012) (n = 2) were used to elicit reasoned positioning, to collect further data, and to validate existing findings. All data obtained were analyzed using Mayring's Qualitative Content Analysis (Mayring, 2015). The questionnaires were evaluated deductively using a category system developed on a literature-based factual analysis, while the interviews and the reflection tasks were evaluated inductively. The deductively developed category system is divided into the main categories “chemical content knowledge” and “limit value knowledge”.

RESULTS OF THE QUESTIONNAIRES

Table 1 shows the codings of the first three questions of the questionnaire related to the level of expertise. The first question was about the characteristic properties of the oxides of carbon and nitrogen, the second question was about formation and emission sources, and the third question was about the consequences for humans, animals and the environment. From each of these, the three categories below were derived as the main categories, which can be further differentiated. Table 1 shows that an overall improvement can be observed in chemical content knowledge on the oxides of carbon and nitrogen: while in the pre-questionnaires a total of 78 codings are detectable, 113 codings can already be set in the post-questionnaires.

Table 29. Codings of chemical content knowledge in the questionnaires.

Deductively formed categories of chemical content knowledge	**Pre-questionnaire**	**Post-questionnaire**
Characteristic properties of carbon and nitrogen oxides	58	56
Formation and emission source of carbon and nitrogen oxides	13	37
Consequences of carbon and nitrogen oxides’ emissions	7	20
Codings of chemical content knowledge overall	**78**	**113**

The fact that the amount of characteristic properties of carbon and nitrogen oxides is minimally declining can be explained by the fact that two questionnaires were incomplete. The results reveal that from the beginning, the chemistry students have significantly more expert knowledge with regard to the characteristic properties than with regard to formation, emission sources and consequences. In the last two categories, there is a clear increase from the pre- to the post-questionnaires over the course. It is striking, for example, that one person answered the question about the consequences of the oxides of carbon in the pre-questionnaire on the one hand superficially with the term *“greenhouse effect”* (ABS234A, PrF) [all translations by the authors] and, on the other hand, answered more substantially in the post-questionnaire: “*First, there are some effects on the climate, or functions in the atmosphere, namely absorption and reflection of thermal radiation. When there is too much CO_2 in the air, more thermal radiation is reflected back to earth, which has a warming effect*” (ABS234A, PoF).

Table 2 shows the codings for the limit knowledge that was collected in the questionnaires via questions four and five. The fourth open-ended question addressed meanings of limit values on the oxides of carbon and nitrogen: "*What do the limit values of the oxides of carbon and nitrogen, which are discussed in the media, mean or say?*". The fifth open question is: *"Describe possible problems, challenges as well as insights associated with the limit value discussion about the oxides of carbon and nitrogen"*. Since these two questions thematically survey limit value knowledge, five main categories were deductively formed, which are reflected in Table 2.

Table 30. Codings of limit value knowledge in the questionnaires.

Deductively formed categories of limit value knowledge	**Pre-questionnaire**	**Post-questionnaire**
Intentions, expressiveness and specific values of limit values of carbon and nitrogen oxides	5	6
Monitoring compliance with the limit values for carbon and nitrogen oxides	1	5
Process of setting limit values for carbon and nitrogen oxides	0	12
Social discourses on limit values of carbon and nitrogen oxides and their implications	3	10
Communication of limit values for carbon and nitrogen oxides taking uncertainties into account	0	3
Codings of limit value knowledge overall	**9**	**36**

With regard to limit value knowledge, they improved from nine codings in the pre-questionnaires to the 36 codings in post-questionnaires. Especially in the category on the processes for setting limit values for carbon and nitrogen oxides, there are no longer zero codings in the post-questionnaires, but twelve codings. The course also enabled preservice chemistry teachers to deepen their knowledge of social discourses on limit values for carbon and nitrogen oxides and their implications, as the codings enhanced from three in the pre-questionnaires to ten codings in the post-questionnaires. While in the pre-questionnaires the students often noted statements with regard to the discourse of limit values for pollutants in the air, such as *"however, these values are often arbitrarily set (e.g., by the EU) and rarely scientifically proven"* (ÖLF569F, PrF), a clear improvement in the technical depth and differentiation could be noted in the post-questionnaires. This is evidenced by statements with regard to the negotiation processes underlying limit settings, such as: *"It is an interplay between health/conservation and economic/political interests"* (PWÜ528Q, PoF)

RESULTS OF THE REFLECTION EXERCISES

In order to document their development preservice chemistry teachers were asked to write a reflective assessment. To assist them, they were provided with a list of assessment prompts that address, for example, knowledge enhancement, challenges, and insights in the context of the course. The importance of the initiating impulses can be exemplified by the challenges of researching adequate information and sources. The following quotation illustrates that due to the abundance of information, a reasoned selection must take place. Therefore, competencies are needed to assess reliability of information*: "When I looked on the Internet, I also found that there was an abundance of material that one often couldn't be sure of whether it was reputable or not"* (ASD869S, RW). Therefore, especially for scientific laypersons, there is a need for teaching competencies in dealing with data and information sources. It also turned out that reliable sources are often not accessible without barriers. Sometimes access on the Internet is subject to a fee. Especially the research of suitable sources on the Internet via search engine, which is also the preferred access for most citizens, is challenging: *"Finding suitable sources has always been a clear challenge. Many sources are either not scientifically reliable or protected by various paywalls"* (SDC556H, RW).

In the reflection exercises, 40 % of the participants describe the critical examination and assessment of information, sources, and media as a central further development, which is also confirmed by the two interviews. In the reflection tasks, around 67% of the participants named researching adequate information and sources as a particular challenge. With regard to the further development of preservice chemistry teachers, it was inductively deduced as a category that competencies for critical examination and assessment of information, sources and media represent a central further development. On the one hand, students were encouraged to be critical of statements from the media in such a way that every statement must pass a content-based test: *"I was encouraged to deal more with these realistic, every day and important topics in detail and also to critically question every statement. From measurement procedures to established limit values"* (UDG631Z, RW). On the other hand, in addition to classical media, many of the students also refer to (explanatory) videos to gain knowledge, so that they could now have the insight that these videos cannot be regarded as error-free from the outset, which makes an important contribution to dealing with social media in general: *"Be more sensitive with YouTube videos, which can have errors and cause misconceptions with students"* (GGT887T, RW).

RESULTS OF THE INTERVIEWS

At the beginning of the course, preservice chemistry teachers mostly assumed that the applicable limit values are set by science. The following quotation shows that the student reflects successfully on the process of setting limit values: *"What is exciting somehow is (...), someone must have said yes: yes, from this limit value, from here it becomes harmful. And then, above all, it is ultimately a decision that actually initiates actions, somehow in the political context and they have to be made by experts and they come mainly from the health sector and the scientific sector somehow"* (AQY987G, I). This quotation illustrates that an understanding of limit value setting requires the competence to reflect on it as a discursive process in order to adequately participate in corresponding social discourses.

Furthermore, the interviews show that competencies in handling data and information sources critically could be acquired. The following statement proves that checking the author can be a first step when there are uncertainties about the credibility and validity of the source: *"That you just look carefully, if necessary, look at the author: Does he have any particular CV? Where* *did he graduate if he graduated at all?"* (WER861V, I). This was coded inductively as part of the challenge to research adequate information and sources.

The following passage illustrates that a critical attitude towards statements made in the media is transferred to everyday life: "*Yes. In any case, I notice that the very fact that you have dealt with such a topic, be it air pollutants or anything else, like climate or environment, once you have dealt with it and you encounter it again, be it in the media or anywhere else, (.) that the first reaction is not: >>* ***Oh, yes, that's the way it is.*** *<<, but: >>****Aha, is that so?*** *<<"* (AQY987G, I). Here, a conceptual change initiated by the course becomes obvious.

DISCUSSION OF THE RESULTS AND CONCLUSIONS

The results of the questionnaires show that the acquisition chemical knowledge and limit value knowledge was successful, so that preservice chemistry teachers could improve. With regard to the results of the reflection tasks and interviews, it can be stated that first steps were taken to reduce uncertainties in dealing with data and information sources. In follow-up studies, more attention should be paid to knowledge about science communication and the handling of evidence. The interviews revealed that the perspective for dealing with discourses about societal challenges has changed.

However, it is also apparent that the contextualized limit value knowledge can still be extended. Therefore, concept maps are to be designed for networking during the knowledge acquisition phase. In addition, the number of participants has to be increased and further topics (such as microplastics or nitrate pollution) have to be developed.

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CRITICAL THINKING IN SCIENCE - TEACHERS' PERSPECTIVES

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Critical thinking is considered to be a key to mastering current and future global, ecological and social challenges. However, the understanding of the concept of critical thinking in the literature is manifold and partly different. We are guided by Dewey, for whom thinking and acting form a coherent unit. In the context of school, action should be oriented towards the goals of education, so that critical thinking in science teaching cannot be implemented in isolation from contexts, norms and values. From this we have derived the question, which perspectives on critical thinking exist among (science) teachers? These perspectives could be helpful clues for the development of school and teaching approaches that focus on critical thinking as well as in the context of Socio-Scientific Issues (SSI) in science education. For this purpose, an exploratory questionnaire study was conducted among teachers, with open and closed questions, which also indicates a diverse understanding of concepts among teachers. There are also indications of differences with regard to specifically science subjects and e.g., mathematics, which can be expected to provide detailed findings in the context of a validated main study. The teachers were also asked to assess themselves and their students with regard to the practice of critical thinking in class. Here, a discrepancy seems to emerge between the perceived lack of critical thinking on the part of the students and too few situations where they are actually allowed to think critically.

Keywords: Critical Thinking, Scientific Literacy, Teachers' Perspectives

THEORETICAL BACKGROUND

Critical thinking is an important approach to social, economic, and environmental problem solving and decision making (Rychen, 2008). In particular, critical thinking is said to help students understand and grasp complex contexts (Staudinger, 2019; Bourn, 2018). In the German school context, critical thinking makes up an important skill in the context of education for sustainable development (MSB NRW, 2019; Grundmann 2017, Riekmann, 2016) as well as in the subject of philosophy, where critical thinking is originally an integral part (Künzle, 2016; Pfister 2020). Furthermore, in German-speaking countries there are hardly any approaches to embed critical thinking in school (Petri, 2003; Rosa, 2017; Rafolt, Kapelari & Kremer, 2018, 2019; Drerup, 2021), in contrast to countries with a curricular connection to critical thinking and a scientific discourse about critical thinking in school (Ennis, 2016; Nygren, Haglund, Samuelsson, Af Geijerstam & Prytz, 2019, Abrami et al., 2015, Balin, 2002; Sternberg, 2020). Embedding critical thinking in science education seems on the one hand obvious in the context of ESD. On the other hand, the broader question arises to what extent critical thinking could be an aspect of science education that not only focuses on intellectual skills and knowledge, but also includes the ethical dimension of scientific issues in a societal context related to socio-scientific issues (SSI) (Nerdel, 2017, Dittmer, Gebhard, Höttecke & Menthe, 2016). A major problem is the conceptual understanding of critical thinking, which can vary widely or is not explained at all in this context.

While there are approaches such as critical thinking skills that are more in line with a cognitive psychology perspective, these are not necessarily congruent with a philosophy of education perspective. Rafolt et al. (2019) have developed a synergy model for critical thinking in science education, in which certain characteristics and criteria guide the process of critical thinking. They address aspects of critical thinking skills and consider areas such as norms and values, attitude, and motivation among others. Moreover, there seems to be sufficient reference to subject teaching of critical thinking in science education so far (Sternberg, 2020).

In our approach, we assume that a school concept of critical thinking is to be constituted from across different subjects, from which a subject-specific conceptualization is to be derived, and that science education must also contribute to education. In this regard, we refer to Dewey, who emphasizes: "No one doubts theoretically the importance of fostering good habits of thought in school." (Dewey, 1916, p.179). Furthermore, Dewey does not view thinking and acting from a dualistic perspective: “Thinking [...] is the intentional endeavor to discover specific connections between something which we do and the consequences which result, so that the two become continuous” (Dewey, 1916, p. 170). Going further, for Dewey, thought and action must be successful. What successful action can mean, however, requires concretisation. In the context of socio-scientific issues, reference could be made here to norms and values, such as those formulated in the SDGs (Hasslöf & Malmberg, 2015). Yet, critical thinking is not only passively influenced by norms, values or personality traits, but also has an effect on them through action. That is, critical thinking can also lead to a change or renegotiation of norms and values. And at the same time this interaction can contribute to personality formation.

For science teaching and school practice in general, this raises the question of how situations for critical thinking and the corresponding interactions can be facilitated and promoted. The basic requirement for these situations is that critical thinking must be able to develop tangible relevance. The space for action must therefore not remain abstract or hypothetical. School practice is primarily planned by teachers, but teachers' ideas about critical thinking and the provision for critical thinking in the classroom are unknown (Rafolt et al., 2019). This finding is the starting point of this study, which addresses the following research questions:

- What are teachers' perceptions of critical thinking and its importance for schools?
- To what extent is critical thinking currently an issue in school and classroom practice?
- How do teachers assess their learning groups in terms of attributes relevant to critical thinking, such as attentiveness, reflectiveness or the pursuit of knowledge?
- Are there subject-specific perspectives on critical thinking, e.g., in science?

METHODS

A self-developed, online-based questionnaire was used to examine teachers in an exploratory study. The target group of the exploratory study was teachers of german secondary education [N=50]. The questionnaire contains both open and closed response formats.

The questionnaire includes questions about teachers' perceptions of critical thinking (10 items) and teachers' perceptions of their student body (11 items). The questions on critical thinking include aspects such as understanding and defining critical thinking, characteristics of a critical thinker and classroom references. Teachers' assessments of their students refer to personality traits or classroom behaviours, such as attentiveness, reflectiveness, or thirst for knowledge. Response options were scaled as a rating scale (Döring & Bortz, 2016) according to the estimated proportion in the learning groups (all, many [more likely the majority], about half, fewer [more likely the minority], none, not specified).

The open-ended response formats were interpreted using qualitative content analysis (Mayring, 2010), while the closed questions were analysed descriptively or exploratively using factor analysis with SPSS.

RESULTS

In this small sample, 50 teachers of german secondary education participated. Of these, 40.8% were male and 57.1% were female. The teachers had an average seniority of 14.7yrs. (SD 12yrs). Science subjects were reported as 12% biology, 10% chemistry and 12% physics. The first results of the explorative study show that all teachers, irrespective of subject, believe that critical thinking is an important teaching goal. However, there are clear differences in their understanding of critical thinking, both across all subjects, but also among the science teachers. The content-analytical evaluation of the question on the definition of critical thinking shows from the teachers' point of view that questioning (52%) constitutes the essential aspect for critical thinking. Judging (32%), reflecting (28%) and forming opinions (24%) are also important. Critical thinking was defined as a skill in 10% of the statements, while the term competence did not appear at all. In contrast to the open-ended response option in the definition of critical thinking, responses to the question *What knowledge, skills and dispositions must a critical thinker have?* show that self-reflection, judgement, evaluation of skills, ambiguity tolerance and analytical thinking skills are important characteristics for critical thinking. Empathy is also an important factor from the teachers’ point of view. Figure 1 shows the aspects that teachers consider important for critical thinking.

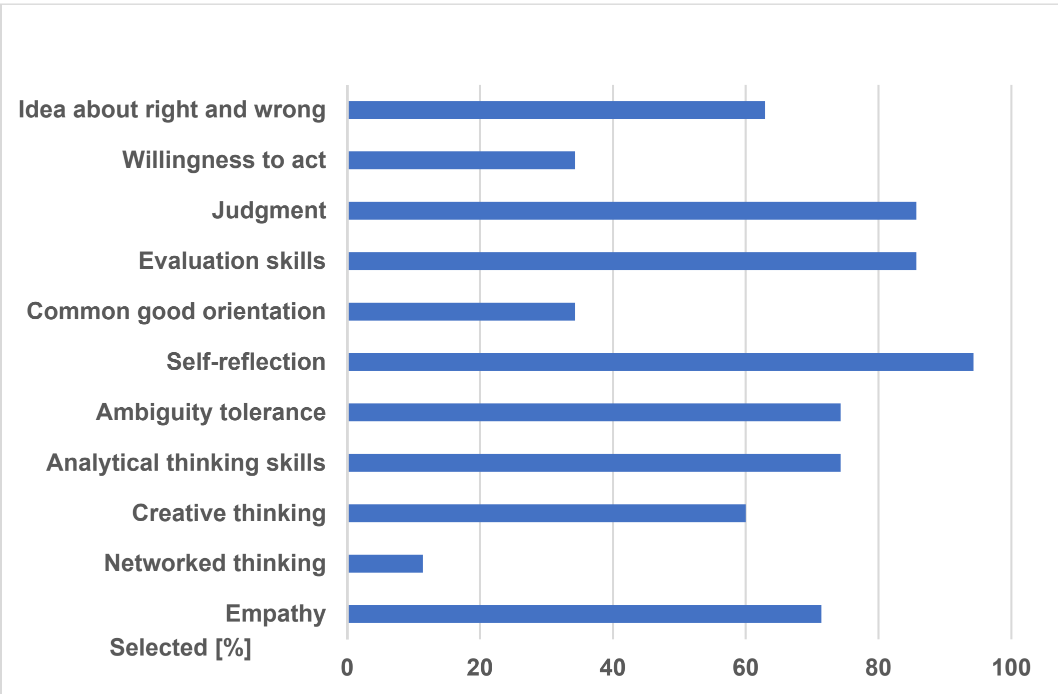

Figure 1. What knowledge, skills and dispositions must a critical thinker have?

In contrast to the definitions given about teachers' critical thinking, the ability to self-reflect is most frequently mentioned here. Empathy is also highlighted. This picture largely coincides with the definitions of the APA.

In our survey, we were also interested in the extent to which teachers assessed students' abilities in the context of critical thinking within their classes. To this end, we asked teachers what proportion of students in their class they would rate to have following skills, e.g., "How many of your students are ready to think independently about complex questions and issues?" The response options here were none (=1), less than half (=2), about half (=3), more than half (=4), or all (=5). Here we found that, on average, the teachers estimated that about half of their students

- engage with open-ended questions and problems (M = 2.86, SD 0.73)
- are able to independently seek out reliable information on a new and complex topic. (M 3.34, SD 0.73)
- are able to reflect on their own thinking (M 3.43, SD 0.74)
- are able to recognize experts in a topic area as such (M 3.0, SD 8.4)
- are able to reflect on their own learning (M 3.06, SD 0.80)
- are willing to think independently about complex questions and issues (M 3.11, SD 0.68)

On average, teachers estimate that many (rather the majority) of the students stand out as attentive (M 2.34, SD 0.54).

An exploratory factor analysis showed that the relationship of students towards critical thinking allows for two subscales, which can be characterized once as Independent Reflection (3 items, Cronbach's α= 0.72) and Willingness to Think (3 items, Cronbach's α= 0.62). We hope that this picture will be consolidated in the next survey.

When it comes to the question of where critical thinking is integrated into subject lessons, the focus is on environmental, climate- or ecological topics. About 20% of the answers (free response format) had their focus here. The following excerpts exemplify some responses:

"Critical thinking can be tied to observed phenomena from a biological perspective: "Why are honeybees dying?", “Why are there so many bark beetles?” These questions lead directly to changes in ecosystems, which are also linked to climate change. Students must therefore inevitably ask themselves what contribution each individual can make to changing the problem.” “Genetic engineering, vaccination, cell culture technology (ethical discussion), sustainability and environmental protection (biodegradable plastic versus conventional plastic)." "In combination with classroom topics, e.g., climate change in physics and its effects (panel discussion, etc.)"

The teachers were also asked to indicate in which subjects critical thinking can be particularly well stimulated. Here we observed that the main subjects Mathematics, German and English were mentioned comparatively little (12-14% each), while social science subjects such as Religion (42%), Philosophy (54%), History (44%) and Social Sciences (44%) are frequently named. The science subjects are also named less frequently, contrary to the topics mentioned (see above): Biology (20%), Chemistry (18%) and Physics (14%).

DISCUSSION

The results of the exploratory study show that all teachers, regardless of subject, consider critical thinking to be an important instructional goal. However, there are significant differences in the understanding of critical thinking, both across subjects and among science teachers. For example, when asked what qualities are relevant to critical thinking, there is undisputed agreement only on self-reflection and networked thinking.

However, it also becomes clear that teachers on the one hand advocate for critical thinking skills. On the other hand, their understanding of critical thinking seems to go beyond these skills, especially in the aspect of empathy. This raises the question of how empathy skills could be taught in science classes.

When assessing students, it appears that teachers only attribute important qualities, such as the ability to self-reflect or the willingness to engage with complex issues, to half of their students. Together with the teacher's feedback that, from their point of view, there are only few opportunities in the subject lessons for critical thinking, it also seems to emerge here that the subject lessons hardly promote critical thinking. On the question of where critical thinking is integrated into subject lessons, the focus is clearly on environmental or ecological topics, as the following excerpts exemplify: "Critical thinking can be hung on observed phenomena from a biological perspective: "Why are honeybees dying?" "Why are there so many bark beetles?" These questions lead directly to changes in ecosystems." It seems obvious that these topics are likely to promote critical thinking. However, it should be noted that a topic alone does not necessarily stimulate critical thinking. It depends on how deeply the connections to social issues are considered and what opportunities are provided for students to make critical thinking relevant.

In summary, science education should integrate critical thinking explicitly and implicitly as an important educational goal. In this context, subject-specific scientific knowledge is an important prerequisite for critical reflection in the context of social science issues. Here, interdisciplinary networking between subjects or teachers is probably necessary in order to be able to draw on non-scientific expertise.

More historical, biographical or societal contexts as well as case studies related to science are needed to provide suitable teaching occasions for critical thinking (e.g., Schaake, 2011; Henke & Höttecke, 2011, Wilhelm, Rehm & Reinhard, 2011). This is also associated with more teaching opportunities in which students feel more engaged emotionally by problems, so that critical thinking can be practiced and internalized situationally.

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EMOTIONS ABOUT SOCIOSCIENTIFIC ISSUES TO DEVELOP CRITICAL THINKING IN SPANISH PRE-SERVICE SCIENCE TEACHERS

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Nowadays, science education should focus on the development of competences in students, and especially on the development of different skills that allow them to work out their critical thinking without forgetting the emotional aspects of students that can significantly influence the teaching-learning process. Argumentation and decision making are considered important skills to foster critical thinking and can be developed through socio-scientific issues in the classroom. A training programme for pre-service science teachers (PST) on critical thinking was developed based on these ideas, focusing on socio-scientific issues in different formats (text, video and opinions). This programme was implemented with 43 Spanish PSTs from the Master in Secondary Education at the University of Málaga (Málaga, Spain) during the academic course 2019-2020. The first phase analysed the emotions felt by the PSTs during the implementation of different issues included in the programme focused on energy, health, or technology. For data collection, the PSTs completed a questionnaire, including a list of emotions. The data were analysed qualitatively, comparing positive and negative emotions. It was found that, regardless of the dilemma format used, the emotions felt by the PSTs were positive, with particular emphasis on their interest and attentiveness. Insecurity appeared in the short opinions´ format to solve the dilemma as a main negative emotion. These results show that the use of socio-scientific issues in different formats can be very suitable for developing critical thinking since the emotions detected favour learning.

Keywords: Emotion, socio-scientific issues, critical thinking

INTRODUCTION

In recent years, there has been growing concern about students' declining interest in science learning, among other reasons, because it focused on the transmission of knowledge based on conceptual change and without considering the emotional side (Mellado et al., 2014). An understanding of the role of emotions in science education, and the ability to reflect on them, implies an understanding of the nature of the cognitive processes involved (Franco-Mariscal, Cebrián & Rodríguez, 2021). Different studies in science education provide evidence that positive emotions and enjoyment from learning science play a significant role in learning outcomes and serve as a driving force for self-learning, and for retaining knowledge (Nicolaou Evagorou & Lymbouridou, 2015). It is necessary to train competent teachers with critical thinking who know how to diagnose and self-regulate their emotions both in the cognitive and affective areas.

In science education, critical thinking includes as fundamental aspects criticism and questioning in the practice of science since it seems impossible to think that without arguments and their evaluation it would be impossible to build reliable knowledge (Osborne, 2014). According to Vázquez and Manassero (2018, 2020), creativity, reasoning, argumentation, and complex processes are critical thinking's outstanding skills, both in the cognitive and attitudinal fields. In short, science education faces the challenge of forming competent citizens who incorporate argumentation, criticism and decision making into their daily lives and, at the same time, self-regulating their emotions as they can act as facilitators or obstacles to teaching-learning.

Although the literature includes different teaching strategies to develop critical thinking, there is no clear identification of a valid methodology for the classroom. An overall strategy is the use of educational issues or situations posed through socio-scientific problems (Evagorou, Jiménez-Aleixandre & Osborne, 2012), in which the student must decide reasonably between apparently incompatible options (Franco-Mariscal, Hierrezuelo-Osorio, Cruz & Cebrián, 2021) and where they also work on important skills such as argumentation and decision making (Fang, Hsu & Lin, 2019).

This work presents the results of the emotions felt by Spanish pre-service science teachers who participated in a training programme on critical thinking focused on the development of argumentation and decision making as important skills in science education and using socio-scientific issues as a teaching strategy.

METHOD

Participants

This study was performed with 43 pre-service science teachers of the Master in Secondary Education of the University of Málaga (Málaga, Spain). The 56.3% were women and 43.7% men, aged between 21 and 51 years. The pre-service science teachers studied innovation and educational research in Physics and Chemistry (N=16) and Biology and Geology (N=27) specialities during the academic year 2019-2020.

Instruction

The pre-service science teachers participated in a programme with eight sessions of 90-minute in which argumentation and decision making were addressed as critical thinking skills (Sadler, & Zeidler, 2005; Jimenez-Aleixandre, 2010) and different socio-scientific issues related to energy, health and technology were analysed (Hierrezuelo-Osorio, Franco-Mariscal & Blanco, 2022). The programme was developed in the following four phases (see figure 1):

- Phase 1. Initial assessment of pre-service science teachers' argumentation and decision-making skills as important critical thinking skills and their perception about them (1 session) (pre-test). In this session, several activities focused on socio-scientific issues in different formats and a questionnaire about critical thinking (CPC2) (Santiuste et al., 2001) were used as a pre-test.
- Phase 2. Instruction with pre-service science teachers (4 sessions). This phase addressed different models of argumentation and critical thinking, analysis of an issue, and preparation and staging of a role-play.
- Phase 3. Application of knowledge (2 sessions). Pre-service science teachers, in the role of teachers, designed a group activity to develop critical thinking skills with students at their level of education and presented them to their peers.
- Phase 4. Evaluation of critical thinking skills and perception of the pre-service science teachers after the programme (post-test) (1 session) was assessed with different

instruments. A questionnaire about emotions (KPSI) (Martínez, Jiménez-Liso & Evagorou, 2019) was administered in this phase.

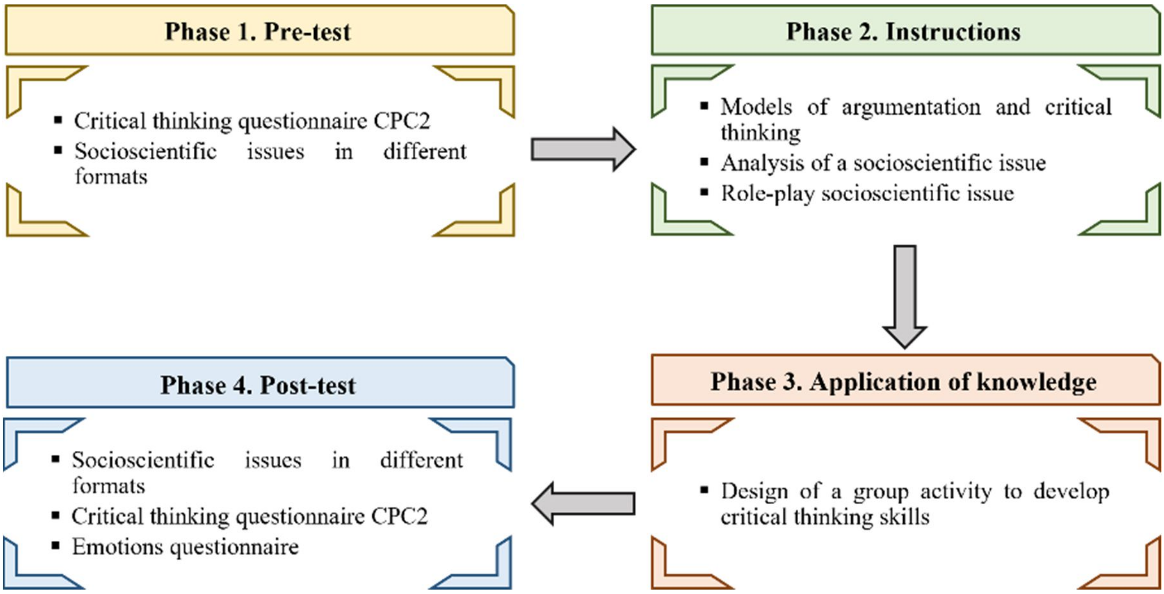

Figure 19. Phases of the critical thinking formative programme for pre-service science teachers.

Some examples of issues were the possible implantation of an artificial moon in China (Hierrezuelo-Osorio, Brero & Franco-Mariscal, 2021), the healthy or unhealthy nature of a vegan diet (Hierrezuelo-Osorio, Brero & Franco-Mariscal, 2020), the use of plastics (Hierrezuelo-Osorio, Cebrián, Brero & Franco-Mariscal, 2021) or the use of autonomous cars (Hierrezuelo-Osorio, Brero & Franco-Mariscal, 2021).

The issues were presented in different formats: text, video and opinions. The text format included two broad texts, one with arguments for and the other with arguments against the issue. Similarly, the video format included two short videos in favour of/against it. The opinion format provided short argued sentences from different roles involved in the problem. The pre-service science teachers also had the opportunity to design an issue to be implemented with secondary school students. Table 1 shows the characteristics of the three formats used for socio-scientific issues design.

The emotions felt by the pre-service science teachers in the development of the different activities with issues were investigated using an adaptation of the KPSI questionnaire (Martínez, Jiménez-Liso & Evagorou, 2019), where they had to choose one or several positive emotions felt (confidence, attentiveness, satisfaction, interest) or negative ones (insecurity, rejection, dissatisfaction, boredom, shame) and justifying their elections. It is a qualitative and quantitative tool simultaneously since it allows, on the one hand, to measure emotions, but from the student's vision. A percentage analysis of emotions was carried out, and positive emotions were compared with negative ones for each issue format.

Table 31. Characteristics to consider when designing socio-scientific issues in different formats.

Text	Video	Opinions
1. Defining the socio-scientific issue.		
2. Propose an initial decision on the problem (no access to information).		
3. To elaborate, from news items, two texts with opposing ideas on the problem to be dealt with, including different arguments for and against the problem that make the student think about it.	3. Find or edit two videos with opposing ideas about the problem with arguments for and against the problem. For classroom implementation, digital platforms such as *Coannotation* (Cebrián, 2016) can be used to annotate videos.	3. Draw up a set of opinions on the problem by specialists. Opinions from blogs/forums can also be included as long as they contain contrasted information with arguments for and against and allow for reflection on the issue.
4. Texts/videos/opinions should not necessarily be faithful copies of the original and may be adapted to avoid unnecessary information.		
5. It is important not to warn students of the contrasting nature of the texts/videos/opinions to prevent them from being influenced.		
6. Make a final decision on the problem after having analysed the information.		

RESULTS

Figure 2 shows the percentages of emotions felt by the pre-service science teachers after implementing the issue-based activities in the classroom in different formats (text, video and opinions). In general, positive emotions prevail in all formats (confidence, attentiveness, satisfaction and interest), especially in the text format (73.4%) compared to video (67.8%) and opinions (57.8%), which shows the good reception of this type of activities by the pre-service teachers.

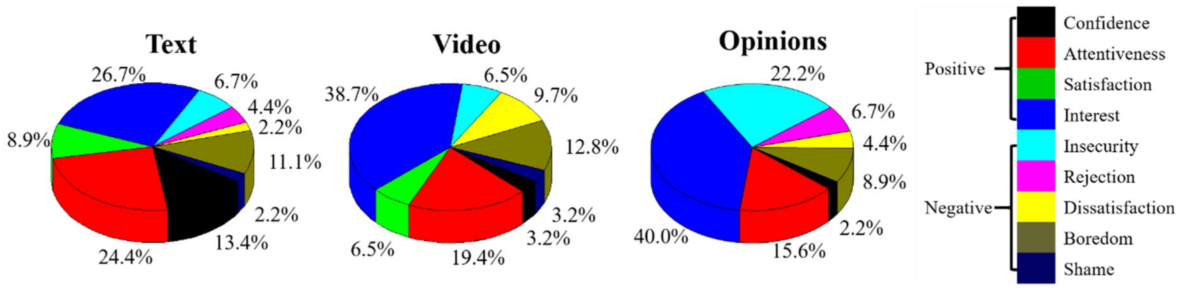

Figure 20. Emotions felt by pre-service science teachers in activities with issues in different formats.

If we focus on positive emotions, we see that interest is the main emotion, with values between 26.7% (text) and 40.0% (opinions). Some of the comments collected for this dilemma:

> *"I thought it was an efficient activity aimed at making students see that science is part of their daily lives"* [text format].

> *"I found it interesting to use audio-visual resources to develop and assess critical thinking"* [video format].

"I was interested since it was an issue, I disagreed with, but it also made me see other realities and act accordingly" [opinions format].

Attentiveness was the second most considered positive emotion, with values between 15.6% (opinions) and 24.4% (text). Regarding this emotion, the pre-service teachers commented that:

"High attentiveness was necessary to locate the arguments for and against the issue" [text format].

"Analysing every minute of the video brings high attention" [video format].

"I was reading opinions with which I was not very familiar, which meant that I had to focus on the content quite a lot in order to understand it" [opinions format].

Other minority positive emotions were confidence and satisfaction, and some comments in relation to these emotions were:

"*With audio-visual resources it is more entertaining and more attention-grabbing"* [confidence, video format].

"I find it a very interesting tool to use" [satisfaction, text format].

On the other hand, negative emotions are not so clearly in the majority in all formats. Boredom seems to remain constant in all three formats, with percentages ranged from 8.9% (opinions format) to 12.8% (video format). Some comments made by the pre-service teachers were:

"I don't think students are used to doing this kind of activity" [text format].

"I found it to be a heavier activity" [video format].

"I think it could have been a good activity to approach it in a different way" [opinions format].

Another major negative emotion was insecurity which remained between 6.5% and 6.7% in the video and text format respectively, reaching 22.0% for the opinions format. This last value can be attributed to the lesser amount of information provided in that format. In this case, the pre-service science teachers reflected that:

"Students are not used to critical thinking" [text format].

"Because only with videos, students cannot know the information well and have to argue a little bit for their own knowledge" [video format].

"I think it can give many faults from a technical point of view that can make the activity fail" [opinion format].

Other more minority emotions were rejection, dissatisfaction and shame with values below 10% in all formats. Some comments were:

"Students may be rejected by the fact that they have to deal with two long texts" [rejection, text format].

"*Since I found its use complicated to understand"* [dissatisfaction, video format].

In the case of shame, the students showed disagreement in relation to the content provided to carry out the activities. An example would be: *"I feel ashamed how someone is capable of* *saying so many barbarities without having any consequences, the worst of all is that there are people who, if they do not investigate in other sources, will take as true information that is totally wrong and built from a previous ideal"* [video format].

FINAL CONSIDERATIONS

This work has shown the emotions felt by pre-service science teachers when involved in the resolution of socio-scientific issues in different formats (text, video or opinions) that aim to develop their critical thinking.

Regardless of the issue's format, the pre-service teachers showed positive emotions, mostly interest and attentiveness. These results show the good reception of this kind of activities by the pre-service science teachers and show their usefulness to favour the teaching-learning process. In this sense, as a future line, we intend to investigate if the positive emotions of the pre-service science teachers influence the development of different critical thinking skills, especially in argumentation and decision making through the issues and the possible effect of each format.

ACKNOWLEGMENTS

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REDESIGN AND EVALUATION OF INSTRUCTION FOR PRIMARY STUDENTS' SOCIOSCIENTIFIC DECISION-MAKING TOWARD CONSENSUS BUILDING

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This study examined changes in the quality of primary school students' decisions on socioscientific issues (SSI) after undergoing relevant instruction designed to enhance their socioscientific decision-making towards consensus building. The instruction emphasised the generation of solutions for issues. We developed an SSI-based curriculum unit that provided primary school students training on socioscientific decision-making strategies toward consensus building. We implemented the curriculum unit over a two-year period and redesigned it in the second year. The participants were 63 and 68 Japanese primary school students (10 and 11 years old) in the first and second years, respectively. Before and after the unit, students worked on assigned tasks to measure the transfer of acquired decision-making competence to similar issues. The quality of students' decisions was analysed based on three components: supportive arguments, counterarguments, and solutions. We observed a post-instruction increase in the number of two-sided arguments containing solutions, especially in the second year. This study demonstrated that the instruction promoted students' socio-scientific decision-making toward consensus building. This study contributes to creating a strong research base that supports the curriculum and pedagogy suitable for primary students.

Keywords: Socioscientific issues, primary school, decision-making

INTRODUCTION

Socioscientific issues-based instruction for primary students

Socioscientific issues (SSI) represent complex social dilemmas related to the application of scientific principles and practices. The role of SSI has proven to be a major impetus in the promotion of scientific literacy within the science education community over the last two decades (e.g., Zeidler, Herman, & Sadler, 2019). A number of SSI-based instruction units have been developed for junior high and high school students, college students, and pre-service teachers (Fang, Hsu, & Lin, 2018), but only a few are available for primary school students (Evagorou, Sadler, & Tal, 2011). Kahn (2020) developed and implemented SSI units in the first, second, and fourth grade science classrooms over a one-year period. Ke, Sadler, Zangori, and Friedrichsen (2020) presented socio-scientific issues and model-based learning (SIMBL) as the framework for SSI instruction and demonstrated in detail how a third-grade student engaged in scientific modelling and socio-scientific reasoning. Nicolaou, Evagorou, and Lymbouridou (2015) interviewed sixth grade students individually at the end of instruction and explored their emotions about the learning environment. Karpudewan and Roth (2018) implemented eight SSI-based tasks to sixth grade students during a science curriculum and progressively measured students' levels of informal reasoning using an open-ended questionnaire. Nevertheless, there is a persistent lack of empirical research using quantitative data, and intervention studies with primary school students are even fewer.

Socioscientific decision-making

Decision-making about socioscientific issues involves the processes of considering the pros and cons of decision alternatives from multiple perspectives, including scientific, ethical, environmental, and social ones (Lee & Grace, 2012). In socioscientific decision-making, students first need to understand and describe SSIs in terms of their complexity; second, they are required to generate solutions that account for multiple perspectives on the issue; and third, they must critically evaluate solutions (Eggert, Ostermeyer, Hasselhorn, & Bögeholz, 2013). Fang et al. (2018) proposed a socioscientific decision-making framework that comprised three phases: formulating the decision-making space, positing a decision-making strategy, and reflecting on the decision-making process. Kim, Ko, and Lee's (2019) community-based SSI programme (SSI-COMM) included the phase of action taking, wherein students looked for and implemented the best solutions to the issue.

Science education research has identified the ability to use trade-offs as a crucial aspect of socioscientific decision-making (e.g., Eggert & Bögeholz, 2010). The use of trade-offs is characterised by the ability to consider and compare the advantages and disadvantages of multiple options and is described as a compensatory decision-making strategy. In contrast, intuitive decision-making was characterised by the use of non-compensatory decision strategies (cut-offs), that is, considering one criterion at a time. Some studies surveyed primary school students' decision-making approaches using written tasks (Papadouris & Constantinou, 2010; Xiao, 2021). Papadouris and Constantinou (2010), for example, investigated sixth-grade students' approaches to compare rival solutions in several socioscientific decision-making contexts and demonstrated that they could not consistently select an effective decision-making approach to different socioscientific tasks.

Various instructional interventions have been developed to support students' use of appropriate decision-making strategies, such as introducing an optimisation strategy (e.g., Böttcher & Meisert, 2013) and using additional meta-cognitive approaches (Eggert et al., 2013; Gresch, Hasselhorn, & Bögeholz, 2013). Intervention studies that focus on young students' decision-making skills help them apply the optimization strategy (Nicolaou, Korfiatis, Evagorou, & Constantinou, 2009; Papadouris, 2012). Moreover, these studies have focused on choosing the best option among possible solutions rather than developing new alternative solutions. To overcome this issue, there is a need for further studies on socioscientific decision-making to create a strong research base that supports the curriculum and pedagogy suitable for primary students.

The aim of this study

Therefore, this study examined the effect of SSI-based curriculum units on the quality of primary school students' decisions on socioscientific issues, that is, to ascertain how and whether engaging an instructional intervention enhances primary students' socioscientific decision-making towards consensus building. Socio-scientific decision-making towards consensus building, in this study, emphasises generating solutions to resolve issues. We developed an SSI-based curriculum unit for primary school students, wherein the students identified multiple conflicts among various stakeholders' opinions and proposed solutions to resolve them by focusing on consensus building. The training on socioscientific decision-making strategies in a cooperative learning setting with embedded metacognitive questions (Eggert et al., 2013), and previous studies on socioscientific action taking (Kim et al., 2019) serve as the theoretical background of this intervention. We implemented the unit in the first year, and then redesigned it for the second year based on the students' performances in the first year. The effects of this curriculum unit were measured with a paper-and-pencil task on the transfer of acquired decision-making competence to similar issues.

METHODS

Participants

For the first year, we recruited 63 students (30 girls and 33 boys) in the fifth grades (10-11 years of age) from two classes at a national university-affiliated elementary school in the Kansai region. All the students were Japanese and had a middle-class socioeconomic background. The second-year students included 68 fifth-grade students (35 girls and 33 boys) in the same primary school. All of them were Japanese, except for one Russian girl. The students were given tasks in Japanese and they answered them in Japanese, as it was their language of instruction. In Japan, primary science begins in third grade (8–9 years of age). The students had not received any SSI instruction prior to this study.

The students' regular science teacher taught the SSI-based curriculum. He had taught science for nearly 13 years. The head of the school recognises the participating teacher as a teacher with excellent content knowledge and instructional strategies for regular science classes, while not having much experience teaching SSI.

Curriculum unit

The goal of the curriculum unit was to provide primary school students with the training on socioscientific decision-making strategies towards consensus building, that is, the generation of two-sided arguments containing solutions to resolve multiple conflicts. For this purpose, we selected the genetically modified organisms (GMOs) as the focal issue and conducted collaborative sessions to discuss this matter.

The content of the instructional sequence is presented in Table 1. The curriculum unit consisted of 18 lessons (each 45 minutes) and included two phases. Phase 1 included an information search for science ideas surrounding the issue and arguments for both sides. The students learned about the scientific background of the process and treatment of allergies and GMOs. They then explored opinions favouring or opposing the focal issue, thus examining the benefits and drawbacks of the genetic modification technology. The favouring or opposing opinions were taken from a doctor, patient, scientist, farmer, and so on. We created eight dialogue-videos to help students understand the explanatory materials provided by each stakeholder. Students viewed four dialogue-videos at a time, read the corresponding materials, and then discussed the content of the videos in pairs. In phase 2, the students were provided with a decision-making strategy for consensus building and had to apply it correctly to cooperative learning settings. They clarified the complex relationships among the views, and identified concerns and conflicts among stakeholders. The students were guided to identify three concerns: economy, treatment or health, and environmental impact. Finally, they engaged in group activities for consensus building. They were provided with worksheets containing scaffolding to construct solutions and reviewed these solutions via peer critique from the perspective of whether each stakeholder was convinced. They tried to expand solutions that could convince multiple stakeholders and reach a consensus.

After reviewing the first year's implementation, we partially improved the learning materials and activities in Phase 2. The first improvement was the assessment and review of students' solutions through peer critique, that is, reflection on the decision-making process (Fang et al., 2018). It was because a few intervention studies fostering decision-making competence emphasised metacognitive reflection about the decision-making process and the nature of decision-making strategies (Böttcher & Meisert, 2013; Eggert & Bögeholz, 2010). We improved the content and layout of the worksheets used in the learning activity to more clearly scaffold the activity of examining whether each stakeholder was convinced with the proposed solution and the activity of revising the solution through peer critique. In addition, we held two lessons for each conflict to ensure sufficient time for the activities. The second improvement concerned decision-making strategy training. After the completion of activities for consensus building around the focal issue, the lesson to facilitate the transfer of learning was added. Students were provided with four new SSIs on papers and they adapted the decision-making strategy for consensus building into one of them. New SSIs were created as isomorphic problems for the focal issue; the contexts were security cameras, mega solar, invasive species, and swine fever vaccine. Each student selected one issue and constructed arguments adapting the decision-making strategy they learned. With these improvements, the curriculum unit in the second year consisted of 22 lessons.

Table 1. The content of the instructional sequence and corresponding elements of the instructional model.

Phase	Contents and learning activities in this programme
1. Information search	Japanese cedar-pollinosis-alleviating rice (i.e., a functional rice developed through genetic modification to alleviate cedar pollinosis allergy.)
	- Learn about the scientific process and treatments of allergies, and the GMOs. - Explore opinions favouring or opposing the focal issue and examine the benefits and disadvantages of genetic modification technology.
	Learn using materials on YouTube and the dialogue-videos that contained each stakeholders' opinion around the issue.
2. Decision-making for consensus building	Clarify the complexity of relationships among views and identify concerns and conflicts
	Construct solutions to resolve conflicts and revise these solutions through peer critique.
	Only the 2nd year: Practice to adapt the decision-making strategy for consensus building into new SSIs.

Socioscientific decision-making task

The students in both years were assigned a task on the transfer of acquired decision-making competence to similar issues before and after the unit. This task included a different SSI from that in the curriculum unit: to determine whether local governments should provide subsidies to encourage the purchase of electric vehicles (EVs). The students read background information on EVs and stakeholders' opinions on convenience, and the economic and environmental aspects. In order to assess their spontaneous decision-making behaviour, we asked them to construct arguments as though they were making a decision on behalf of the local governments regarding subsidies to encourage the purchase of EVs.

Analysis

Few studies have quantitatively analysed students' written arguments on socioscientific decision-making. Evagorou (2011) suggested the following six levels to analyse students' artefacts: level 1 – arguments consisting of a simple claim versus a counterclaim or a claim versus a claim; level 2 – arguments consisting of a claim versus a claim with either data, warrants, or backings, but without rebuttals; level 3 – arguments consisting of a series of claims or counterclaims with either data, warrants, or backings with the occasional weak rebuttal; level 4 – arguments with a claim and a clearly identifiable rebuttal. Such an argument may have several claims and counterclaims at level 5, and an extended argument with more than one rebuttal at level 6.

In this study, data or warrants were provided as opinions favouring or opposing the focal issue, and students were expected to choose and describe some of them as supportive arguments or counterarguments to justify their decision. Moreover, students were encouraged to generate solutions to resolve the issue (Eggert et al., 2013), instead of rebutting their opponents. We analysed the quality of students' decisions using three components: supportive arguments, counterarguments, and proposal of solutions. Eggert et al.'s (2013) scoring guide for the assessment of students' solutions rated a solution on the basis of two or more aspects higher than a solution on the basis of one solitary aspect, and a solution on the basis of two aspects with an even higher relation. Informed from the rubric of Evagorou (2011) and Eggert et al. (2013), the evaluative rubric of the decision-making level is presented in Table 2. The rubric comprises six levels, the lowest of which includes only an unsubstantiated claim. Successive levels include supportive arguments, counterarguments, and solutions. Proposals of detailed solutions were categorised as being at a 'higher level' if they also intended to resolve multiple conflicts.

We take the description in the last line of Table 2 as an example to illustrate the evaluative process. The learner chose a position in favour of subsidising the purchase of electric vehicles [*claim*] and justified it with the following *supportive arguments*: EVs are more environment friendly than gasoline-powered cars because they emit less carbon dioxide; they are more economical because the price of electricity is relatively stable; and they are convenient to use because many gas stations have charging spots. The learner also described *counterarguments* related to convenience and environmental concerns. Based on these facts, she proposed a *solution* to resolve each conflict. For environmental concerns, she suggested the use of solar power, and for concerns of convenience, she suggested the creation of maps and signs showing the locations of power generation spots. In summary, we rated it as Level 5 because it generated two-sided arguments and proposed solutions to resolve multiple conflicts.

Table 2. Rubric for assessing the decision-making level and examples from this research.

Level	Description	Examples
0	Made only simple claims, without justification.	Our city does not provide subsidies [*claim*]. If I have an accident with my EV, I might lose the deposit and the cost of charging the car. (The following is omitted)
1	Made claims justified by supportive arguments, but there were no counterarguments (one-sided arguments).	Our city does not subsidize for EVs. The reason is, it takes time to recharge the battery and one has to wait while other cars are being charged [*supportive argumen*ts]. (omission) EVs are not environment-friendly because they involve disposal of spent fuel from nuclear power generation and carbon dioxide emissions from thermal power generation [*supportive argumen*ts].
2	Generated supportive arguments and counterarguments (two-sided arguments).	Our city will provide subsidies. EVs are superior in that they emit no carbon dioxide while running and are environmentally friendly. Besides, the fuel cost is low, which helps the citizens economically [*supportive argumen*ts]. Although carbon dioxide is generated during power generation [*counterarguments*], it is less than that of gasoline-powered vehicles, so EVs are more suitable for improving the global environment [*supportive argumen*ts]. Therefore, they should be subsidized.
3	Generated two-sided arguments and suggested the need for a proposal to resolve some conflicts.	Our city will not provide subsidies because they think EVs are not environment-friendly [*supportive argumen*ts]. In order to meet our power needs, we have to produce electricity at power plants, which causes problems such as the disposal of spent fuel from nuclear power plants and increased carbon dioxide emissions from thermal power plants [*counterarguments*]. (omission) I think we can go to towns that use EVs and gather feedback while also testing the air quality of the town [*suggest a need for solutions*]. EVs do not emit carbon dioxide, but the community as a whole emits a lot of carbon dioxide.
4	Generated two-sided arguments and constructed a solution to resolve one conflict.	Our city will subsidize it. There is an objection that it takes a lot of time and effort to find out where the charging facilities are [*counterarguments*]. To solve this problem, we can create a map showing the locations of charging facilities [*solution to resolve conflicts: Convenience*]. (omission) Considering the time of power generation, carbon dioxide emissions are not zero [*counterarguments*], but they are very low compared to conventional cars. Thus, we can say that the car is environment-friendly [*supportive argumen*ts]. Our town will therefore provide subsidies.
5	Generated two-sided arguments and constructed a solution to resolve multiple conflicts.	Our city subsidizes EVs. This is because EVs are economical as they use electricity at a stable price, are environmentally friendly because they emit less carbon dioxide than cars that run on gasoline, and many gas stations already have charging facilities anyway [*supportive argumen*ts]. However, opponents point to the inconvenience of having to seek out charging facilities in unfamiliar places and the fact that power plants emit carbon dioxide [*counterarguments*]. In order for EVs to become more convenient and more environment- friendly, I suggest attaching solar power to cars and houses. Using nature's power to generate electricity further reduces carbon footprint and improves environmental friendliness [*first solution to resolve conflicts: Environment*]. In addition, finding charging facilities in each city should be made easier by posting maps and signs indicating their location [*second solution to resolve conflicts: Convenience*].

RESULTS

For the decision-making level scores of socioscientific decision-making tasks in the pre- and post-test segments (see Figure 1), we conducted two-way ANOVAs with POSITION (for and against) and YEAR (first and second). We found that in the pre-test segment, students who agreed to the issues had higher-quality decision-making abilities than those in opposition ($F(1,127) = 13.580, p<.001$). Further, in the post-test segment, students in the second year outperformed those in the first year ($F(1,127)= 4.120, p<.05$). Moreover, the interaction effects were found to be nonsignificant in both tests.

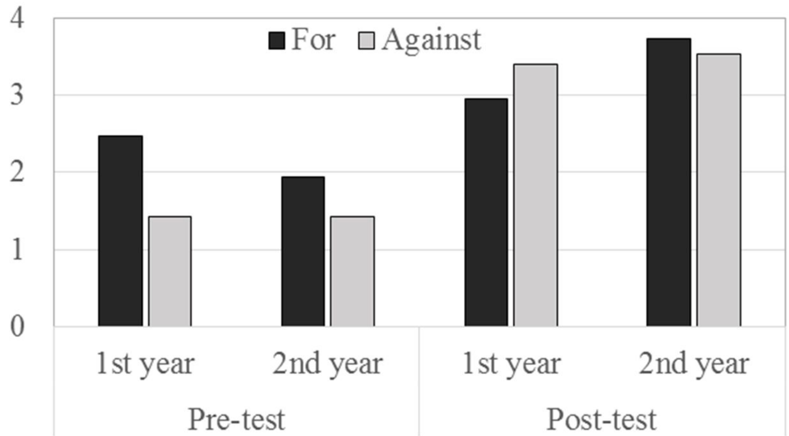

Figure 1. Mean score of the levels of the students' decisions by approval or disapproval of the issue.

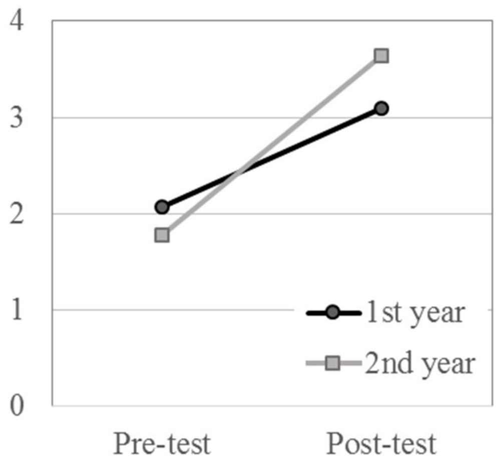

Figure 2. Mean score of the levels of the students' decisions in the pre- and post-tests.

Figure 2 shows the mean scores of decision-making of all the students. The two-way ANOVA revealed the statistical effects of TEST (pre and post) and the interaction effects between TEST and YEAR ($F(1,129)=110.927, p<.001; F(1,129)=8.989, p<.001$), but not in YEAR ($F(1,129)=.602$, *n.s.*). The post hoc test showed that the increase in levels after the intervention was significant in both years. In addition, while the mean scores of the pre-test did not differ by year, the post-test level scores of the second year were higher than those of the first.

DISCUSSION AND CONCLUSION

We developed an SSI-based curriculum unit for primary school students to learn about socioscientific decision-making strategies toward consensus-building. Students were trained in socioscientific decision-making strategies in a cooperative learning setting and reviewed their solutions with metacognitive scaffolding. The effects of this unit were measured using the transfer task. The results from the socioscientific decision-making tasks showed that the instructions developed for this study promoted the quality of students' socioscientific decision-making toward consensus building. In the pre-test segment, the decision-making levels of the students who opposed the promotion of the purchase of EVs were lower in both years. However, in the post-test segment, both students who agreed and those who disagreed generated two-sided arguments containing solutions, and the difference between them disappeared. The effect was especially large in the improved instruction, which was implemented in the second year. Helping students to reflect on their decision-making process and providing them with more experience in adapting to the decision-making strategy were effective.

This study contributes to creating a strong research base that supports the curriculum and pedagogy suitable for primary students. Future work should analyse data on learning activities in the curriculum unit and their relationship to performance in decision-making tasks.

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THE EFFECTS OF A SOCIO-SCIENTIFIC DECISION-MAKING INTERVENTION ON GREEK STUDENTS' KNOWLEDGE AND ATTITUDES TOWARDS VEGETARIANISM

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This paper reports on the effect of a socio-scientific decision-making intervention on Greek primary school students' knowledge and attitudes towards vegetarianism. A number of 190 6th grade students from four primary schools in Greece enrolled in a pre-test post-test socio-scientific decision-making intervention that aimed to improve their decision-making skills. Vegetarianism was chosen as the main topic of the intervention for two main reasons: (1) there are limited studies looking at children's knowledge and attitudes towards vegetarianism and (2) Greece has one of the highest rates of childhood obesity in Europe partially because of heavy in meat diet followed by children and young people. The results show that students improved their vegetarianism knowledge scores at the post-test, but this improvement was not found significant. This finding shows that exposing students in the knowledge is not merely enough to improve their knowledge and more focus should be given to content knowledge when students engage in socio-scientific decision-making. However, it seems that students shifted their attitudes towards adopting a vegetarian diet. More specifically, 20% of the students stated that they had thought of the possibility of becoming vegetarians at pre-test, while double the proportion of students (41%) reached a decision in favour of adopting an only-vegetarian policy at their school after having been exposed to the arguments in favour and against vegetarianism. This is an important finding that can inform diet-related interventions to reduce children's daily meat intake and improve their diet habits, which is of crucial importance for the Greek context

Keywords: socio-scientific issues, decision-making, vegetarianism

INTRODUCTION

An important aim of science education is to train students to be participatory citizens who are able to make systematic and well-informed decisions about issues concerning the society (Gresch et al, 2013). Socio-scientific issues can be defined as the issues that have a basis in science and can potentially impact society. In general, socio-scientific issues refer to real-world scenarios that are complex issues with no definite answers, including scientific knowledge, personal values, and ethical reasoning. Apart from encouraging decision-making, socio-scientific issues can improve critical thinking and provide an appropriate context to teach science content (Zeidler & Nichols, 2009). The purpose of this study is to explore whether a socio-scientific decision-making intervention has an effect on students' socio-scientific knowledge and attitudes.

Examples of socio-scientific issues that have been used in studies are wind energy (Sutter et al, 2019), genetically modified food (Bottcher & Meisert, 2013) and natural selection and antibiotic resistance (Peel et al, 2019). The main socio-scientific issue that was used in this study is vegetarianism for its theoretical and practical importance for the Greek context. Although there has been extensive research establishing adult vegetarians' conceptions and attitudes towards vegetarianism in Western countries like the USA and the UK, there are limited studies focusing on young children from different cultural backgrounds (Rosenfeld, 2018), with no other study found in the Greek context. What is more, young Greek people turn to fast food options that are largely meat-based (Papadaki et al, 2007), while the frequency of meat consumption is particularly high, with the presence of meat on the plate for almost every occasion in Greek family and social life. Data from the WHO 2009/2010 survey in 53 countries revealed that Greece comes second after the USA in childhood obesity with one in four 11-year-old boys (26%) and one in five girls (18%) classified as obese or overweight as well as is the leading European country for childhood obesity with 33% of 11-year-olds (both genders) being obese or overweight (WHO, 2015). This trend indicates the need for diet-related research with Greek children in order to establish a baseline of their current knowledge and attitudes so as to design culture-appropriate interventions to improve their dietary habits.

METHOD

Participants

A total of 190 Year 6 participants (11-12 years old) from four different public primary schools in a semi-urban area with a population of 75,000 citizens in central Greece participated in the present study. The participating schools were typical in terms of academic ability, and socio-economic resources. The sample consisted of 57% male and 43% female participants. The study obtained approval from the Research Ethics Committee of the Faculty of Education University of Cambridge and the Greek Ministry of Education and Religious Affairs. Parents completed opt-out forms and students gave their ascent.

Procedures

The students participated in a larger PhD project (Tsapali, 2019) on decision-making on socio-scientific issues that was classroom intervention-based, lasting approximately one month for each school. A pre-test, post-test, delayed post-test design was followed with the intervention spaced across three sessions over two weeks (for an overview see Tsapali & Ellefson, 2019). Figure 1 shows the different intervention sessions and data collection time-points. At pre-test, students were tested on their knowledge and attitudes towards vegetarianism as well as on their pre-existing decision-making skills. During session 1, students were presented through PowerPoint slides with four arguments in favour and four arguments against vegetarianism from four different categories (animal life, diet/health, environment, and human evolution). Students had the opportunity to explore the arguments and ask questions to comprehend them. During Session 2, students were taught a compensatory decision-making strategy and had to apply it to make a decision about vegetarianism. During this process, they had to use the arguments in favour and against vegetarianism and fill in a decision-making matrix with the options and the criteria relevant to their decisions. A few days later and after one more session (session 3) in which students had the opportunity to practise their decision-making strategy, they completed the post-test which included two questions referring to the associated risks and benefits of vegetarianism.

Figure 1. Overview of intervention and data collection time-points. The highlighted parts refer to the vegetarianism knowledge and attitudes collection time-points.

Students' knowledge of vegetarianism was examined at the pre-test and post-test through two open-ended questions. Table 1 shows the questions that were used to elicit students' knowledge of the benefits and risks of vegetarianism, followed by the scoring scale and relevant examples. Students were asked to think of any benefits and risks associated with vegetarianism that they know of. Students were assigned a score of 0-2 for each of the questions pending on their knowledge of potential risks and benefits associated with vegetarianism. Students' attitudes of vegetarianism were examined at two instances: 1) at the pre-test with an open-ended question (Have you ever considered becoming a vegetarian?) and 2) at the end of Session 2 after completing the vegetarianism scenario in which they had to make a decision on whether they would accept an only-vegetarian meals policy in their school cafeteria. Students' decision was recorded to represent their attitude towards vegetarianism after being exposed to the arguments in favour and against.

Table 1. Scoring scheme for vegetarianism knowledge.

Question	Scoring	Score Description
Do you know of any benefits associated with following a vegetarian diet?	0-2	0: No answer/irrelevant/ Answer includes positive response but with no explanation 1: Answer includes specific benefits associated with vegetarianism from one group of arguments. For example: *it is good for our heart* 2: Answer includes specific benefits typically associated with vegetarianism from two or more groups of arguments. For example: *we will have better health and get protein from other vegetarian food*

Do you know of any risks associated with following a vegetarian diet?	0-2	0: No answer/irrelevant/ Answer includes negative response but with no explanation 1: Answer includes specific dangers associated with vegetarianism from one group of arguments. For example: *it can cause very serious health problems* 2: Answer includes specific risks typically associated with vegetarianism from two or more groups of arguments. For example: *if they (vegetarians) are not cautious they might not be getting all the nutrients and in this way to have many health-related problems*

Data analysis

For the purpose of this analysis, two variables were used: students' vegetarianism knowledge at pre-test and students' vegetarianism knowledge at post-test. These two variables represent students' content knowledge of associated risks and benefits of vegetarianism at the pre- and post-test timepoints. All the assumptions were explored before proceeding to the main analysis.

A paired-sample t-test was performed to identify whether there were any significant differences between students' content knowledge of vegetarianism scores between the pre- and post-test. In other words, the analysis aimed to examine whether the intervention had any effect on improving students' knowledge and understanding of the associated benefits and risks of vegetarianism.

For students' attitudes, we looked at students' individual decisions right after the decision-making intervention, for which students had to apply the taught strategy and make a decision regarding the vegetarianism scenario and compared them to their responses regarding adopting a vegetarian diet at the pre-test. No statistical analysis was employed here as students responded to different questions in the two instances.

RESULTS

Knowledge

Overall, 177 students responded to both the pre-test and post-test. On average, participants scored higher on the post-test (M = .68, SE = .06), compared to the pre-test (M = .56, SE = .05). This difference, -.12, was found non-significant, $t(176) = -1.36$, $p = .18$.

Attitudes

The data presented here refer to 167 students who completed all the relevant worksheets and questions. Table 1 illustrates that almost half of the students stated that they would not become vegetarians after reviewing the arguments in favour and against vegetarianism but interestingly 40 per cent of the students stated that they would accept an only-vegetarian policy in their school and 6 per cent of them said that they would opt for both vegetarian and non-vegetarian meals at school. At pre-test, only 21 per cent of students had thought of the possibility of becoming a vegetarian but they still noted that they would go for that choice, while after the intervention almost double the number of students stated that they would accept having only vegetarian meals at school. What is more, at pre-test, 79 per cent of the students stated that they have not thought about the possibility of becoming a vegetarian in the past or they don't want to be, but the equivalent number after the intervention was 54 per cent, which indicates some shift in their attitudes towards vegetarianism.

Table 2. Frequencies and percentages of students' responses before (pre-test) and after the intervention (intervention worksheet) regarding their attitude towards vegetarianism.

Question	Yes		No		Both	
	f	%	*f*	%	*f*	%
Have you ever considered becoming a vegetarian? (Pre-test)	35	21	132	79	-	-
Would you accept an only-vegetarian food policy in your school? (Intervention worksheet)	67	40	90	54	10	6

DISCUSSION

The findings indicate that the decision-making intervention did not have a significant effect on students' improving their knowledge of vegetarianism. Possible explanations could be that students that were exposed to the content briefly and that they had to work on the decision-making strategy which potentially led to an increase in their working memory load, and they did not have much memory space to process the vegetarianism content (Sweller, 2003). This finding shows that exposing students in the knowledge is not merely enough to improve their understanding of it, and more focus should be given to content knowledge when students engage in socio-scientific decision-making. However, students' attitudes towards vegetarianism seem to have shifted as the number of students thinking positively about adopting an only vegetarian meal policy in their school grew considerably.

One of the main limitations of this study is that students' attitudes towards vegetarianism were measured through a few questions in a worksheet and thus, the reasons behind students' responses could not be explored further. Future qualitative research looking at students' attitudes in more depth through interviews, for instance, could provide more context to the observed change and shed light on students' thinking processes.

Overall, the findings of this study show the potential of such socio-scientific decision-making interventions to reduce children's daily meat intake and improve their diet habits, which is of crucial importance for the Greek context.

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CONCEPTION OF BIODIVERSITY VALUES IN PRE-SERVICE SCIENCE TEACHERS ON A SOCIO-SCIENTIFIC DISCUSSION

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This study aims to assess pre-service teachers' values of biodiversity during a training course. The focal group was used as the methodological approach for stimulating the debate about the socioscientific problem of disappearance of bees. This topic of discussion was chosen because it is caused by the indiscriminate use of pesticides in agriculture, and we are experiencing a moment of flexibility in the use of these chemicals in Brazil. Considering this context, it is necessary to highlight the discussion about the values of biodiversity, especially in a pre-service science teacher preparation course. The discussions were mediated by the questions: 1) What is the importance of bees for the environment and society? 2) What causes the bees to disappear? 3) What are the consequences of using pesticides? The participants' speeches were recorded, transcribed, and analyzed according to four categories of biodiversity values: instrumental, eudaemonic, moral intrinsic, and absolute intrinsic. After the analysis, a total of 76 occurrences of values were identified (instrumental - n = 22, eudaemonic - n = 2, moral intrinsic - n = 25 and absolute intrinsic - n = 27). Scientific education plays an important role in the acquisition of biodiversity values, especially moral and absolute intrinsic ones. Hence, it is important to foster high-quality teacher training so that pedagogic practice promotes biodiversity values in children and teenagers. This study may contribute to educational propositions based on citizen empowerment for more just, ethical, and responsible actions regarding biodiversity issues.

Keywords: Teacher Preparation, Values in Science Education, Environment

INTRODUCTION

Biodiversity can be defined as the variety of forms living in nature that exists as a result of an evolutionary process (Wilson, 1992). The human being is dependent on the resources that come directly and indirectly from nature, and yet, its action has played a significant role in modifying ecological processes and in environmental degradation (Alho, 2008). The role of biodiversity is complex and environmental degradation can affect countless other ecosystem components. Economic, social, and political consequences affect populations unevenly. In these situations, we face diverged interests linked to the conservation of biodiversity. In this respect, economic, ecological, and ethical reasons can be cited (Léveque, 1997), based on moral, philosophical, and political arguments that seek to attribute values to biodiversity.

According to Wiegleb (2002), the term "biodiversity" always has an evaluative connotation, allowing different groups to define it according to its bias. The author performed a bibliographic review of the values of biodiversity from an ethical perspective of nature, looking for relationships between the currents of thought arising from economics and philosophy. He proposed four values to the biodiversity: the instrumental value is associated with direct and indirect use, from necessity of basic elements, from food to ecological functions of a given ecosystem; eudaemonic value is related to human well-being, e.g. aesthetic, emotional, and religious values; moral intrinsic value is related to the moral obligations of the human being with other species; absolute intrinsic value is derived only from the properties of the object itself, such as diversity and individuality.

Table 1. The values of biodiversity and its meanings adapted from Wiegleb (2002).

Value of biodiversity	Meaning
Instrumental value	associated with direct and indirect use, from the need of basic elements, such as food, even the ecological functions of a given ecosystem. Includes nutrition, pharmacology, raw material, scientific use, and nature's services;
Eudaemonic value	related to human well-being, including aesthetic, emotional and religious values. Also includes peculiarity, originality, beauty, symbiosis with nature, conviviality, divinity (holiness) of nature, and unity of the creation;
Moral Intrinsic value	related to the moral obligations of the human being with other species. Includes egoism, anthropocentrism, pathocentrism, biocentrism, physiocentrism, and cosmocentrism;
Absolute Intrinsic value	derived only from the properties of the object itself, such as diversity and individuality;

We believe that the absence of values of biodiversity or exacerbated focus on instrumental values may be detrimental to the environment. Among the anthropic actions of ecosystem degradation, we mention the indiscriminate use of pesticides, whose side effects can be related to the disappearance of bees due to behavioral changes and possible residual effects (Tadei et. al., 2019). In Brazil, the reduction in the bee population affected several wild species in the biomes (Tadei et al., 2019), and we live in a time of flexible production, commercialization, and use of these chemicals. Such public guidelines contribute not only to bee issues but also to public health problems and the monopoly of agricultural inputs. Besides, the economic and social impact linked to the disappearance is alarming since these insects pollinate plants of economic interest for food production, as well as maintain plant biodiversity in different biomes (Tadei et al., 2019; Puig & Evagorou, 2020).

We can observe that the context in which the problem is inserted in Brazil is an emerging one. It requires a critical discussion focusing on a scientific and political vision, since this is a real problem that can affect student's lives. The school must address problems such as this aiming at the formation of critical citizens. In addition, it allows students to question and discuss concrete socio-political problems from a scientific basis and, thus, have robust arguments for their action and participation in society.

Considering the severity of the environmental impacts caused by human activity, the need for people to value biodiversity, and the importance of teachers in the science education process, our goal in this study is to assess pre-service teachers' values of biodiversity during a teacher training course in Brazil.

METHODS

This study involves a qualitative research approach and results in descriptive data. It intends to raise the conceptions of pre-service science teachers about the values of biodiversity. The participants of the research were science and biology pre-service teachers in a training course that took place in the city of Ribeirão Preto, Brazil.

The focal group was used as the methodological approach for stimulating the debate about the disappearance of bees and providing the explanation of spontaneous conceptions arising from the process of interaction and opposition of the subjects' ideas. It allows participants to express their opinions about another member's speech, jointly constructing their arguments (Stewart & Shamdasani, 2014). According to Hodson (2018), it is important to develop discussions to assess the impacts due to technology and cultural changes, health risks, and environmental degradation; which are considered as ethical-moral dilemmas that can decrease the power of choice and freedom.

The focal group

A problem-solving situation was chosen to promote decision-making on emerging aspects in society. In this perspective, the socio-scientific theme of the disappearance of bees was chosen due to its relation with social and environmental issues, being a problem that permeates the theoretical framework of this research in a meaningful way.

Based on the presented theoretical-methodological contribution, a focal group was built, consisting of mediation materials composed of preliminary questions: 1) What is the importance of bees for the environment and society? 2) The use of pesticides - What causes the bees to disappear? 3) Legislative aspects on the production and commercialization of pesticides in Brazil - What are the consequences for the environment and society? (Freitas, Nascimento, Castro, & Motokane, 2020).

The analysis

In this study, we use the data obtained from the participant’s interactions in two different focal groups. All interactions of both focal groups (n_1 = 10, n_2 = 6) were recorded and transcribed according to guidelines presented in Preti (1999). An episode is a portion of the speech with clear limitations within a theme, tasks or didactic phase. The episodes were subdivided into turns, smaller units of analysis, which present the subjects' speeches. Finally, the speaking shift was considered as the period in which speech changes between interlocutors during the dialogue (Preti, 1999).

Episodes in which participants manifested biodiversity values were considered for analysis. Every speech was read and classified according to Wiegleb’s (2002) four categories of values: instrumental, eudaemonic, moral intrinsic, and absolute intrinsic. The total number of occurrences of each value was counted and the results were furtherly discussed in the light of the theoretical framework.

RESULTS AND DISCUSSION

A total of 76 occurrences of values were identified in 50 utterances among focal groups. They were divided into instrumental (n = 22), eudaemonic (n = 2), moral intrinsic (n = 25) and absolute intrinsic (n = 27) (Figure 1). In some utterances, more than one value was identified. Instrumental and moral intrinsic co-occurred 7 times, instrumental and absolute intrinsic, 4 times, moral and absolute intrinsic, 15 times, and moral intrinsic and eudaemonic, once. 7 statements were identified as criticizing human action driven by instrumental values.

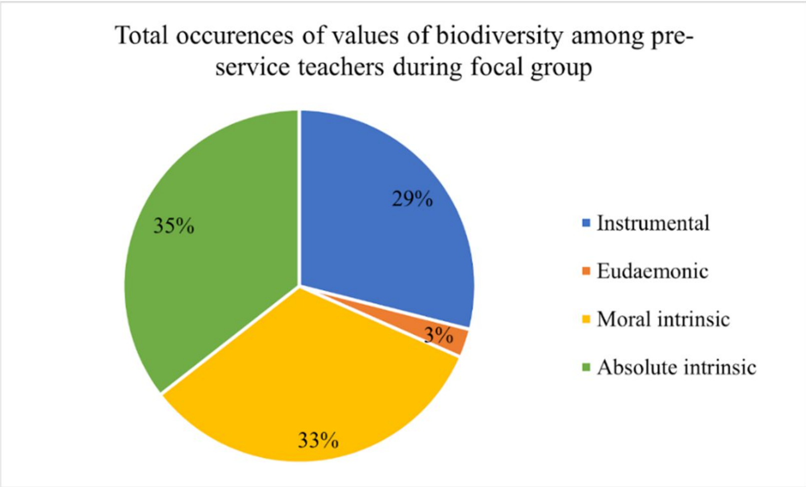

Figure 1. Circle chart picturing percentage of each of the four values of biodiversity about a total number of occurrences.

In the following, we exemplify each category and co-occurrences by illustrative quotations from participants' interactions during focal groups.

- Instrumental value

*I think people don't know, don't see this relationship between pollination and the food in our table. (FG1 – S3)**

There is a study that says that, without bees, ninety percent of food production would be impossible. (FG2 – S9)

(*) the codification includes the code of the sample group (Focal group 1 or 2) following with the number identifying the participant in the group.

- Eudaemonic value

I'm against it because of the social issue...I think it's very wrong for you to try to replicate a living being using technology. You're going to use that for bees, then the other species is becoming extinct, instead of trying to preserve it, let's replace it. I don't know what this could turn into. (FG2 – S15)

- Moral intrinsic value

It depends on what you have, because sometimes you want to produce a lot of honey and you end up exploiting this bee in a way, I don't know if it's free enough for the bees to be in your home (FG1 – S4)

Individual action... in addition to changing the view, I think we can make our neighborhood aware, try to find out which plants the bees pollinate and have them here in our neighborhood, you know...small actions that help. (FG2 – S15)

- Absolute intrinsic value

  I think that if such exchange exists, there will be more variability, there will be more variations and I think that's what contributes to the appearance of more different types of species. Because of a great variation in plants, then at one point you can generate a new species… self-fertilizing and have genetics… I think this contributes to new species (FG1 – S2)

  It will participate in some food chains, right... so this species ends up being affected (FG2 – S10)

- Instrumental and moral intrinsic values

  They are releasing a lot of pesticides and this contributes to the death of bees, then these people understand that in addition to being bad for health, pesticides also contribute to this mass death and to the end of food. Maybe people could value more organic food and start to buy more of them. If people don't buy non-organic food, sales start to drop and maybe this impacts the production of pesticides and then it kind of generates a cycle to use less pesticides. (FG1 – S4)

- Instrumental and absolute intrinsic values

  I think this issue of pollination is more obvious because whether you like it or not it would affect the majority of people directly. And not just the pollination of plants and fruits that we consume. They also pollinate others that are not for human consumption and this would also be affected and would affect the food chain in general...not just us and the food issue...so there is a lot of this ecological imbalance that can cause and interfere in a food chain. (FG2 – S13)

- Moral intrinsic and absolute intrinsic values

  I think that I would still not support it because it would convey the idea that everything in nature, all cycles can be replaced with something. So just as today we talk about the importance of preserving bees and then one day, they are extinct and we are able to supply this, it will imply that everything we believe in conservation can be resolved, so I think it will cause a collapse in society of not wanting to take conservation and preservation issues seriously. (FG1 – S3)

- Moral intrinsic and eudaemonic values

  A very basic thing is that insects and other animals that are considered fluffy and cute would be taboo, especially in childhood. So, there's a child playing and there's a little bee nearby, sometimes she gets scared and then she creates a fear of several flying animals. So, I think that it's necessary to change the relationship of children with insects since early stages of education. I also think that it is something that in the future, when the child becomes an adult, he/she will have a better relationship with that little animal, he/she sees a bee and doesn't want to kill her, for example. And the fact that the video also brings the possibility of raising bees in your house, I think many people would never do it because they would be super scared because 'it will sting me'. Even though it's a stingless bee, people still don't believe that the bee won't do they any harm. (FG1 – S3)

- Criticizing instrumental values

  This happens a lot, people determining whether a thing is valid or not valid if it exists or if it's preserved for its economic value. This way of thinking is very problematic because not everything has to have economic value, right? If things exist it's because they exist...We taking away... creating ways to make money with these things... things were not created to make money. (FG2 – S16).

Most instrumental values arose from arguments that defend bees' importance for providing ecological services such as pollination of plants directly related to human nutrition. In some cases, it was said that bees' conservation may lead to less use of agrochemicals in crops, reducing damage to human health. As for eudaemonic values, the only two utterances observed were related to the importance of people losing fear from stingless bees and criticizing the replacement of living beings with technological artifacts. Regarding moral intrinsic values, the human's moral obligation with other species appeared related to distinct ethics, such as egoistic-oriented and physiocentric/cosmocentric-centered statements (Wiegleb, 2002). Lastly, absolute intrinsic values were expressed based on bees' properties, e.g. ecological interactions, such as plant pollination and feeding relationships; bees' evolutionary history and species diversity; ecological balance maintenance.

Instrumental and egoistic-oriented moral intrinsic values were frequently manifested in the early stages of discussion. This spontaneity may occur due to the hegemony of neoliberal ideology, manifested through institutions and social relations and tacitly acquired throughout communicative processes (Bernstein, 2003). Neoliberalism aims to subject social, political, and ecological issues to capitalist market dynamics (Büscher, Sullivan, Neves, Igoe, & Brockington, 2012), which can be detrimental to the environment.

Over time and presenting a conclusive bias, pre-service teachers' arguments shifted towards criticizing instrumental values and manifesting absolute intrinsic and physiocentric/cosmocentric-centered moral values of biodiversity. Since such values often require some scientific knowledge, they are not as spontaneous to the general public as instrumental and egoistic-oriented moral ones (Hunter & Brehm, 2003). Hence, they must have been developed in specialized contexts (Bernstein, 2003). We believe that attending a higher education biology course plays an important role in pre-service teachers' comprehension of intrinsic values of biodiversity. Learning about biodiversity enables students to investigate underlying values, assumptions, worldviews, and interests concerning environmental conflicts, among other abilities (Wals, 1996).

It is a noteworthy fact that eudaemonic values appeared only twice during both focal groups. This may be explained due to the training course's context. In many academic environments, positivism still lingers as a research paradigm. Under such a paradigm, knowledge is objectively developed without the influence of researchers' values (Park, Kong, & Artino, 2019). Therefore, topics such as emotions and religion are not welcome in these environments. Nevertheless, this does not necessarily mean the absence of eudaemonic values in pre-service teachers' discourse in other contexts. Further research would be needed to assess whether such values exist or not.

In conclusion, pre-service teachers manifested a wide array of values of biodiversity, except for eudaemonic values. We believe that scientific education plays an essential role in the acquisition of values of biodiversity, especially moral and absolute intrinsic ones. There is no need to postpone biodiversity learning to higher education; it has to be done since elementary schools. Hence, it is essential to foster high-quality teacher training so that pedagogic practice promotes biodiversity values in children and teenagers. This way, students can construct, critique, emancipate and transform their world (Wals, 1996), contributing to biodiversity conservation and reduction of environmental damage. Questioners and well-informed students can become critical citizens in decision-making regarding the complexity and breadth of environmental issues (Hadjichambis & Reis, 2019). In this context, scientific knowledge emerges as a possibility of unveiling unequal socio-environmental situations. This way, biodiversity education can be considered as a tool for social transformation, a goal of citizen formation, to settle and expand environmental actions in the society. Thus, this study may contribute to educational propositions based on citizen empowerment for more just, ethical, and responsible actions regarding biodiversity issues.

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EXPLORING A SCIENTIST-TEACHER PARTNERSHIP MODEL TO SUPPORT SCIENTISTS' OUTREACH EFFORTS

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The way science is taught in school does not reflect how scientific research proceeds in universities and research institutions. Connecting scientists with K-12 students via creating instructional materials related to current research may help bridge this gap. The purpose of this qualitative case study is to investigate if a scientist-teacher partnership can support scientists in creating a quality lesson plan. Using a Theory of Planned Behavior framework, this study looks at three cases of graduate student scientists and attempts to characterize how they work with K-12 science teachers to develop a lesson plan that can be implemented in the classroom. It also seeks to understand the impacts of this collaboration on the scientists' attitudes and sense of self-efficacy regarding curricular material creation. The study found that scientists and teachers primarily worked together asynchronously, with teachers providing resources and feedback through email. Scientists sought out support primarily at the outset, with teachers helping to brainstorm how the scientists' ideas could be adapted to classrooms and made to fit science standards. They got feedback on their final product at the end of the process. There is evidence that these partnerships contributed to the scientists' self-efficacy and impacted their attitudes toward the behavior, but further research is needed to support this assertion. Implications for best practices for future partnerships are also discussed.

Keywords: Science Communication, Informal Learning, Qualitative methods

INTRODUCTION

The way science is taught in schools — through textbooks and formulaic labs — does not model how scientific research proceeds in universities and research institutions. There is a push to teach science with authentic questions generated from student experiences (Trautmann & Makinster, 2005) and to better understand the nature of science as inquiry (NRC, 2012). One approach is for scientists to participate in the K-12 education system, such as creating classroom materials to introduce students to current, real-world research (Brown et al., 2014). Creating instructional materials is one of the most direct ways to bridge current science with the classroom (Brown et al., 2014 pp. 256-7).

Providing guidance for scientists to do this type of work is essential, as training is crucial to ensure success, especially when the new skill involves domain-specific knowledge (Tricot & Sweller, 2014). Without adequate training and support, scientists risk being frustrated or feeling as if their efforts are inadequate or even wasted (Falloon & Trewern, 2013; Laursen et al., 2007; Simis et al., 2016). Graduate student scientists, in particular, may not have much teaching experience and their formal education rarely includes pedagogy, curriculum development, or how to create engaging classroom activities (Brownell et al., 2013; Gardner et al., 2017; Tanner & Allen, 2006). Existing training programs tend to be time- and/or resource-intensive (Ufnar et al., 2012) and are only available to a small portion of those interested in doing classroom outreach.

Scientist-Teacher Partnerships (STPs) are one way to support scientists who want to engage in K-12 classrooms while also improving science instruction. Historically, when scientists interacted with K-12 teachers and students, they served as a content experts and would visit a classroom to lead one or a few activities; teachers were left to translate the advanced science concepts into grade-appropriate and curriculum-aligned materials (Brown et al., 2014; Falloon & Trewern, 2013). STPs, on the other hand, emphasize *collaboration* and two-way communication between the scientist and teacher that are mutually beneficial to both parties and produce relevant instructional materials. Though the scientist may lead classroom instruction of materials that come out of the STP, the chief emphasis of the partnership is the collaboration itself (Brown et al., 2014; Tanner et al., 2003).

This study looks at how scientists and teachers work together to create instructional materials, specifically a lesson plan in the 5E format (Bybee et al., 2006), and how these interactions affect the scientists' attitudes toward volunteering in schools and their self-perception of their ability to do so successfully. The research questions guiding this study are: (1) How do scientists, specifically STEM (Science, Technology, Engineering, and Mathematics) graduate students, work with K-12 science teachers to develop lesson plans that can be implemented in the classroom? And (2) What do the scientists perceive as the impacts of this collaboration on their attitudes and self-efficacy to successfully create a lesson plan? Findings from this study will provide insight into how teachers can be a resource for scientists looking to develop classroom-ready instructional materials that introduce students to current scientific research.

Theoretical Framework

This research is guided by the Theory of Planned Behavior (TPB) (Figure 1), which posits that behavior can be predicted based on one's intention to engage in an activity, and intention is informed by one's attitudes toward the behavior, subjective norms regarding the behavior, and the perception that one can successfully perform said behavior (Ajzen, 1985).

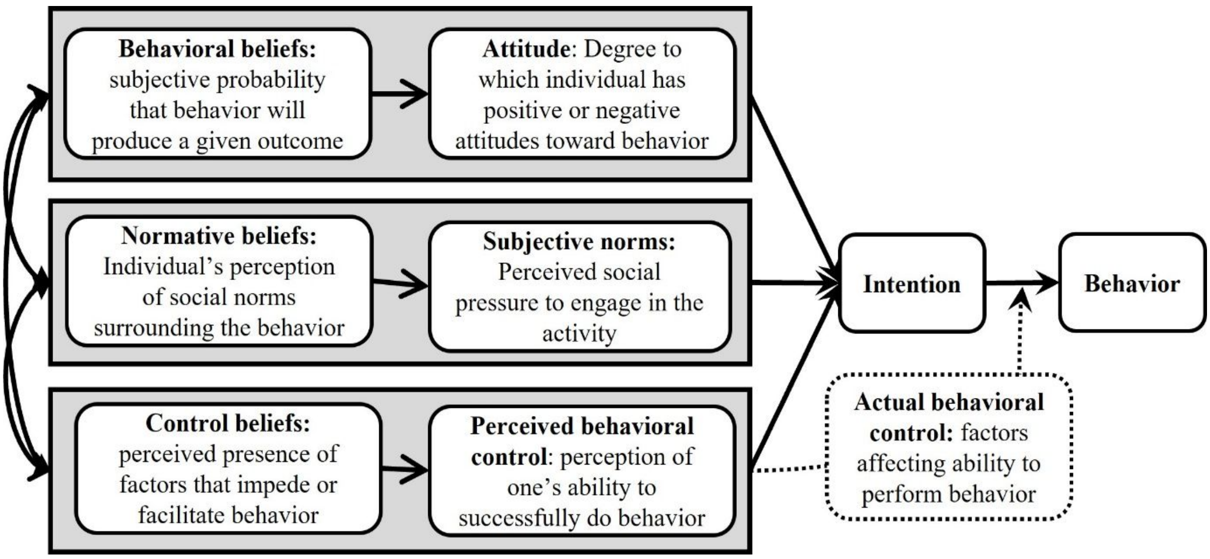

Figure 1. TPB diagram, adapted from Ajzen (2019).

Literature Review

In light of calls to reform K-12 science education, there have been efforts to more directly connect science instruction with current science research. Benefits to teachers of having a scientist in the classroom include increased self-efficacy for understanding and teaching of science (Foster et al., 2010; Gamse et al., 2010; Hamos et al., 2009), increased content knowledge (Foster et al., 2010; Gamse et al., 2010; Ufnar et al., 2017), and a greater willingness to use open-ended, inquiry-based pedagogical approaches when teaching science (Foster et al., 2010; Gamse et al., 2010; Trautmann & Krasny, 2006). There is also research highlighting the benefits to K-12 students, particularly that incorporating hands-on, inquiry-based activities led by scientists fosters excitement about science and increases student engagement (Clark et al., 2016; Foster et al., 2010; Laursen et al., 2007; Ufnar et al., 2012, 2017; Williams, 2002).

The limited research on the impact to scientists of engaging in K-12 classroom outreach shows that it positively impacts scientists' confidence and self-efficacy for teaching undergraduate students and conducting research (Laursen et al., 2007, 2012; Stylinski et al., 2018). It also leads to a better appreciation of the scientists' chosen field (Clark et al., 2016; Laursen et al., 2012; Trautmann & Krasny, 2006) and enhances transferable skills like communication, leadership, and time management (French & Russell, 2002; Gamse et al., 2010; Laursen et al., 2007, 2012; Storksdieck et al., 2017; Williams, 2002). However, there is a lack of research looking at the impacts on scientist participants' attitudes or self-efficacy toward engaging in K-12 classroom outreach.

METHODS

Study Context and Participants

This study employs a qualitative, multiple case study design (Yin, 1994). The context is graduate students in STEM fields who hope to create classroom content for grade school students (kindergarten through 12th grade, approximate ages 5-18) and opt to participate in a scientist-teacher partnership. Participants were recruited from graduate students who took part in an existing two-hour lesson plan development workshop. The workshop was part of a local networking opportunity, The Scientific Research and Education Network (SciREN), which seeks to bring current research and scientists into local classrooms by having scientists create lesson plans highlighting their research.

Interested participants were asked about their previous outreach experiences, including science communication training and formal or informal teaching experience. Three participants were chosen to maximize variation, and each represents a bounded case (Yin, 2009). The participants — Lee, Jessie, and Parker (pseudonyms) —are described in more detail in table 1.

Table 1. Participants' responses to recruitment questions (edited for brevity and to maintain anonymity).

	Lee	*Jessie*	*Parker*
Year in grad school	2nd	3rd	5th
STEM Area	Psychology and Neuroscience	Bioengineering	Pharmacology
Target grade(s) for lesson plan:	K-2, 3-5, 6-8	3-5, 6-8, 9-12	9-12
Experience with K-12 students and/or schools:	In high school: classroom assistant; helped with science demos for elementary school students	[*No response*]	In high school: classroom visits; coaching swimming

Previous trainings or other experience:	Experience in science consulting and writing	None	Science communication 2-day workshop

Data Collection and Analysis

Semi-structured interviews (average length 38 minutes) were conducted with the graduate students following their partnerships. They were transcribed by the first author, de-identified, and returned to participants to review. Feedback was also sought from teachers to triangulate the findings. Interviews were analyzed using the constant comparative method (Corbin & Strauss, 2008). For the first research question regarding how the STEM graduate students and teachers worked together, in vivo coding was used to summarize the data and pattern codes were identified during second cycle coding (Miles et al., 2014). For the second research question, a priori codes relating to the impacts of this collaboration on the graduate students' attitudes, subjective norms, and self-efficacy were developed based on the TPB framework.

FINDINGS

RQ1: Characterizing the Partnerships

The first research question sought to characterize how the graduate students interacted with their teacher partners and what types of support were provided. The pairs primarily interacted asynchronously, sharing lesson plan drafts and feedback via email, though some did have a video call to speed up the collaborative process. As Jessie explained: "it was mostly through email, and she was just giving me advice mostly. We did have, I think, one, Zoom call, just to kind of make things go faster and more efficient. But then after that it was mostly just email communications." The scientists most wanted input at the beginning of the lesson creation process. For example, Lee mentioned that one of her teachers provided "starting points for how to think about approaching the topic in a more problem-oriented way." Jessie similarly sought help getting started:

> There was a lot [of interaction] in the beginning because I didn't really know where to start. I had this kind of nebulous idea about, you know, what I wanted to do with teaching [the topic]. But then, kind of fleshing it out to see which grade levels that would be appropriate for, I think, was the most helpful.

Jessie and Parker also mentioned wanting the teachers' feedback on the final product to learn where they could improve the lesson and if it could be implemented in the classroom and expressed disappointment that they did not receive it.

The three scientists differed on whether they felt they received a good amount of support; Jessie felt that she got enough support throughout the process except at the end, where she would have liked feedback on the final product, whereas Lee wanted more help at the beginning of the process to figure out how her research could be translated to a lesson for younger students. Parker was dissatisfied with the partnership and felt that he did not receive enough support from his teachers overall:

> I pretty quickly got the impression that I wasn't going to get a whole lot out of [the teachers]. And I'm, like I said, I'm super busy myself and, video conferencing, I only try

> to do it when it's mandatory. And if I'm going to be drawing blood from someone I don't, I'm not gonna do that. I'm not going to pull teeth so…

As far as types of support, the teachers provided helpful tools including digital resources, a list of age-appropriate books, and the vocabulary list that students were provided for the course. For instance, Lee's teacher shared a PowerPoint that Lee could use as a model for the activity:

> [The teacher] had this really cool interactive PowerPoint slide that linked out to all of these different smaller links. And [the teacher] was like, 'I could imagine you doing something like this where you like kind of change the hyperlinks and it becomes this kind of like engaging thing where kids can click out and that's fun' which I really appreciated.

All of the scientists expressed the need for guidance on mapping their ideas onto the 5E lesson plan template and how to connect these ideas to a formal curriculum. This was supported by teacher feedback, as several mentioned that the scientists seemed to have a hard time with formalized aspects of teaching including aligning activities to education standards. For example, Jessie's partner teacher noted that Jessie especially sought input on aligning activities to the North Carolina Essential Standards. One of Parker's teachers shared a vocabulary list that he used to find relevant standards. He explained that he was glad not to have to try to understand the standards or navigate their online databases: "I will say, it was great to see that [the vocabulary list] and not have to search through all of the weird standard sites that don't really have keywords set up properly, it seems."

RQ 2: TPB Components

The second research question concerned the Theory of Planned Behavior's three components: attitudes, subjective norms, and behavioral control. Interviews were analyzed to look for indications of the scientists' attitudes toward engaging in classroom outreach and/or participating in a scientist-teacher partnership (STP), to look for the scientists' perception of others' attitudes toward these types of activities, and for references that alluded to whether the scientists felt they could successfully do this type of activity.

The three participants already valued outreach, as evidenced by signing up for the SciREN workshop that preceded the STP opportunity (**Attitudes**). Jessie and Lee indicated positive attitudes toward working with teachers specifically. Jessie mentioned that she appreciated the chance to gain a novel perspective: "I have a couple friends, or I know a couple people who are K-12 teachers, and they talk to me about their jobs and stuff, but, hearing it from kind of a different perspective [was helpful]." In contrast, Parker had more negative attitudes toward the partnership, mentioning that the teachers did not seem interested in helping him develop his lessons, and getting any engagement from them was "like pulling teeth." He indicated that he had low expectations from the outset: "the partnership aspect, it probably met my expectations, but they were low to begin with."

Both Lee and Jessie were involved in their lab group/department's outreach efforts and indicated that doing public engagement was valued by their peers (**Subjective Norms**). When asked about other outreach activities, Jessie spoke of her efforts at the university level: "I already do a lot of intradepartmental outreach, I guess, to undergrads in our department and to other graduate students." Lee is her lab group's 'Outreach Manager' and has engaged with numerous activities across age groups. Furthermore, many of her lab mates were eager to help with the lesson plan development. Lee spoke of an increased recognition of the value of public engagement by others in her department:

> For sure this has been a whisper across the department, and it's been a conversation in my lab, specifically… I don't know if it's been a conversation, but in the kind of small communities that I'm a part of, we have had conversations about how to bring people in and how to also take advantage of the work we do that has meaningful implications for everyday people. And so that's been a conversation about recruitment and outreach and also accessibility.

In contrast, despite being very involved in public engagement himself, Parker felt that scientists generally do not believe that outreach is a good use of their time. This was evidenced when he spoke of himself as "a researcher who's already kind of breaking the rules to do this in the first place" and mentioned, "us scientists, we're not educators." The phrase 'breaking the rules' implies that he feels there is an implicit rule that scientists should not do outreach. By emphasizing that scientists are not educators, it seems that Parker feels that scientists generally do not do this type of behavior, or at least do not do it well.

The scientists initially had reservations about creating a quality lesson plan **(Perceived Behavioral Control**). Jessie spoke of being "scared or intimidated by doing this because I'd never considered myself an educator, really, I don't think that I would be a very good teacher." However, by the end of the partnership, she expressed that she would like to continue working with teachers in some capacity: "I think it was a good experience. I don't know if I… I don't think it's convinced me that I would be a good teacher or anything, but I definitely like thinking about it from that angle […] being a resource for teachers who want to know more about what I do like 'how can I teach this?" It's not clear that the partnership increased her confidence in her ability to create curriculum materials specifically, but it does seem to have impacted her confidence in working with teachers more generally. Lee similarly hoped to continue K-12 outreach and felt that working with a teacher made her lesson plan better. Parker entered into the partnership confident that he could effectively create a lesson plan, saying that feedback from teachers indicating that he was on the right track was not helpful because he "already knew that." He did acknowledge that other scientists might be more in need of such feedback: "I honestly didn't get much more than an 'attaboy!' and a slap on the back. While that, for a lot of people that would be reassuring, for me it was kind of disconcerting."

DISCUSSION AND IMPLICATIONS

The findings from this qualitative case study indicate that when participating in a scientist-teacher partnership, most interaction was virtual and asynchronous (i.e., Zoom video calls and email) and that scientists sought more support when first ideating their lesson plans and when aligning their ideas to formal standard and curricula. This is unsurprising considering that effectively using state or national science standards requires domain-specific skills that are rarely part of a scientist's education (Brown et al., 2014). Working with teachers can help bridge this gap without requiring extra training for the scientists. The teachers also helped connect the scientists' ideas to specific grades levels and subjects, likely due to the breadth and depth of their curricular knowledge and pedagogical experience.

This type of scientist-teacher partnership has the potential to increase scientists' self-efficacy and support their ability to create classroom materials relating to their research. Both Jessie and Lee initially had concerns about their ability to be successful, but both spoke of the partnership as being very helpful for overcoming those concerns. Furthermore, all three participants seemed to think that this type of public engagement activity was worthwhile. However, they did not all seem to perceive that other scientists necesarily felt the same way, as evidenced by some of Parker's statements.

This research supports the notion that STPs can provide effective support for scientists to create classroom materials while still allowing for a minimum time commitment from already overburdened teachers. However, the scientists and teachers both expressed frustration at the lack of structure. Future partnerships would benefit from clear expectations for both parties from the outset. A checklist, suggested timeline, or even concrete deadlines would be helpful for both groups to make sure their expectations are in sync and that they make steady progress. However, the expectations need not be the same for all partnerships; some would benefit from the teacher being involved from the initial stages of ideating activities, as was the case with Lee and Jessie's partnerships, while others may only ask teachers to run through a final version of the lesson, similar to what Parker hoped to gain from the partnerships. Effective partnerships may increase scientists' self-efficacy to do this type of activity, which, according to TPB, may increase their intention to do this activity and eventually their actual behavior. Because this model involves limited financial resources and time from the host organization, it has the potential to be widely implemented to help bridge the gap between scientists and classrooms and potentially help support more authentic science instruction in the future.

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THE MEDIATING ROLE OF SCIENCE LEARNING EXPERIENCES BETWEEN FAMILY SCIENCE CONNECTION AND STUDENTS' SCIENCE CAREER INTENTIONS

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Students' engagement and participation in science have substantial meaning for international development and social justice. Family science connection (or family science capital) has been considered as an important factor which influences students' science intentions. Looking through the theory lens of social cognitive career theory (SCCT), this study supports the hypothesis that students' learning experiences can function as a bridge between family science connection and science career intentions. The findings about the relation between family science connection and learning experiences provide implications for further intervention studies about enhancement of students' science intentions through school learning experiences.

Keywords: science learning experiences, family science connection, science career intention

INTRODUCTION

If students have positive relationships with science and technology, then social, economic and environmental consequences are to be expected (Potvin & Hasni, 2014). However, during school years, numerous students lost their scientific career intentions (Krapp & Prenzel, 2011). PISA has investigated 15-year-old students' career expectations among 72 counties, in which only a quarter of students showed interest in science-related careers (OECD, 2016). In some particular fields of science, the working-class group was notably under-represented (WISE, 2012).

Broadening and increasing students' engagement in science has many substantive meanings. For government, science and technology are regarded as important tools to improve competitiveness (Tytler & Osborne, 2012). In addition, enhancing students' participation in science could contribute to social justice, given that science can provide the under-developed group a route to social mobility (Godec, King & Archer, 2017).

This study focuses on an important factor, family science connection, whose effects on science-related intentions have drawn many researchers' attention (e.g. Hamlyn, Matthews & Shanahan, 2017; ASPIRES, 2013). Specifically, through involving family science connection in a SCCT theory-based model, the mediating effects of learning experiences between family science connection and science career intention are quantitatively represented under the model construct.

The findings of this study can provide suggestions for school science education as well as vocational psychology intervention.

THE THEORY FRAMEWORK: SCCT MODEL

The social cognitive career theory (SCCT) plays a crucial role in vocational psychology research (Tokar et al., 2012). Lent, Brown & Hackett (1994) established the SCCT framework to explain the mechanism of peoples' career intention development by involving person-cognitive factors (e.g., self-efficacy, outcome expectation, and interests) and environmental factors (e.g. family factors, school learning experiences). According to Lent and colleagues (1994), people's self-efficacy and outcome expectation could influence their interest respectively and the interest could further make effects on their career intention. In terms of the delineation of learning experiences in SCCT, Lent et al. (1994) correspond to the idea of Bandura (1986) that learning experiences are the sources to build people's self-efficacy. Specifically, there are four sub-constructs of learning experiences: mastery experiences, vicarious learning, verbal persuasion, and affective state (Lent et al.,1994; Bandura, 1986). This statement has also been supported in empirical research by Pajares and Usher (2009). Additionally, SCCT further considers the paths through which several background contextual affordances influence career choice behaviours (Lent, Hackett & Brown, 2000). Specifically, Lent et al. (2000) state that background contextual affordances can make effects on career intention by directly influencing learning experiences. Consistent with the explanation of background contextual affordances by Lent et al. (2000), family support can be considered as a kind of background contextual affordance, which could influence career intention through the mediation effects of learning experiences (Garriott et al., 2014).

THE CONTENTS OF LEARNING EXPERIENCES

According to Bandura (1986) and Lent et al., (1994), people could develop their self-efficacy by perceptualizing different learning experiences. People could gain sense of capability from mastery experiences, which contributes to their self-efficacy building (Britner & Pajares, 2006). People, especially those who have limited relevant experiences and are uncertain about their ability, can construct their self-efficacy by vicarious learning - observing others conducting tasks (Britner & Pajares, 2006). Positive verbal persuasion including encouragement and empowerment may contribute to self-efficacy beliefs while negative persuasion may undermine self-efficacy. However, in practice, the diminishing effects of negative verbal persuasion tend to be stronger than the enhancing effects of positive verbal persuasion on self-efficacy (Pajares and Usher, 2009). Affective states such as anxiety and stress which are interpreted as negative, contribute to lower self-efficacy (Britner & Pajares, 2006).

AN EFFECTIVE FAMILY FACTOR INFLUENCING SCIENCE CAREER INTENTION: FAMILY SCIENCE CONNECTION

It is evidenced that students' engagement, aspirations, and attainment in science are associated with their familial effects (Archer et al., 2012). For example, Aschbacher, Li, & Roth (2010) state that parents' biased perceptions of science could deprive those students who have initial interests in science from potential science-related trajectories. Although family factors have found to have strong influences on students' science perceptions and career intentions, their relationships are complicated, which are worthy of further investigations (Atherton et al., 2009).

Among studies of numerous family-related factors influencing people's science intention, there are two large scale science education projects observing a family factor termed either family science connection or family science capital. Family science connection represents people's existing science-related resources that are mainly obtained from the family members' attitude and relationship to science (Hamlyn et al., 2017). This kind of science-related resource contains people's family-associated science-related knowledge, interest, experiences and contacts (Archer et al., 2015).

The two projects related to family science connection are shown as follows. The results of the Science Education Tracker project showed that young people with strong family science connections (FSC) were more prone to be keen on science-related careers and to have engaged in more science-related experiences than young people with weak family science connections (Hamlyn et al., 2017). Consistent with this result, in the ASPIRES project, Archer and her colleagues argued that although there was no straightforward causality between family science connection and science aspiration, students from families with high family science connection (she used the term family science capital to denote the science-related resources that a family holds) showed more preference for science-related jobs (Archer, et al., 2015). Archer and her colleagues also did a further in-depth qualitative study to explain the effects of family science connection, which showed that family habitus and privileged science cultural resources collaboratively contributed to people's science preference (Archer, et al., 2012).

RESEARCH AIM AND THE POTENTIAL RESEARCH SIGNIFICANCE

Although family science connection's effects on science career intention have been supported by many previous projects, it is challenging to conduct further interventions for science engagement enhancement based on family science connection. Since family science connection is more likely to be a kind of privileged cultural capital for the middle class (Hamlyn et al., 2017; Archer, et al., 2012), it is difficult to enhance the family science connection in practice, to promote students' science intentions. Fortunately, the delineation of the relationship between learning experiences and family factors in the SCCT model indicates an implication that family science connection may have effects as background affordances on learning experiences and further influence people' s science career choices. If this hypothesis could be supported by empirical studies, future vocational interventions could be conducted aimed at enhancing students' good learning experiences to compensate for students' lack of family science connection. Specifically, based on the sub-factors of learning experiences, future research could provide particular interventions on optimising the school learning context to enhance mastery experience, vicarious learning, verbal persuasion, and positive affective state.

METHODOLOGY

Research design

This study investigates whether family science connection could be involved into the SCCT-based construct. Specifically, the aim is to create a structural model, including students' learning experiences, scientific self-efficacy, enjoyment of science, family science connections and science-related career intentions. The postulated model is illustrated in Figure 1.

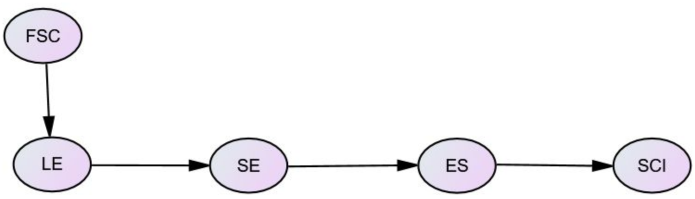

Figure 1. The structure of the postulated model.

NOTE: FSC: family science connection; LE: learning experiences; SE: self-efficacy; ES: enjoyment of science; SCI: science career intention.

Analysis method

To achieve the research aim, the structural equation modelling (SEM) approach is employed. The analysis program employed in this study is Amos 24. Specifically, the approach to structural equation modelling (SEM) in this study involves these two steps (Anderson & Gerbing, 1988).

1. Confirmatory factor analysis (CFA) is employed to test and modify the measurement models.

2. Structural regression (SR) model is created to investigate the structure model of the factors.

Measurement instruments

Only peer-reviewed measurement instruments are employed in this study (as Table 1 shown). To be applicable for the research place China and the targeted high school students, they have been executed some modifications.

Table 1: measurement instruments.

Learning Experiences Questionnaire (Schaub ,2004)	The index of self-efficacy in science (OECD, 2016)	The index of enjoyment of science (OECD, 2016)	Math/Science Intentions and Goals Scale (Smith & Fouad, 1999)	Family Science Connection Index (Hamlyn et al., 2017)

Data sources

There are 1161 high school students (16-18 years old) in China participating this study. Among all the students, there are 491 (42.25%) male students, 669 (57.57%) female students and 1 (0.17%) other. 456 students are from urban schools and 705 students are from rural schools. After checking the missing data and screening the multivariate normality outliers, there are 1155 cases for further model test.

ANALYSIS RESULTS AND FINDINGS

In the SEM research, there are three primary indices which are widely used to assess model fit: the comparative fit index (CFI), the standardized root mean squared residual (SRMR), and the root mean squared error of approximation (RMSEA) (Lent et al., 2018). The model fit may be considered adequate when CFI values are ≥0.90 (Hoyle & Panter, 1995) and preferably, ≥0.95 (Hu & Bentler, 1999); SRMR values are ≤0.08 (Hu & Bentler, 1999); and RMSEA values are ≤0.08 (Browne & Cudeck, 1992) or, more stringently, ≤0.06 (Hu & Bentler, 1999). It is considered that a model can offer a representation of the relations of variables if it meets one or more of these criteria (Lent et al., 2018; Kenny, 2010).

According to Anderson and Gerbing (1988), in practice, there are two steps to test a postulated structural model: A> examination of measurement model by confirmatory factor analysis (CFA) B> examination of regression structural model.

Examination of measurement model by CFA

The results of CFA are shown in Table 2.

Table 2: The model fit indices of postulated measurement model

CFI	RMSEA	SRMR
0.948	0.068	0.057

Although all the goodness of fit indices shown above indicate that the postulated measurement model could converge the data, we should also pay attention to the factor loadings that describe the relations between the observed variables (individual questions) and their corresponding latent variables (factors which will be further investigated in structural model) in each measurement construct (Kline, 2010). The data shows that in the "learning experiences" construct, "affective state" is not significantly correlated with "learning experiences" ($p>0.05$). That implies that the observed variable "affective state" may not be consistent with the learning experiences construct for the Chinese high school participants. In this study, affective state is deleted from learning experiences construct and to distinguish with the previous four-factor construct, the new learning experiences construct containing three sub-factors is termed as "positive learning experiences" (PLE).

Since the measurement questionnaires have been modified to be applicable for the practical situation in China, it is necessary to consider the reliability and validity of the instruments employed in this study. According to Fornell and Larcker (1981), in SEM, the reliability of a single measurement question could be represented by Squared Multiple Correlation (SMC) and the reliability of a measurement model could be represented by composite reliability. SMC>0.4 represents good reliability of a single question and composite reliability>0.7 represents good reliability of a measurement model (Hair et al., 2010). What is more, according to Fornell and Larcker (1981), the Average Variance Extracted index (AVE) could represent convergent validity of a measurement model. If the AVE is less than 0.5, the variance due to measurement error is larger than that due to latent variables. Then both the validity of individual measuring question and the whole measuring model may be bad.

After checking the SMC of all the questions, there are only two questions from the self-efficacy questionnaire that are lower than 0.4. To warrant the reliability of this measurement construct, these two questions are deleted. The composite reliability and convergent validity of each measurement construct are shown in table 3.

Table 3: Composite reliability and convergent validity of every measurement construct.

Measurement construct	Composite reliability	Convergent validity
FSC	0.789	0.556
PLE	0.835	0.627
SE	0.878	0.546
ES	0.947	0.782
SCI	0.862	0.613

NOTE: FSC: family science connection; PLE: positive learning experiences; SE: self-efficacy; ES: enjoyment of science; SCI: science career intention.

The model fit test, reliability test and convergent validity test cooperatively support the proposition that the measurement instruments employed in this study are appropriate for Chinese participants and are suitable for execution of the next step, exploration of a regression structural model.

Examination of regression structural model.

Model fit tests executed on the postulated structural model indicate that this model can converge the data well. The model fit indices are shown in Table 4.

Table 4: The model fit indices of the postulated structural model.

CFI	RMSEA	SRMR
0.945	0.066	0.074

DISCUSSIONS AND IMPLICATIONS

The fitted postulated structural model provides the empirical evidence that family science connection can influence peoples' science career intentions by exerting direct effects on positive learning experiences. Positive learning experiences consist of three factors: mastery experiences, vicarious learning, and verbal persuasion.

Compared with the learning experiences construct with four sub-factors supported by Lent et al. (1994), the positive learning experiences construct with three sub-factors may be more consistent with this study. Actually, the correlations between affective state with the other three sub-factors of learning experiences have also drawn attention of Tokar and his colleagues (2012). Tokar et al. (2012) have investigated the structure of learning experiences questionnaire and found that differentiated from the robust inter-correlations between the other three sub-factors, affective state only had modest correlation with the other three sub-factors respectively. Tokar et al. (2012) tried to explain the inharmonious results of affective state theoretically by the explanation of affective state from Bandura (1986) and Lent et al. (1994). Bandura (1986) states that the nature of affective state is different from the other three types of learning experiences. He (1986) states that affective state is not only a mode of learning but also a response to learning. People may observe their feeling of anxiety when they conduct hard tasks and the observation of personal psychological arousal may be perceived as a kind of learning which teaches them to link the psychological arousal with the specific tasks. Whereas the nature of learning, affective state is still often perceived as a kind of emotion responding to a learning experience, which implies that affective state could be results of the other three sub-factors of learning experiences. In addition, in terms of the items of affective state in the questionnaire, such as "Reading articles about science has made me feel uneasy", they represent students' recollection of the past experience. In accordance with Lent et al. (1994), people's recollection of past experience may be filtered by their affective disposition, especially their recollection of a past affective state. In this sense, the examination of past affective state experience has the risk of being masked by their personal character.

Besides from the explanation based on theory from Bandura (1968) and Lent et al (1994), the source of science anxiety also shed a light on the explanation of this problem. Mallow and Greenburg (1983) state that source of science anxiety may be from some intrusive image of painful memories. However, in the learning experiences construct, mastery experience, vicarious learning, and verbal persuasion are all experiences linked with positive or moderate memories. It implies that students' science anxiety may be more sensitively affected by painful and negative experiences but be hardly influenced by positive and encouraging experiences.

In addition, according to Usher and Pajares (2009), middle school students' affective state is not significantly correlated with mathematics skills self-efficacy and mathematics courses self-efficacy and it is only correlated with mathematics grade self-efficacy. However, in this study, the science self-efficacy questionnaire drawn from PISA is a science skills self-efficacy measure. It is consistent with Usher and Pajares (2009) that affective state is not be involved in a structural model with science skills self-efficacy in this study. Although, statistically, affective state is freed from the learning experiences construct for Chinese high school students, the relevant in-depth qualitative studies are proposed as a focus for future research.

The relation between family science connection and positive learning experiences may shed new light on approaches to enhancing students' science engagement in school education. It also provides implications for the future career intention intervention studies. Specifically, school constructs and activities which could contribute to students' sense of achievement about science are suggested. Corresponding to the importance of vicarious learning, the role models from school, family or society inspire students' aspiration. Insofar as that, the contents related to model-setting are suggested to permeate through science courses and school activities. Finally, the importance of verbal persuasion suggests that more encouragement to students indeed can make effects on engagement. It should be a matter of concern that according to Pajares and Usher (2009), the destructive effects of negative verbal persuasion may be stronger than the constructive effects of positive verbal persuasion. Students probably are more sensitive to depreciating and negatively criticising words. Hence, it is recommended that teachers should be cautious about negative verbal communication with students.

The mediating role of positive learning experiences between family science connection and science career intention may provide an approach to transferring the "task of enhancing students' science participation" from family to schools. Although previous studies constantly reinforce the crucial effects of family science connection on students' science engagement, it seems that if this inspirational research result only piles the task of encouraging students' science engagement on parents, in practice, it is hard to make significant effects. Given family science connection is more likely to be a privileged resource for the middle class (Archer et al., 2012), for families which are not able to gain the conditional socioeconomic resources, the inspirational research result about family science connection appears to be a beautiful but untouchable flower. In addition, the mediating role of positive learning experiences also provides theory rationale for interventions studies that is aimed at enhancing students' science engagement through improving students' positive learning experiences. This implication is especially meaningful for students who have insufficient family science connections.

CONCLUSION

This study investigates the mechanism of the effects of family science connection on science career intention. The findings show that family science connection can be regarded as a kind of background contextual affordance in the SCCT model and positive learning experiences including mastery experiences, vicarious learning and verbal persuasion play a mediating role between family science connection and science career intention. It implies that interventions on learning experiences may be able to compensate for lack of family science connection, to enhance students' science engagement.

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THE ROLE OF PHOTOGRAPHY IN THE PERCEPTION OF ANIMAL WELFARE: A STUDY WITH FUTURE TEACHERS OF PRIMARY SCHOOL

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The role of photography in the perception of animal welfare: a study with pre-service teachers. The present study aims to check the perception of animal welfare in six different situations through the observation of photographs. For that, 194 pre-service primary school teachers (103 Portuguese and 91 Spanish) were inquired. To this end, two versions of the same questionnaire were administered, including for the same situation one photo intended to induce a more positive perception of the welfare of animals. The results of the two versions were compared in terms of the global sample and by country. In general, the animals confined in zoos or bird cages, but where bars were not observed, led to a better perception of the animal welfare. When the photos dealt with a situation about which the respondents had a very critical position, as it was the case of bullfighting, the framing of the photograph had no effect on the perception of animal welfare. The photos where human beings were interacting with animals induced different perceptions, depending on the situations presented. The results allow concluding that photographs can lead to a more or less critical perception of the animals' welfare, with an impact on the assessment of the quality of animals' lives. This conclusion emphasizes the need of a careful selection of the photos in school context, as the ones included in educational resources designed or selected by teachers and in textbooks. Implications of the present results for students of any cycle of schooling are also discussed.

Keywords: Photography, Animal welfare, Teacher training

INTRODUCTION

Animals have always been a source of interest to humans. However, the issue of animal welfare only recently appeared explicitly in the curricula of non-higher education in Portugal and Spain. Thus, the need to work this subject with pre-service teachers is very important due to the following reasons: to help them to be more conscious about the factors that affect animals' quality of life; to help them to better assess the conditions that promote animal welfare, including those related to the health of the ecosystems; to reflect about the impact of different instrumental uses of animals by humans; to develop their skills in the design of activities and resources dealing with the animal welfare issue.

Independently of the approach of the present issue in formal education, the information society broadcasts, through the media, a multiplicity of photos of animals in the most diverse situations and whose observation and analysis allow to perceive whether their welfare is being respected or not. But, as Moutinho (2007) points out, photos do not translate reality, but rather provide a perspective about reality, which allows their use to convey a different set of values and to be at the service of distinct ideologies. Thus, photos reflect the subjectivity of those who take them and are subject to the subjectivity of those who interpret them, and this interpretation can be strongly conditioned and manipulated (Sumozas & Almeida, 2020). Therefore, a photo can enhance a positive animal welfare perception or, on the contrary, promote the opposite idea, even when that does not correspond to reality.

Students of different ages are confronted with photographs involving animals on the internet, in books, in textbooks or in the resources selected or designed by their teachers. These photos can influence students' way of thinking uncritically about the use of animals in the most diverse situations, especially if they are not object of analysis and discussion and, in most situations of daily life, this possibility is difficult to imagine.

The importance of photographs for indoctrination of the perception of reality is not a recent subject, though often forgotten. Hanson (2002) stated that William Hornaday, in 1904, as director of the New York Zoological Park, favoured the following idea: presenting photographs with animals between bars stimulates the negative perception of zoos and makes people feel sorry for their captivity condition. But photos in which the animal appears head erect and properly posed in open spaces makes them forget the condition of captivity of the animals and enhance the perception of welfare.

In this text we present the results of a research from an artistic and constructive perspective, developed between the Polytechnic Institute of Lisbon, Portugal, and the University of Castilla-La Mancha, Spain, focused on the development and use of the artistic photography as a resource for knowledge and reflective analysis of animal welfare. The strategy sought in this work is the analysis of the images by pre-service teachers of both countries, also aiming to verify their ability to construct and elaborate their own interpretation and speeches through the visualization of different images.

METHODOLOGY

The present study involved 103 pre-service Portuguese teachers of primary school, 99 female, and with an average age of 24 years, and 91 Spanish, 57 female, with an average age of 21.3, from two higher education institutions, one from each country.

A questionnaire was designed in two versions involving six situations with animals. Five of them reported situations of instrumental uses of animals by humans (a lion in the zoo, ponies used to transport children, bullfighting, dolphins in captivity, and birds in cages). The sixth situation involved gazelles in their habitat.

In each version, one of the photos intended to give a more positive perception of animal welfare, although the situation surrounding the animals was strictly the same. To emphasize this apparently more positive perception, the following strategies were used: dissimulation of the situation of captivity and the presence of human beings in an empathic relationship with animals, namely children. The most negative perception was given by the presence of confinement bars, harmful actions to the animals by humans and the presence of predators in an ecosystem context.

The photos selected in each version of the questionnaire are presented in Figure 1, with an indication of which ones were selected to induce a more positive or negative perception for each situation.

	A	B	C	D	E	F
	-	+	+	-	-	+
Q1						
Q2						
	+	-	-	+	+	-

Figure 1. The photos present in the two versions of the questionnaire (Q1 and Q2), portraying six different situations (from A to F) for assessing the respondents' perception of animal welfare. It was sought that one of the images would enable a more positive perception (+) and the other one a more negative perception (-) for the same situation.

Thus, 103 respondents (53 from Portugal and 50 from Spain) responded to version A of the questionnaire and 91 (50 from Portugal and 41 from Spain) to version B, randomly chosen. For each situation associated with each photo, it was questioned whether the welfare of the animals was being respected (Yes or No) and why.

Relative frequencies for each situation in each version of the questionnaire were calculated. A chi square test was used to check differences in the animal welfare perception of the participants, comparing the incidence of positive and negative answers in both versions of the questionnaire in each situation. The level of significance considered was $p < 0.05$. The content of the justifications was analysed and is presented concisely due to space limitations.

It is important to explain a few theoretical principles that support the preset methodology, since it was focused especially on visual analysis situated in the context of art-based research methodologies, centred on the ideas of Eliot Eisner. Eisner (1995) considered that the use of forms of thought and representation provided by arts can be research facilitators, highlighting as a good example the possibilities given by photography for reflection about different issues. Within this perspective, one of the methodological research modalities is the A/r/tography, promoted by Irwin (2013) and Marin-Viadel and Rodán (2019), and which unifies artistic actions and research development.

Visual inquiry through photography about human actions is an exercise for helping visualizing the complexity of the world and can be a natural ally in actions and investigative practices (Ramon, 2019). To do this, the concept of visualization implies the development of a complex analytical gaze that embodies our relationship between our personal identity and the environment that surrounds us. It also implies a necessary union between the use of methodological tools with the community and social tendencies of contemporary art, such as "artivism", an acronym formed by the combination of the words "activist" and "artist", which means "art with an explicit social content ", a good example of which is the approach of animal welfare in art and photography.

In the present methodological approach, it is also important to highlight Benjamin's (2014) concept of "observing", as a tool for analyzing different aspects of the reality, including the way humans observe animals. Thus, the present methodology is based on photography as an analysis tool that involves the artistic drift that allows us to pay attention to the welfare of animals, taking it into consideration in our society. The observation of photographs can facilitate reflection, interpretation and understanding of the situations in which animals are involved.

A great aim of the present study was to seek precisely these aims in pre-service teachers about animal welfare issue, allowing students to create their own discourse about the photos proposed. The comments derived from the photographs thus become an analysis instrument that constitutes an important data collection for the research process.

Working on photographic images and on the ideas they provoke on the viewers allow to involve students in the subject of animal welfare, which is not often approached in teacher training, helping students to assess the quality of life of the different species, especially those that are used instrumentally by humans in different situations.

RESULTS

The results allow concluding that, in general, the respondents' perception about the welfare of animals in different situations was greater when viewing the photos selected to induce a positive perception. However, not all the results corresponded to what was expected. Global results and per country are shown in Table 1.

Table 1. Relative frequency of positive (Y) or negative (N) perceptions of animal welfare in each situation (A to F) considering the global sample and per country, in both versions of the questionnaire (Q1 and Q2). It includes the *p* value obtained by the application of a chi-square test, by comparing the perception of well-being according to the pair of photographs presented for the same situation (see the methodology section).

	A			B			C			D			E			F		
	Y%	N%	*p*	Y%	N%	*p*	Y%	N%	*p*	Y%	N%	*p*	Y%	N%	*p*	Y%	N%	*p*
Global sample																		
Q1	8.7	91.3	0.00	5.8	94.2	0.01	2.9	97.1	0.87	33.0	67.0	0.20	9.7	90.3	0.00	89.3	10.7	0.00
Q2	33.0	67.0		16.5	83.5		3.3	96.7		41.8	58.2		33.0	67.0		68.1	31.9	
	Confirmed			Not confirmed			Not confirmed			Confirmed			Confirmed			Confirmed		
Portuguese sample																		
Q1	7.4	92.6	0.00	9.3	90.7	0.19	1.9	98.1	1.00	44.4	55.6	0.96	7.4	92.6	0.03	92.6	7.4	0.03
Q2	44.0	56.0		18.0	82.0		0	100		44.0	56.0		30.0	70.0		76.0	24.0	
	Confirmed			Not confirmed			Not confirmed			Not confirmed			Confirmed			Confirmed		
Spanish sample																		
Q1	10.2	89.8	0.21	2.0	98.0	0.02	4.1	95.9	0.65	20.4	79.6	0.52	12.2	87.8	0.01	85.7	14.3	0.00
Q2	19.5	80.5		14.6	85.4		7.3	92.7		39.0	61.0		36.6	63.4		58.5	41.5	

Confirmed	Confirmed	Not confirmed	Not confirmed	Confirmed	Confirmed

Thus, the presence of bars in cages that are clearly visible in the frame of the photos where the animals are found, as it happens in two situations of questionnaire 1 (lion and birds), decreased the perception of the animals' welfare. In the case of the lion in the zoo, in the Spanish sample, a statistically significant difference was not obtained between the two versions of the questionnaire, because these students presented more critical justifications regarding zoos, even in the photo in which the perception of well-being was considered to favour the animal. Even so, it was this photo that received a greater number of favourable perceptions.

The presence of human beings in the photos, however, led to different perceptions, a few of them unexpected. In the case of the ponies, the presence of children riding them was perceived as a form of exploitation of the animals, and not as a way to establish a more empathic relationship between animals and children, which could benefit their welfare. Also, the presence of human beings with the dolphins did not significantly change the perception of their welfare. However, the almost identical perception of the situation involving the dolphins in the two photos happened because the participants considered that the tanks in the photo without humans were near the sea and idealized that it would be possible for the animals to make incursions in the ocean and return. In the case of bullfighting, the photos did not motivate changes in the perception of the students, who proved to be very critical of this show considering it very cruel to animals, and despite being a show rooted in the Spanish and Portuguese cultures. Finally, the presence of a feline in one of the photos with gazelles led to a different perception in the welfare of these animals, although the predator in the image did not appear to show any particular interest for its potential prey.

DISCUSSION AND CONCLUSIONS

The present study shows how photos can influence the perception of reality and lead the subjects to interpret a certain context as being more or less positive in terms of animal welfare. However, in situations where the respondents' critical opinion was stronger, as it was the case of bullfighting, the photos did not affect the perception, a dimension that needs further research. The presence of human beings in interaction with animals was not always perceived in the same way, an aspect that also deserves further research.

Even so, this pioneer study shows how the selection of photos during the teaching practice is important for the perception of students about the welfare of animals in different situations. This selection can also be used to develop their critical thinking about the use of animals by humans, namely in the way of looking at situations that involve captivity. It is therefore considered important to extend the present study in the future to students of different schooling cycles, in order to assess the power of photos in the perception of animal welfare. Finally, it seems relevant to highlight the importance of the present issue in teacher training, relating it to the need of developing the critical thinking of all students, regardless of their age.

With the present study it was possible to verify possibilities of a successful connection between the fields of Environmental Education and Artistic Education, through the incorporation of methods and tools such as photography, which functioned as a stimulus for the identification of pupils' perception about animal welfare, showing animals in different situations. It also opens other opportunities for future interdisciplinary research in the field of animal welfare or other environmental issues, helping teachers to become more conscious about their didactic options, due to the implications of the results in the children's perceptions about animal welfare.

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COVIEWING AND INTERTEXTUALITY IN THE USE OF VIDEOS IN CHEMISTRY CLASSES

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The aim of this study was to identify what strategies chemistry teachers adopted to relate the teaching objectives and the films and videos shown in class to motivate the students' interest in the discussion and learning of Chemistry. The participants were three teachers and their students in a public high school. The data were produced from the analysis of the videos displayed, observation of the teachers' actions during the classes, and interviews with them. Teaching actions generally had a regulatory effect and sought to control the students' understanding and participation. Coviewing and intertextuality were the main strategies adopted by teachers. These strategies helped students to put themselves in the position of seeing the videos in order to learn, and to accept the videos concerned the teaching-learning processes. According to these results, the motivation to learn science was not automatic and depended on the strategies adopted to insert the videos in the classes.

Keywords: Multimedia and Hypermedia Learning, Teaching Practices, Video Analysis.

INTRODUCTION

The research literature on video use in Science Education has affirmed the motivating and facilitating character of learning of this resource (Frey, Mikasen, Griep, 2012; Cajigal *et al.,* 2014; Yerrick, Simons, 2017). There is also a constant concern to justify the use of audiovisual as valid and necessary to teach science (Rezende *et al*., 2015). However, the literature has not found answers related to how this motivation or learning facilitation is obtained, nor on which factors interfere with audiovisual teaching-learning. This leads us to consider that researches assume these potentialities of motivation and facilitation of learning are inherent to audiovisual. We disagree with this understanding, because the display of videos in teaching can also provoke resistance that leads, precisely, to the demotivation of students. In this context, teachers seem to be the central actors in the construction of the conditions and contexts of showing videos to teach science, because their actions turn to the need to insert and adapt the audiovisual to classes, so that it is related to teaching. We call this process of adaptation and appropriation "audiovisual readdressing" (Rezende *et al*., 2015). The readdressing results in new contexts for the presentation of the works, contexts that stimulate new reading goals related to the teacher's curriculum and teaching objectives. The teacher's mediation when showing audiovisual has been shown, therefore, to be a fundamental aspect of this practice. We present below the results of a research on the readdressing of audiovisual materials in Chemistry classes. We assume that films and videos are always addressed (Ellsworth, 1997), and their use for educational purposes potentially involves some kind of adaptation.

When readdressing videos or films, the teacher performs actions that interfere with the reception and the way of reading them. This mediation, therefore, is an action that can affect not only the meaning, but also the way in which information is presented, the story is narrated, or the characters represented, among other aspects. Thus, when showing a commercial film, for example, the teacher may be interested in showing certain aspects that his students would not give relevance in another context.

Readdressing thus implies building a specific context to (re)watch a film in the classroom, considering educational purposes such as identifying, understanding or deepening the scientific concepts more or less evident in the film. Therefore, the concept of readdressing aims to specifically study the displacements of spectatorship produced by the teaching-learning situation as conditions for this situation.

Based on this understanding, we formulated this study guided by the following question: how do chemistry teachers integrate films and videos into their classes to make students understand them as learning resources and thus motivate them to learn science? The aim of this study was to identify what audiovisual readdressing strategies they adopt to relate teaching objectives and audiovisual materials and to motivate students' interest in the discussion and learning of chemical concepts.

METHODS

As the main theoretical framework, we used the concepts of modes of address and readdressing. We started from the premise that films and videos are always addressed (Ellsworth, 1997), and that their use for educational purposes implies adaptation. Readdressing is a new address produced from the conditions built by the teacher to display a film and taking into account its original address. Other concepts were included throughout the analysis, such as coviewing and intertextuality. According to Kirkorian, Wartella & Anderson (2008) *coviewing* is observed when, for example, children watch television programs in the company of a mediator (parents, siblings, guardians). These, through comments on what is seen, can control, stimulate and monitor the child's production of meaning. *Intertextuality* is defined as the insertion of other texts, audiovisual or not, to be read in the light of each other, thus potentially modulating their meanings (Werner, 2004).

The methodology of this study is organized according to the articulation of several stages and instruments, also considering the necessary articulation between the data produced. Thus, in order to achieve the main objective of the studies, it was necessary to describe the classes with video and the actions taken to adapt the selected material to achieve the teaching objectives. As a result of this procedure, and in a complementary way to it, it was necessary to analyze the specificities of the chosen films and videos, identify the teaching objectives of the teachers and, to some extent, the knowledge they mobilized to build the readdressing. The survey was designed in this way in order to generate enough data for the readdressing analysis.

The participants of this study were three teachers and three classes of students (50 students in total) of Chemistry of a public high school in Rio de Janeiro (Brazil). This school was chosen because it met the following criteria: to offer the necessary conditions for the use of audiovisuals, and to have a teaching staff with experience and solid disciplinary background. Teachers were selected through questionnaires that identified the frequency and type of use of audiovisual in the teaching of Chemistry. The participating students were those present in the observed classes.

The data produced came from the analysis of the videos displayed, observation of the participating teachers' actions during the classes in which they displayed videos, and individual in-depth interviews with the teachers.

Data collection was done through notes in a field diary and voice recordings of teachers during classes and interviews. The recordings and interviews were transcribed and, as well as all the documentary material, were analyzed using a specific instrument of analysis developed by the authors. The videos shown in class were analyzed so that fundamental elements of their original address were identified, such as objectives, preferential meaning, content, language and aesthetic elements that would allow assessing which audience is potentially included or excluded as a preferential audience, that is, their address (Ellsworth, 1997). This information is important to analyze how the address is modified or not through readdressing strategies. In addition, the identification of elements that characterize the address is a central procedure to understand how these elements are displaced or highlighted, what emerges or disappears and what must be inserted by the teacher in his proposal for the student to see the film from a certain point of view and with a specific objective. Such aspects were considered as part of the construction of a specific "spectator place" from where the student should see the work in order to learn.

The observation of classes was adopted as a procedure because it would allow us to describe the teachers' actions when showing videos and identify those that were related to readdressing. From the observation we obtained data on what exactly teachers do to adapt the video(s) to their classes. These data refer to any and all teachers' actions concerning the video(s), such as interruptions, explanations, and notes. They also turned to those actions that referred directly to the "public", that is, to the students. With this information, we analyzed how audiovisual was inserted in the classes (with what objectives, what functions were assigned to them, etc.), as well as which care was taken to adapt them to the class (explanations, cuts, editions, etc.) and to the teaching objectives.

The interviews, in turn, helped us to identify the reasons why the teachers decided to adopt the procedures and cautions effectively adopted during the class, in addition to deepening the questioning about aspects of the class that were not clear during the observation. We also requested access to the participating teachers' planning, contents, class objectives and, mostly, to the audiovisual materials that would be used. These materials were analyzed prior to the observation of their exhibition in class with French Film Analyses (Vanoye & Goliot-Lété, 1993).

RESULTS

In the first class observed, the teacher used an audiovisual report that focused the controversy about the construction of a hydroelectric power plant. The students watched in *coviewing* with the teacher and, later, she inserted some concepts of Chemistry that were not part of the video, through the reading of a printed text (intertextuality). In the debate after the video was presented, the teacher sought to control the meanings produced by the students. We observed resistance on the part of the students to the reading of the teacher, since they positioned themselves in a convergent sense to the meaning conceived by the producers of the report, and not to that defended by the teacher.

The discussion after the video generated a dispute over its meanings. In general, the students were in agreement with the perspective adopted by the reportage. However, throughout the debate, the teacher negotiated the meanings that she initially defended, and reconsidered her position in the face of some students' objections, sometimes converging with their reading. The readdressing strategies made by the teacher were aimed both at the insertion of scientific concepts (intertextuality) and at coviewing, in this case in a clear attempt to control the students' reading, even without success. There was, therefore, a prevalence of the preferred meaning of the video over the teacher's coviewing. The interaction between the teacher and the students built new readings of the materials used, despite the attempt to control the students' readings.

In the second observation, the teacher exhibited the American feature film *Erin Brockovich*. She chose this film because there was a specific scene about the relationship between oxidation number and water contamination. The teacher aimed to relate the socio-environmental problem focused in the film to the recent ruptures of mining waste dams in Brazil. In the classes, the reading of journalistic reports (intertextuality) after the screening of the film in two parts aimed to direct students to relate the dam ruptures and chemistry content, through the example presented in the narrative of the film. The analysis of the film indicated that its preferred meaning addressed questions about, for example, female empowerment and citizen action, and not exactly concepts of Chemistry. Nevertheless, the teacher used strategies such as scene repetition, *coviewing* and intertextuality to direct students' readings to the relations between chemistry and environmental pollution. The readdressing actions evidence the teacher's intention to provoke a spectatorial shift: from a common spectator to a Chemistry student. This shift seems to have occurred, since the meanings established by the students corresponded to the teacher’s intertextual referral, albeit within certain limits. The dominant understanding of the students followed the teacher's orientations.

In the last class observed, the teacher exhibited a set of videos whose contents converged to an expanded discussion about organic functions and illicit drugs. The teacher's motivation to show these videos lies primarily in their recognition of correct and quality content. But the teacher identified in these videos not only relationships with the content of the Chemistry class, but also their suitability for the age group, the level of knowledge or maturity for discussion and some of the students' tastes, needs and interests.

Despite being didactic videos, the teacher made edits to adjust its duration to the available class time and inserted conceptual information through his speech (coviewing) and slides (intertextuality). These modifications of the videos were subtle, but necessary to insert them in the reading path the teacher wanted to reinforce. Thus, the main readdressing strategy was coviewing. Coviewing occurred when the teacher shared information before and during the video, and orally guided students. He prepared students to view images with human organs and emphasized what they should observe and understand from the videos. Thus, it is presumable that the action of preparing to view human organs was done with the intention of reducing resistance to the video content, as well as the sharing of information during the exhibition to reduce difficulties of understanding or biases. These statements aimed to reduce both possible resistance to the visualization of the images, as well as questions and misunderstandings. In addition, the strategy of using slides and the insertion of complementary and conceptual information between the videos (intertextuality) were also strategies of readdressing, which, as well as coviewing, contributed to the effectuation of the student's displacement to the position of "apprentices of Chemistry", and not just "curious spectators".

DISCUSSION AND CONCLUSIONS

In this research, two main strategies of readdressing were found: coviewing and intertextuality. Coviewing proved to be a strong readdressing strategy in the observed classes. The main mark of coviewing in this research is the teacher's speech before, during or after the videos are shown. Among its functions, we found to direct and modify the meanings produced by the students (control of the polysemy of readings), reduce resistance to the characteristics of the videos, and draw the attention of the students to certain aspects of what was displayed.

Intertextuality, on the other hand, was also frequently adopted in the classroom. The functions of intertextuality were to promote associations of meanings between the texts used (and not only of the videos); direct students to the objectives of the class, avoiding dispersions brought by the videos; and "didatize" the videos, encouraging them to be read "in the light" of each other, and not randomly.

Thus, readdressing actions generally had a regulatory effect, which sought to control the students' understanding and participation. Among its results, we may notice that the students' readings were more directed to the objectives of the class, and that there was, in general, recognition by the students of the appropriate pedagogical use of films and videos, as relevant and appropriate teaching materials for the classes. Coviewing and intertextuality strategies, among others, such as edits, cuts and different forms of exhibition, aimed at objectives such as preparing to watch the video, complementing and "didacticizing" the content, approaching the students' universe (in a kind of contextualization), and the control or reduction of resistances.

Thus, coviewing and intertextuality collaborated so that the students, as spectators, placed themselves in the position of seeing what was exhibited in order to learn (Odin, 2000), and to accept that the videos concerned the teaching-learning processes in which they participated. The construction of this position can be noted when students were encouraged to put the expectations of entertainment they could have in the background, and to devote themselves to occupy the position of "science learners", as in the class with the film *Erin Brockovich*, or when students watched videos about illicit drugs to "learn Chemistry", and not just for an individual curiosity. On the other hand, they also reinforced a position of study in front of the videos, directing their reading and understanding to objectives related to the discipline and the subject taught. Therefore, the actions performed by the teachers, when showing films and videos in class, were directed to create a context that made the students understand that the materials displayed concerned the contents and objectives of the class, and therefore were of interest to their learning. Thus, the motivation to learn science came from the set of activities in which the video was included, and not from it alone.

In relation to literature, this research allowed us to question how much one can actually assume that the exhibition of films and videos in science teaching is automatic and necessarily motivating. As we have seen, depending on factors such as the type of audiovisual, its duration, the activity in which it is inserted and the mediation of the teacher, the exhibition can provoke resistance that leads, paradoxically, to the failure of the activity and, precisely, to the demotivation of the student.

Likewise, no matter how much readdressing strategies try to build a fixed, coherent and inclusive position for the students, having a regulatory effect, the students, in general, have kept their autonomy in the production of new meanings. Thus, to be motivated to teach with audiovisual, students first needed to realize that this material concerns them, and also concerns the teaching-learning processes in which they participate. This audiovisual potential seems to depend on the strategies adopted by teachers to insert audiovisual in the class.

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EFFECTS OF DOING HOME EXPERIMENTS WITHIN A CHEMISTRY CITIZEN SCIENCE PROJECT

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Citizen science has become increasingly popular in many areas of research, in particular in biodiversity, ecological and environmental sciences. In addition to its scientific potential, many citizen science projects aim to promote citizens' education and sensitivity to environmental issues. In an ongoing chemistry citizen science project in Northern Germany, in which citizens monitor nitrate values in local waters, educational aspects are supposed to be fostered by conducting home experiments. In an accompanying study, the effects, such as an interest in science and nature, self-efficacy for environmental action concerning the nitrogen problem and scientific enquiry skills, are being assessed. The initial results show slightly positive effects that are irrespective of gender or age. To gain deeper insights into the potential of home experiments in connection with citizen science projects, qualitative interviews, based on the initial findings that are presented in this study, will be conducted.

Keywords: Society and Environmental Education, Informal Learning Environments, Self-efficacy

INTRODUCTION

Citizen science, in which members of the public actively participate in scientific research, can be traced back hundreds of years. It has paved the way for our current understanding of nature and the environment to a significant extent (Miller-Rushing, Primack, & Bonney, 2012). In recent years, citizen science has experienced an enormous growth and also change, proving its potential, not only for collecting scientific data but also for fostering educational aspects and environmental awareness of participating citizens (Brouwer, van der Wielen, Schriks, Claassen, & Frijns, 2018; Conrad & Hilchey, 2011).

Several studies have examined participant learning outcomes in citizen science projects, and have shown that participating in such projects can have a positive impact (Hiller & Kitsantas, 2014; Peter, Diekötter, & Kremer, 2019). There are also studies that reveal no significant change in aspects such as attitude, scientific knowledge and understanding or scientific skills (Brossard, Lewenstein, & Bonney, 2005), which leads to the question of how citizens can be further supported in their learning process. This support can vary, depending on the anticipated learning outcomes as well as the number and location of the participants. Although various supporting opportunities have been reported, including interactive, digital platforms (Herodotou, Aristeidou, Sharples, & Scanlon, 2018), training programmes (Cronje, Rohlinger, Crall, & Newman, 2011), accompanying reading material and the performance of experiments to gain deeper scientific insights (Kruse, Kiessling, Knickmeier, Thiel, & Parchmann, 2020), little research has been conducted on the effectiveness of these actions.

To address this research gap, a citizen science project has been designed and is being carried out in Northwest Germany (Brockhage, Lüsse, Pietzner, & Beeken, 2021). In this project, students and citizens conduct research together with scientists on the nitrogen pollution of local waters. Around 200 students have been trained in different ways to become experts, for example in student laboratories and online seminars, which enables them to support the allocated citizens. Most of the 600 participating citizens have received material to fundamentally elaborate on the topic. The focus of our study, however, lies on around 100 citizens who received optional training through the so called 'Nitrogen Box'. This box contains an experimental kit with information material and home experiments that allows these citizens to gain a deeper understanding of the topic, including an understanding of the nitrogen cycle and an investigation of fertilizers and legal bases, for example. In a school setting, home experiments have already been successfully implemented, albeit in the field of electrochemistry, and were perceived positively by the participants (De Vries, Martin, & Paschmann, 2006). In the context of citizen science, the potential of home experiments has not yet been investigated. An exploration of the following research questions should help to close this research gap:

1. How are the content and the handling of the Nitrogen Box perceived by citizens?
2. What impact does the use of the Nitrogen Box have with respect to interest in science and nature, self-efficacy for environmental action concerning the nitrogen problem and scientific enquiry skills?
3. How do interest, self-efficacy, scientific enquiry skills and perceptions of the content and handling of the Nitrogen Box differ with respect to the gender, age and educational level of the citizens?

CITIZEN SCIENCE AND SCIENCE EDUCATION

Citizen science, also referred to as public participation in scientific research (Bonney, Ballard, et al., 2009) or community-based environmental monitoring (Conrad & Hilchey, 2011) describes the participation of non-professionals in authentic scientific research, in partnership with professional scientists and institutions (Dickinson et al., 2012). The degree of participation, however, can vary and is categorised into different project types. In contributory projects, the project structure and goals are defined by researchers and the public is primarily involved in data collection. In collaborative projects, citizens not only collect data but also help in other parts of the project, such as data analysis and the dissemination of findings. In co-created citizen science projects, at least some, if not all, citizens get involved in almost all aspects of the research process (West & Pateman, 2017).

Many citizen science projects do not only focus on the collection of scientific data but also, or even mainly, pay attention to citizen education (Jollymore, Haines, Satterfield, & Johnson, 2017; Kelemen-Finan, Scheuch, & Winter, 2018). In Europe, educational objectives are pursued by the COST Action CA15212 'Citizen Science to Promote Creativity, Scientific Literacy, and Innovation throughout Europe' (COST Association, 2016; Roche et al., 2020). According to PISA 2006, scientific literacy is characterised by 'scientific knowledge and use of that knowledge to identify questions, acquire new knowledge, explain scientific phenomena and draw evidence-based conclusions about science-related issues', by 'understanding of the characteristic features of science as a form of human knowledge and enquiry', by the individual's reflective behaviour and 'willingness to engage with science-related issues and with the ideas of science' as well as the 'awareness of how science and technology shape our material, intellectual, and cultural environments' (OECD, 2006). Scientific literacy does not only address knowledge about science and the environment but also comprises how individuals respond to scientific and environmental issues, which can be reflected in the interest for science, scientific enquiry and a willingness to take on responsibility for sustainable development (Bybee, 2008; OECD, 2006). The attainment of scientific literacy aims to enable learners to actively participate in socio-scientific issues, socio-political action and dialogical processes concerning science-related and environmental issues (Liu, 2013; Santos, 2009). The potential of citizen science in this context has already been outlined by Bonney, Cooper, et al. (2009). However, these researchers identified the measurement of the improvement in the participants' scientific literacy as being challenging. By reviewing citizen science projects investigating educational impacts, Bonney, Ballard, et al. (2009) developed four categories to set the first steps towards assessing the project impact. The categories are 1) awareness, knowledge and/or understanding, 2) engagement or interest, 3) skills and 4) attitudes and behaviours. Phillips, Porticella, Constas, and Bonney (2018) continued this work by extensively examining the learning outcomes in citizen science, based on other studies in the field of informal science education as well as on survey data of citizen science projects, to develop a framework to describe and evaluate learning outcomes (Table 1).

Table 1: Framework for articulating and measuring individual learning outcomes from participating in citizen science, according to Phillips et al., 2018

Learning outcome	Description
Interest	The degree to which an individual assigns personal relevance to a scientific or environmental topic or endeavour
Self-efficacy	The extent to which a learner has confidence in their ability to participate in a scientific or environmental activity
Motivation	The goal-driven inclination to achieve a scientific or environmental behaviour or activity
Content, process and nature of scientific knowledge	Knowledge of scientific content and the nature of science; understanding of the scientific process and how science is conducted
Skills of scientific enquiry	Procedural skills, such as asking questions, designing studies, collecting, analysing and interpreting data, experimenting, reasoning, synthesising, using technology, communicating and critical thinking
Behaviour and stewardship	Measurable actions resulting from engagement in citizen science, such as place-based and global stewardship, new participation and community or civic action

HOME EXPERIMENTS IN CHEMISTRY TEACHING

Using home experiments, also known as kitchen chemistry, to supplement or even replace laboratory experiments has mainly been tested and evaluated in higher education institutions, such as universities, in particular in the context of distance education (Kennepohl, 2007; Lyall & Patti, 2010). The closure of campuses in 2020 and 2021, due to the COVID-19 pandemic, has intensified the need for alternative distance learning opportunities in chemistry education in both schools and universities (Domenici, 2020; Schultz, Callahan, & Miltiadous, 2020). A descriptive study by Sari, Sinaga, Hernani, and Solfarina (2020) in this context has shown that to perform home experiments, easily accessible materials that are already available at home are preferred. However, it is occasionally necessary to purchase special chemicals and materials or to create virtual laboratories. The effectiveness of virtual laboratories in comparison to hands-on laboratories is relatively unexplored so far (Domenici, 2020). The effect of home experiments in 7th grade, however, has been explored by Gendjova (2007), showing that the use of home experiments can increase pupils' interest in, knowledge of and satisfaction with chemistry. These positive effects may account for the connection of chemistry to contexts that are relevant to life. In such contexts, pupils are encouraged to design their own investigations, which is an essential part of fostering their decision-making competences (Gendjova, 2007; Yip et al., 2012). In citizen science contexts, the use of home experiments has not yet been investigated. Nevertheless, possibilities for further citizen involvement in learning and research processes are of research interest (Oliveira, Jun, & Reinecke, 2017). Designing suitable home experiments in citizen science contexts can be particularly challenging, in particular when they concern the fundamental questions that were formulated by Lyall and Patti (2010): 'Who is the target audience?', 'What is the purpose of the experiments?' and 'What are the expected outcomes?'. In comparison to formal education contexts, prior knowledge and experience of participating citizens can be unknown and, above all, extremely diverse.

THE NITROGEN BOX

Through anthropological processes, mainly in food and energy production, the release of reactive nitrogen compounds has increased globally, which causes multiple effects in the atmosphere and in ecosystems and has effects on human health (Galloway et al., 2003). In Germany in particular, surplus reactive nitrogen is considered to be an environmental challenge that results in consequences such as biodiversity loss, reduced groundwater quality and possible effects on human health (Salomon et al., 2016). Governmental approaches to tackle these issues have not yet achieved the desired improvement and conflicting interests of different stakeholders further increase the complexity of this problem (Kastens & Newig, 2007; Kirschke, Häger, Kirschke, & Völker, 2019).

The intention of the Nitrogen Box is to pass on information in a simple, understandable and comprehensive way, enabling citizens to critically reflect on the media presentation of the topic as well as on their own behaviour and attitudes. As shown in Figure 1, the box contains two booklets, equipment, and chemicals. One booklet contains information and answers to questions such as how nitrogen is released and distributed in the environment, what consequences are to be expected when too much reactive nitrogen is released, which laws exist on this topic, how water can be kept clean and how every individual can contribute to environmental protection. Instructions for 15 suitable home experiments that are related to these topics are described in a second booklet:

1. Testing water samples for ammonium ions
2. Testing water samples for nitrate ions
3. Examining the root nodules of legumes
4. Urea decomposition in soil
5. Nitrogen oxides in waste gases
6. Adsorption of ammonium and nitrate ions in soil
7. The effect of urea on soil
8. Investigating the nitrate levels of fruit and vegetables
9. Nitrate and nitrite in spinach
10. Nitrate levels in pickled meat
11. Colour development in pickled meat
12. The effects of different nitrogen inputs on plant growth using cress as an example
13. Determining the nitrogen content in soil
14. Soil nitrogen mineralisation
15. Nitrate removal by means of ion exchange

Figure 1: The Nitrogen Box

All experiments can easily be conducted at home with the aid of the included equipment, chemicals, and general household products such as a funnel, spoons, and jars.

METHOD

A first version of the Nitrogen Box was made available to 13 schools that are participating in the citizen science project. Teachers' feedback after using the box with their pupils was used to improve the box for citizens. Thereafter, out of approximately 630 citizens who are taking part in the citizen science project by regularly measuring nitrate values of a self-chosen water body, around 100 citizens had the opportunity to sign up for the Nitrogen Box. They received the experimental kits by post in August and September 2020, including a four-sided post-questionnaire to evaluate the potential effects of the home experiments. A post-questionnaire only (instead of both a pre-questionnaire and a post-questionnaire) was used since a much lower response rate was expected for combined pre- and post-testing. Therefore, prior validated scales by the Cornell Lab of Ornithology were adapted and translated to evaluate specific targeted learning outcomes. The 12-item 'interest in science and nature' scale (Phillips, Porticella, Bonney, & Grack-Nelson, 2015), the 8-item 'self-efficacy for environmental action' scale (Porticella, Phillips, & Bonney, 2017) as well as the 12-item 'skills for science inquiry' scale (Phillips, Porticella, & Bonney, 2017) were used. All scales were 5-response Likert scales, ranging from 1 for strong agreement to 5 for strong disagreement. Additionally, the citizens were asked to rate the quality, content, and handling of the Nitrogen Box for 12 items related to the included brochure and the experiments, using the same 5-response Likert scale.

RESULTS

In total, 97 citizens received the Nitrogen Box and 36 citizens (25 males, 10 females, 1 N/A), aged between 17 and 83 years, completed the questionnaire. For data analysis, IBM SPSS statistics 27 was used. Regarding the content and handling of the Nitrogen Box, a mean value of 1.75 (SD = 0.51) on a scale ranging from 1 for positive perception to 5 for negative perception was calculated. For the evaluation of the possible impacts of the Nitrogen Box regarding learning outcomes, descriptive statistics were used as well. Interest in science and nature has been rated with a mean value of 2.62 (SD = 0.88), self-efficacy for environmental action concerning the nitrogen problem with a mean value of 2.84 (SD = 0.55) and scientific enquiry skills with a mean value of 2.16 (SD = 0.61), on a scale ranging from 1 for strong impact to 5 for no impact. Mann-Whitney U tests were used to evaluate the possible effects of gender, age, and educational level on the perceptions of the Nitrogen Box, as well as on learning outcomes. As shown in Table 2, no significant differences regarding gender were found.

Table 2: Effect of gender on perceptions of the Nitrogen Box and on learning outcomes.

Factor	Gender	M_{Rank}	U	Z	p
Perception of the Nitrogen Box	Male	19.76	81.000	-1.609	0.113
	Female	13.60			
Interest in science and nature	Male	17.60	93.500	-0.586	0.564
	Female	15.39			
Self-efficacy for environmental action	Male	16.05	83.000	-0.524	0.625
	Female	14.22			
Scientific enquiry	Male	16.86	80.000	-0.829	0.428
	Female	13.89			

To evaluate the possible impacts of age, the sample was divided into two age groups, with half the sample aged between 17 and 51 years old and the other half between 52 and 81 years old. Mann-Whitney U tests showed no significant effects regarding age (Table 3).

Table 3: The effect of age on the perception of the Nitrogen Box and on learning outcomes.

Factor	Age (years)	M_{Rank}	U	Z	p
Perception of the Nitrogen Box	17-51	16.71	131.000	-0.466	0.658
	52-81	18.29			
Interest in science and nature	17-51	16.53	127.000	-0.019	1.000
	52-81	16.47			
Self-efficacy for environmental action	17-51	15.91	89.500	-0.641	0.531
	52-81	13.88			
Scientific enquiry	17-51	16.03	101.500	-0.377	0.711

	52-81	14.81

The only statistically significant difference was found for the perceptions of the content and handling of the Nitrogen Box between citizens with academic degrees ($M_{Rank} = 13.02$) and those without an academic background, as shown in Table 4 ($M_{Rank} = 24.95$; $U = 33.500$, $Z = -3.364$, $p < 0.001$, $r = -0.58$).

Table 4: The effect of academic background on the perceptions of the Nitrogen Box and on learning outcomes.

Factor	Academic degree	M_{Rank}	U	Z	p
Perception of the Nitrogen Box	Yes	13.02	33.500	-3.346	< 0.001
	No	24.95			
Interest in science and nature	Yes	17.26	78.500	-1.121	0.268
	No	13.35			
Self-efficacy for environmental action	Yes	14.63	83.000	-0.124	0.923
	No	14.22			
Scientific enquiry	Yes	14.63	82.500	-0.354	0.729
	No	15.83			

DISCUSSION AND OUTLOOK

The results show that the use of the Nitrogen Box in the context of a chemistry citizen science project tends to have slightly positive effects on the participating citizens' interest in science and nature and on the self-efficacy of citizens to engage in environmental action concerning the nitrogen problem. A greater positive effect can be identified regarding scientific enquiry skills. The minor increase in the interest in science and nature may be due to the assumption that many citizens were already very interested in the topic before using the box, which might not have left much room for further enhancement. However, because of the low number of participants, the study was limited in delivering representative results.

Overall, more men than women participated in the study, which is a typical phenomenon in citizen science projects (Price & Lee, 2013) and one that should be further investigated. Significantly more positive perceptions could be seen among citizens with an academic background than among those without an academic background. This could be caused by the extent and complexity of the material in the box. On the one hand, the Nitrogen Box was designed to be as simple and as understandable as possible but, on the other hand, the content and tasks were made to challenge the citizens and encourage them not only to think critically but also to support their creativity and decision-making abilities with regard to conducting the experiments (Yip et al., 2012). Therefore, simple straightforward tasks and experiments were included as well as more difficult tasks and experiments and longer experiments.

When using experimental kits in a citizen science context in the future, even more attention should be paid to the design of the material and the experiments. Possible opportunities include more and clearly marked differentiation and learning support. Another option would be to reduce the overall scope of the material and the number of experiments. However, although the experimental kit would be overstretching some participants less, it would possibly be too simple for others.

Therefore, to gain a deeper understanding, qualitative interviews with some of the participants have been conducted and will be evaluated in the context of future research. It is expected that through these interviews, information regarding the added value of experimental kits in citizen science contexts can be obtained. Additionally, these interviews may lead to recommendations for future citizen science projects about the way in which such experimental kits should be created, as far as scope and complexity are concerned.

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NAVIGATING MICRO AND MACRO LEVELS OF AGENT-BASED SIMULATIONS TO BUILD ANALOGIES WITH REAL-WORLD ISSUES

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Agent-based simulations are important tools not only for scientists and experts but also for policymakers and citizens that are called to make decisions on these issues. However, simulations are complex tools that require specific competences to be correctly interpreted. In this paper we address the issue of analogies' construction between NetLogo simulations and real-world problems by two groups of upper high school students involved in a future-oriented activity. The analysis shows that the students articulate their analogies alternating reasonings that are typical either of the macroscopic or the microscopic level of the simulation. Effective strategies connect these two levels by identifying and discussing the mechanisms of interaction underlying the evolution of the system, leading to more complete and productive analogies.

Keywords: simulations, analogy, models

INTRODUCTION

Computational simulations are a prominent part of an ongoing revolution that, since the 50s, is changing the ways of doing science and conducting research (Hey, Tansley & Tolle, 2009; Vespignani, 2019), especially in those disciplines that deal with complex systems (Bar-Yam, 2016). However, rather than being a prerogative of scientists, professionals, and experts of the respective disciplines, they have reached the non-expert public. Indeed, in the last decade, for the climate change emergency and recently for the COVID-19 pandemic, citizens have been called to enter social debates and decision-making processes also based on these tools (Schultz, 1974; Lyons, Adjali, Collings & Jensen, 2003).

Simulations have been the object of study of many researchers in science education who have investigated their educational potential as well as the challenges they pose to students' learning. Indeed, even simulations commonly used in education (Greca, Seoane & Arriassecq, 2014) are complex tools that embed a variety of knowledge forms, each of them can trigger more or less productive ways of reasoning depending on the context (Barelli, 2022). Moreover, as particular types of models, simulations can challenge novices' understanding: since all simulations represent a "cut" with respect to the simulated phenomena, a mature epistemological posture is required to fully appreciate them as scientific tools (Barelli, Branchetti & Ravaioli, 2019). Because of this gap between "the real" and "the modelled/simulated", understanding and constructing analogies is crucial for students to enter more in depth in the conceptual aspects of the models and simulations, and to become able to apply them in other contexts (Gilbert & Osborne, 1980; Coll, France & Taylor, 2012).

In this paper we present a study conducted with upper high school students during a future-oriented activity in which they had to analyse a real-world problem of their interest and develop future scenarios based on NetLogo agent-based simulations. The goal of this paper is to investigate how students engaged in a process of analogies' development to move from simple "toy" models to complex real-world issues. For the scope of the article, we will not discuss the correctness of students' analogies, because we focus on characterizing their analogical reasoning based on the elements considered.

FRAMEWORK

The educational issue of constructing analogies

An analogy can be defined as "a comparison between two objects, or systems of objects", usually named source and target, "that highlights respects in which they are thought to be similar" (Bartha, 2019). Philosophers of science have conceptualized different forms of analogies, spanning from *material* i.e., the similarity is recognized because of common observations between the source and target domains, to *formal* analogies i.e., source and target are seen as interpretations of the same formal theory (Hesse, 1966). The development of analogies is an authentic scientific practice and many times, in the history of science, analogies have been drivers of scientific discoveries. We can cite for example Maxwell, whose extensive use of analogies with fluid-dynamics was crucial to develop his electromagnetic theory (Nersessian, 1984). In the field of complex systems, the analogical reasoning has allowed to transfer knowledge obtained within a specific domain to different ones, leading to explanations and models in a wide range of disciplinary fields. It is the case of the Ising model, elaborated within physics to describe magnetic properties of materials but that provided the basis for the interpretation of phenomena in social sciences, for example the formation of opinions and voting preferences (Castellano, Fortunato & Loreto, 2009).

In science education, the role and potential of analogies to support conceptual learning has been an issue of discussion for decades (Duit, 1991). Following constructivist views of learning, analogies are retained crucial since they reflect the essential need of understanding the unfamiliar (the target of the analogy) based on what is already familiar (the source). They have a role also in processes of conceptual change as *bridges* that facilitate the "transition of intuitions" from domains known by the learners to other situations that are initially more problematic and not recognized as analogous to the former (Brown, 1994). However, the process of analogy's understanding and construction is not always straightforward for students. They rarely generate their own analogies (Wong, 1993) but, also when they are given a source and a target linked by an analogical relationship, the mapping process often leads the students to alternative conceptions that go beyond the original scope of the proposed analogy (Harrison & Treagust, 2006). Research on cognition at stake in analogical reasonings has pointed out a significant distinction between analogies constructed based on surface elements' likenesses or process similarities (Carey, 1985). The former, that do not involve any causal characterization of the system or object of reference, are easy to map and favour analogy identification, but the latter lead to deeper thinking and conceptual understanding of both the source and target systems or objects (Holoyoak & Koh, 1987). The distinction between surface and process elements, as well as that between material and formal analogies, set the framework for delineating our levels of analogies' construction based on agent-based simulations.

Agent-based approach to the simulation of complex systems

Most simulations of complex systems can be categorized as equation-based or agent-based. In the former case, the system's evolution is described with differential equations; once they are solved, they give the future state of the system starting from the present. On the opposite, in agent-based simulations, the dynamics of the system is generated making the individual agents evolve according to behavioural rules. Since the 80s, researchers in science education have highlighted the potential of agent-based simulations to foster understanding of systems and to enter the mechanistic dimension of local interactions (Wilensky & Reisman, 2006). Indeed, the understanding of the basic mechanisms of natural phenomena is considered a relevant component of students' sensemaking about those phenomena (Kapon, 2016). The same happens with complex systems, where explanations of the emergent properties must lie on the recognition of mechanistic elements of interaction among components (Barth-Cohen, 2018) and on the connection between macroscopic and microscopic levels (Samon & Levy, 2017). For this study, three NetLogo agent-based simulations (Wilensky, 1999) were chosen as the basis for the future-oriented activity.

<u>Wolf-sheep predation</u> implements a predation mechanism. Two kinds of agents (wolves and sheep) move randomly around a grid. When a predator and a prey meet, the wolf eats the sheep. Each movement costs the wolves energy, and they must eat sheep to replenish their energy, otherwise they die. At each time step, each wolf or sheep has a fixed probability of reproducing. For what concerns the behaviour of the sheep, the simulation has two variations. In the case the grass is modelled as infinite, sheep always have enough food and cannot die from starvation. In the second variation, the sheep must eat grass to maintain their energy and when they reach zero-energy die; moreover, once grass is eaten it only regrows after a fixed amount of time. The two variations lead to different evolutions of the system: while with infinite grass unstable dynamics are produced, when a limit is set on sheep's resources, we observe stable dynamics.

<u>Voting</u> implements a model of opinion dynamics. There are two kinds of agents identified with a binary variable - namely the "opinion". At the beginning, the agents are placed randomly on a grid. Each agent, at each time step, counts the number of neighbours of each kind and keeps or changes its own opinion following the majority. Letting the simulation run, the system reaches a configuration with clusters of agents with the same opinion.

<u>Cooperation</u> implements an evolutionary biology model. There are two kinds of agents that differ for their behaviour in consuming food: greedy cows eat the grass regardless of its quantity, while cooperative cows do not eat the grass if it is below a certain height (below a certain height, the grass grows at a slower rate). When the cows eat, their energy increases, and they can eventually reproduce. When the simulation runs, we observe that, if the cows can frequently move around, the greedy behaviour wins, otherwise the cooperative behaviour is evolutionarily successful.

THE FUTURE-ORIENTED ACTIVITY

The future-oriented activity of scenario building through simulations was part of an 18-hours module, designed and implemented online in January-February 2021. The participants were 35 upper high school students enrolled in an optional course on Simulations of Complex Systems, organized within the orientation programs of the National Scientific Degrees Plan in synergy with the IDENTITIES (www.identitiesproject.eu) and FEDORA (www.fedora-project.eu) projects. The module comprised conferences of experts, roundtables with researchers and interactive lectures. A lecture was devoted to the comparison between equation- and agent-based models and the analysis of the three NetLogo simulations presented in the previous paragraph. The module ended with a future-oriented activity (Levrini et al., 2021) in which students were divided in seven groups. The tasks assigned to the students are reported in Table 1. For the purposes of this contribution, we will focus on the first and second task of the activity, where students had to identify a problem of their interest and find a simulation that could help them to model this new problem.

Table 1. Tasks of the future-oriented activity.

Task 1 - Identify the problem
Pick a problem that you feel urgent today and you would like it resolved in 2040. The problem can concern any context: your schools, your city, Italy, Europe, or the whole world. Each member of the group proposes a problem of their interest. Discuss everyone's proposals, then vote for the most convincing one.
Task 2 - Explore different possible futures
Inspiring yourself with the simulation you think is most suitable, explore possible evolutions of the problem from the present to the future and imagine what scenarios you could arrive at in 2040. Describe at least three alternative future situations that the simulation inspired you.
Task 3 - Imagine a desirable scenario for 2040
Now imagine that in 2040 the problem you selected has been solved. Describe in as much detail as possible your desirable scenario for 2040. Include in your description the stakeholders, the interests at stake, how people live in the context in which you are located, the elements of novelty and those of continuity with respect to the past. At this stage... dream! Throw your imagination beyond the obstacles of the present!
Task 4 - Back-casting and action planning
Starting from the desirable scenario, think about what actions, decisions, policies, contingencies made it possible to realize the ideal future in 2040. Were there any bifurcations, moments of uncertainty? What role have the stakeholders played?
Task 5 - Tell the story of success
Prepare a 10-minute presentation to do during the last meeting to tell everyone your success story of which you were the agents, the protagonists. To do this, decide on a name for your group with which to introduce yourself to others, give yourself a role in the story and develop a presentation method (a story, slides, a video ...). In the presentation, highlight the role that simulation has played for you in analysing the problem, imagining the scenarios, and creating your success story.

RESEARCH QUESTIONS AND METHODS

Framed within wider research on the role of agent-based simulations in carrying out future-oriented activities (Barelli, 2022), this study addresses the following research question: *In which ways did 17-18 years-old students constructed their analogies between simulations and real-world problems?* To answer this question, students' discussions in the groups have been video-recorded and analysed. The analytical process used qualitative methods inspired by grounded theory (Glaser & Strauss, 1967) with explicit back and forth dynamics, from bottom-up data exploration to their theory-oriented interpretation (Anfara, Brown & Mangione, 2002).

More specifically, the data analysis process was articulated in three main methodological phases. The first step consisted in performing the transcription and pseudonymisation of the video-recordings. Because we wanted to keep track of how much the single students talked in each line, the transcription also reported the time duration of each line and indicated moments of silence if present. Since the high time cost of the operation (seven groups, 3 hours of videorecording each), we performed the time-marked transcript for one group and compared the time distribution per student with that obtained substituting the time of each intervention with the number of words of the intervention itself, automatically calculated. Given the substantial similarity of the two graphs, we decided to measure the duration of students' interventions in words rather than in seconds. The second step consisted in selecting the parts of transcript in which the students referred to the three simulations to construct their analogies with the problem chosen; these were the parts that we coded with the categories of analogies development that we will present in the next section, obtained through an iterative process of enlargement of the empirical base until saturation. The final step consisted in the analysis of how the collective negotiation of the simulations to use for the future-oriented activity passed through different levels of analogy construction; guided by the obtained picture, we recognized in the succession of codes patterns and recurring elements.

FINDINGS

Microscopic and macroscopic levels of analogy construction

The first result that we want to present is the categorization that we reached about the levels on which the analogies were negotiated and progressively constructed by the students. In particular, they reasoned on macroscopic and microscopic levels. As detailed and exemplified in Table 2, we refer to the *macroscopic level of analogy* when students reason in terms of aggregate, collective features of the system such as: i) its context of application, ii) the scenarios obtained, and iii) the emergent interaction among populations or groups of agents. On the opposite, the *microscopic level of analogy* is related to the elementary "bricks" on which the simulation is built and is detected when students refer to: i) the types of agents of the system, ii) the meaning of parameters and other elements of the simulation, or iii) the models of interaction among individual agents embedded in the simulation. We stress that in both categories related to interaction, there is a reference to the mechanistic dimension and to causal processes. The difference between the two is that in a microscopic perspective the interaction occurs between individual agents (as actually coded in the simulation), while, in a macroscopic perspective, the students reason about an interaction between groups of agents that can only be observed as a result of the simulation's run.

Table 2. Categories of the levels of analogy development and examples of students' sentences.

Macroscopic level of analogy based on the:	
Macro 1 - Similarity between source and target contexts	"We are talking about different ways to see school so we are talking about opinions as in the voting simulation" [F2]
Macro 2 - Similarity between the imagined scenario for the target system and the simulated evolution of the source system	"I was thinking that voting, in the end, remains always constant because it does not describe an evolution… if we want to analyze a teaching method that evolves, voting is not correct because in a while we reach an equilibrium without analyzing how the change occurred… so, with predation is more adequate because we can see how one method disappears and the other grows" [M3]
Macro 3 - Similarity between the interactions among groups of agents	"As in the Lotka-Volterra model there is a fight between groups of people with different opinions" [F2]
Microscopic level of analogy based on the:	
Micro 1- Characterization of the agents	"With the voting simulation we could do that the blue color is the traditional teaching method while the green color is the innovative method that uses new technologies" [M4]
Micro 2 - Meaning of parameters and other elements of the simulation	"We could do that grass in this case is the level of patience of the students" [M4]
Micro 3 - Interaction among agents and other elements of the simulation	"Greedy cows are the old educational traditions and the cooperative cows are the innovative methods. Both are fed by the consensus of students but there are differences. The cooperative tend not to impose themselves to avoid consuming the grass, they spare the food and let it grow, as the students have time to get acquainted with the new methods. The others, the greedy cows, eat and force the students to their will and do not leave them grow" [F2]

Patterns emerging from the distribution of categories

The categories in Table 2 were used to code the parts of groups' transcripts in which the students discussed the choice of a simulation to analyse their problem of interest. To present the results of our analysis we focus on two groups of students that in the future-oriented activity addressed similar problems, both related to school. Group A focused on the predominance of obsolete teaching methods while Group B chose the high level of stress of students in the current organization of the school system. Moreover, the choice of the two groups was motivated by the fact that both analysed their problem of interest in analogy with the three models of reference. The result of the coding procedure is shown in Figure 2. Even if it can be immediately noticed that the discussion in Group A was longer and more articulate than that in Group B, a finer-grained analysis can be conducted looking at how the categories of analogy construction contributed to structure the discussion in the two groups.

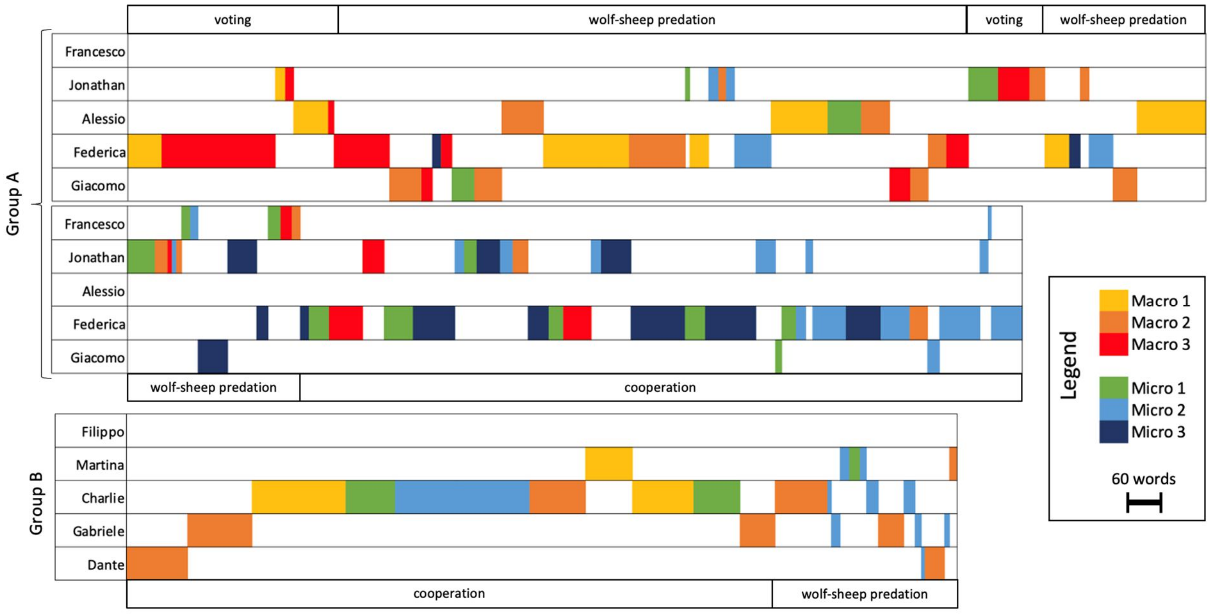

Figure 2. Coding of groups' discussion during the parts of the future-oriented activity in which the students had to choose a simulation to address their problem of interest.

The similarity between source and target contexts (yellow) is a criterion that was considered by both groups in the earliest stages of discussion and was useful to orient the choice of which simulation to take as reference. In Group A, at the beginning of the discussion, observations on the similarity of contexts were followed by reasonings on the nature of interaction between groups of agents displayed by the simulation (yellow-red pairs). This means that, from the beginning, the students not only identified a generic similarity between source and target but were also able to sketch out a possible macroscopic relationship between the groups at stake. This is not the case of Group B, in which the recognition of a similarity of contexts does not reflect an understanding of the underlying or emergent interactions.

As the discussion progresses, the focus on mechanistic dimension progresses from the macroscopic to the microscopic level. Indeed, in both groups we can observe an overall transition from warm to cool colours (even it is more evident with Group A, also due to the longer discussion). In the beginning, the simulations are mainly analysed from a macroscopic perspective; only when these aspects have been discussed, the group can focus on the details of the simulations from a microscopic perspective. It is worth noticing that, in Group A, the transition between macro and micro levels did not occur while reasoning on the same simulation. Indeed, the students were alternating considerations on the wolf-sheep predation and voting simulations until the moment they switched to the cooperation, that was the one they chose in the end. When they moved to cooperation, the students did not need to start from scratch reasoning on the macroscopic levels, such as the likenesses of contexts or the future evolutions of the systems. Indeed, it was the focus on the mechanism of agents' interaction that allowed them to break the previous analogy and move to another one. Then, after negotiating on the new interaction models embedded in the cooperation simulation, Group A was ready to conclude their analysis by mapping the role of parameters and of other elements of the simulation (light blue) in their context of reference. Also, Group B presents a predominance of this level of analogy development in the last part of the discussion, but the lack of a reflection on the mechanistic dimension in the previous part made their analysis rather weak and "blurry". Many interpretations were given to the parameters of the simulation, but none could be argued in the light of an understanding of the underlying mechanism.

A final result that deserves a comment is that in both groups not all the students were equally engaged in the process of constructing analogies. Some of them were completely excluded from the discourse, like Filippo (Group B), and others, like Francesco (Group A), had a marginal role. The case of Alessio (Group A) is even more significant. If we looked at the number and duration of his interventions in the other phases of the whole future-oriented activity, we would see that he was the second most talkative student after Federica for number of words and frequency of speeches. However, when it comes to discuss in depth the three agent-based simulations and develop analogies with the problem of interest, he almost disappears from the discussion and, when he talks, he touches only the macroscopic levels of the analogy, without addressing in any way the issue of interaction.

DISCUSSION AND CONCLUSIONS

In accordance with the cited literature in science education, our findings show that computational simulations are complex objects that are not easy to be correctly interpreted. These difficulties seem, in some cases, to resist instruction, because they have been observed even if the students were guided to analyse these simulations in detail before the task was assigned. In particular, the future-oriented activity made these difficulties emerge because we requested the students not only to analyse a simulation but to move from the level of the model to that of reality, thinking about a real-world issue.

We found that, in constructing their analogies between the source (NetLogo simulations) and their target (a problem of interest), the students put into play reasonings that were typical of the macroscopic or the microscopic level of the simulation. The groups progressively developed analogies alternating, following Carey (1985), observations of the "surface likenesses" of the two systems and a focus on the "similarity of processes" embedded. We stress that, in our categorization, surface-related aspects do not correspond with what we name the macroscopic level. Mapping agents or parameters of the simulations with the analogous elements in the real-life problem refers to a microscopic level of the simulation's analysis but regards issues of surface, since there is not any explicit reference on the processes i.e., the relationships between the agents. On the opposite, the focus on processes and mechanisms can characterize both the microscopic and macroscopic level of the simulation, since in the analogy both interactions between agents and between groups can be mapped.

Effective strategies of analogy's construction connected surface and process, macroscopic and microscopic levels by identifying and discussing the mechanisms of interaction underlying the system's evolution and to which extent these mechanisms were effective in modelling the issue at stake. On the opposite, a lack of focus on the mechanistic dimension resulted in an absence of "discrimination" (from the Latin word dis-cernĕre = to separate) criteria: without them, the different interpretations proposed by the students could not be distinguished and the potential of their comparison to construct a more robust analogy remained unexploited.

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Part 9 / Strand 9

Environmental, Health and Outdoor Science Education

Editors: *Albert Zeyer & Justin Dillon*

Part 9. Environmental, Health and Outdoor Science Education

Ecological and Environmental Education, Education for Sustainable Development, environmental health, health education and health promotion. Lifestyles and attitudes towards health and the environment. Developing and evaluating the impact of programmes and experiences outside classrooms, including those organized by institutions other than schools.

Part 9: Environmental, Health and Outdoor Science Education

Editors*: *Albert Zeyer, Justin Dillon

Introduction

In this strand, we present 18 papers mainly concerned with research on environmental education and education for sustainable development, mostly from European authors but also from Brazil and Japan. The themes discernible in the contributions vary from the UNs Sustainable Development Goals to the greenhouse effect and carbon footprints but also include classical environmental problems such as biowaste, awareness of native species, plastic waste and plant blindness.

Surprisingly, there is a remarkable absence of health issues even though the strand has recently been expanded to include health education. Only one paper (Selles et al.) thematises health education.

Most of the contributions investigate issues in school teaching. Curricula are analysed, educational materials and courses are designed, implemented and researched. Co-design is an issue discussed, as are school programmes involving different methods, from formal teaching to classroom games.

Some of the research reported on take place out of school. A French study (Marchal-Gaillard et al.) investigates the impact of parental composting practices on pre-school children's understanding of biowaste decomposition. Another study (Baruque et al.) incorporates a virtual outdoor experience in chemistry education by identifying local water issues in Brazil using Google Street view.

Research methods used in the contributions include surveys, textbook analyses and the development of scales and test instruments, and they give insight into many positive and critical aspects of teaching issues. For example, researchers aim tp improve students' action competency in sustainable development (Henke et al.) and support the flow experience during biology field trips (Lüking et al.). They identify inadequate answers to the plastic problem (Mar López-Fernández et al.) and inaccurate explanations of the greenhouse effect (Yoshimoto et al.) in textbooks; a mismatch of science communication in museum settings (Alfonso et al.); students' latent misconceptions of the carbon footprint (Galanis et al.); and reductionist visions of a purely instructive and moralising education (Selles et al.).

All in all, the Strand 9 papers represent an interesting panopticon of research into environmental and sustainability issues in Europe and, to some extent, beyond. However, it must also be said that the landscape of the research remains rather traditional and reproduces many points of view that have been researched over years in various versions. If these papers truly mirror the efforts of science education research in Strand 9 issues, then we have to note the absence of important and topical aspects.

Here, we can only sketch out some important questions. First and foremost, it must be asked why issues of health, prevention, and medicine are almost completely missing. In times of pandemic, the era of the informed patient and the century of non-infectious diseases, it must be asked why the obvious situation of mutual benefit between science education and health education rarely emerges in the contributions?

Another aspect that has been frequently discussed is the danger of reducing sustainability issues to environmental problems. Where is the interconnection of these problems with social, economic, and value problems reflected?

In general, important trends in today's science education research, such as argumentation and scientific practices, complexity and uncertainty, diversity, equity and inclusion, or identities and discourse analysis, seem not to be adequately reflected in the work presented here. Finally, movements such as the healthy planet or "One health" could provide important inspiration for our future research activities.

ENVIRONMENTAL SCIENCE AGENCY IN YOUTH: INSIGHTS FROM FIELD-BASED AND ONLINE CITIZEN SCIENCE

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Abstract. Environmental Community and Citizen Science (CCS) programmes provide opportunities for the public including young people to contribute to scientific research as well as opportunities for science learning. Understanding the extent and impact of participation in CCS on young people's learning is crucial to identify the setting and design features that enable youth to gain science knowledge and skills, develop an identity with science, and enact agency with science. We investigated young people's participation and learning in field-based and online CCS programmes led by natural history museums. We conducted and analysed field observations, surveys, and interviews to understand youth's participation and environmental science agency. Young people gained knowledge of science content, science methods, confidence around scientific practices, and enacted agency post-participation in the programmes. Our findings suggest CCS programmes could support youth environmental science agency by enhancing their opportunities to participate and position themselves as actors of an authentic scientific initiative within diverse science communities.

Keywords: Outdoor Education, Citizen Science, Non-formal Learning Environment

INTRODUCTION

Community and citizen science (CCS) is gaining increasing attention as a potentially democratic approach to engaging the general public with science and science learning (Bonney, Phillips, Ballard, Enck, 2016; Herodotou, Sharples, Scanlon, 2018). Most attempts to define CCS agree that its "common, shared goal is to collect and analyse information that is scientifically valuable", which "distinguishes citizen science from areas such as experiential learning or environmental education" (Hecker et al., 2018, p. 2). The premise of CCS is authentic scientific research, going beyond science education, engagement, or outreach activities. Ideally, CCS participation enables engagement with the entire scientific process and hence, potentially supports the formation of scientific citizenship (Wallace & Bodzin, 2017). Participation in CCS may also encourage other societal impacts such as science learning and engagement with Science, Technology, Engineering and Mathematics futures, community empowerment, and environmental stewardship (Kieslinger et al., 2018).

Participants' learning outcomes and other wider educational impacts of CCS are gaining interest in formal and informal learning environments, including Natural History Museums (NHMs) (Dickinson et al., 2012; Harlin et al., 2018; and Phillips et al., 2018). NHM-led CCS targets public engagement of families, adults, and young volunteers with scientific research, which supports science learning and promotes environmental stewardship for conservation

(Ballard et al., 2016). Depending on the degree of participation encouraged by the NHM-led CCS programmes, participants' involvement may expand beyond activities directly related to generating data for authentic biodiversity research, but little is known about young people's participation in CCS programmes. How participants engage in the opportunities offered by CCS programmes plays a key role in understanding the interaction of input, implementation, outcomes, and impact of CCS projects (Shirk et al., 2012; Bruckermann et al., 2020). However, there is a lack of evidence-based studies investigating how young people participate in CCS and what they learn from participating (Ballard, Dixon, Harris, 2017). In addition, most existing studies examine science learning across formal learning settings (e.g., Aivelo & Huovelin, 2020; Kocman et al., 2020). Our work addresses these research gaps as a US-UK research-practitioner partnership between three NHMs and three universities. We examine young people's (ages 5 to 19 years) learning through participation in CCS led by NHMs to answer the following research questions, 1) How do young people participate in NHM-led CCS programmes? 2) What science learning do young people develop when participating in NHM-led CCS programmes?

METHODOLOGY

This is an explorative qualitative research study of four cohorts of focal youth (FY) from online and field-based CCS settings. The research was conducted in three phases of investigation (Table 1).

In the first 1, we studied young people's participation in short-term field-based CCS events, called BioBlitzes (Lorke et al., 2021). BioBlitzes (lasting 2-24 h) fall into the category of "contributory" CCS as they are typically scientist-driven (Shirk et al., 2012) and aim to collect biodiversity data by generating biological records used for scientific research and monitoring.

The second phase explored science learning through longer-term field-based and online CCS independently. We examined learning in longer-term field-based environmental programmes that engage the general public in the biological recording of the biodiversity of a place throughout multiple sessions. We also investigated young people's participation in Zooniverse (zooniverse.org), an online crowdsourcing platform hosting multiple CCS projects from a broad range of scientific disciplines.

The third phase compared learning through CCS across the online and field-based settings. We analysed FY learning who took part in Bioblitz events, longer-term monitoring projects, and two online CCS platforms (Zooniverse and iNaturalist). iNaturalist is a web and mobile app-based platform with a social network for recording organism occurrence; species identification supported by both a computer learning and a user-crowdsourced system for at-will participation of volunteers.

We obtained parental consent in person at the events, over the phone, or via email in accordance with the setting and the Ethics Board protocols. From consented focal youth (FY), we used random purposeful selection for the data collection and selected cohorts for each phase using stratified purposeful sampling (Patton, 2015), using criteria based on their age, interest in science, and empirical data availability.

Table 1. Summary of community and citizen science (CCS) settings and focal youth (FY) cohorts across two phases of investigation

Phases of investigation	**FY cohorts** (5-19 years old)	**CCS setting**	**Data summary**
Phase 1 - defining participation	81 FY; 40 female, 40 male, 1 other; 44 5-10 yo, 20 11-15yo, 17 15-19yo	Bioblitz events across three NHMs	81 field observations
Phase 2 - exploring learning through participation individual settings	22 FY; 12 female, 9 male, 1 other; 2 5-10 yo, 19 11-15yo; 1 15-19yo	Longer-term monitoring programmes across three NHMs	73 field observations, 22 pre-participation survey responses; 17 post-participation survey responses; 22 post-participation interviews
	64 FY; 36 female, 26 male, 2 other; 55 16-21 yo	Zooniverse	64 survey responses
Phase 3 - comparing learning through participation across settings.	37 FY; 20 females, 16 males, 1 other; 37 10-13 yo	Bioblitz events, longer-term monitoring programmes, and online platforms Zooniverse and iNaturalist across three NHMs.	29 post-participation survey responses and 25 semi-structured interviews

To explore and characterise youth learning through participation in CCS, we adopted the Environmental Science Agency (ESA) (Ballard et al., 2017) framework to inform the data collection instruments and data analysis Influenced by democratic science pedagogy researchers Basu and Calabrese Barton (2010) and socio-cultural theorists Lave & Wenger (1991), the ESA framework conjectures that democratic science activities, such as those potentially fostered by CCS, can activate youth's agency and participation in science. It further suggests that environmental agency is a process involving the understanding of environmental science content, skills, and norms (coded as ESA 1); identifying one's own expertise within environmental science (coded as ESA 2); and using one's experiences, for example in CCS, as a foundation for individual and collective change (coded as ESA3.

Phase one: defining participation

Based on the scientific goal of the CCS activity (Isaac & Pocock, 2015), we identified five essential steps to create a biological record. These were defined as a priori codes for the different ways youth could potentially participate during a BioBlitz (Table 2). For the first phase, we observed 81 FY (5-19 years old) across 15 BioBlitzes, documenting all occurrences of behaviours of interest during the entire observation interval (average: 22.3 min). Two researchers structurally and thematically coded evidence of when the young person was engaging in science-related activities; the process was iterative and involved at least two researchers per memo.

Table 2. Potentially available types of participation based on the scientific goals of BioBlitzes

Exploring	Exploring nature to discover organisms, this can involve tools such as binoculars or nets
Observing	Observing organisms in nature, using one's senses to find and study organisms
Identifying organisms	Finding out what organism (e.g., taxon or species) was observed
Documenting	Documenting the observations by generating evidence of the observation, such as a photograph or writing on a data sheet
Recording	Making the documented observation available for biodiversity monitoring or research purposes, ideally providing the Who, When, Where and What aspects of a biological record

The combination of these types of participation were grouped into participation profiles. Participating in all five steps of the data collection process or Recording plus any other combination of the other types was labelled the "Citizen Science" profile. FY in this category generate a biological record that can be used for monitoring or research purposes and contribute to science as intended in BioBlitzes as contributory CCS events (Shirk et al., 2012) by collecting information that is "scientifically valuable" (Hecker et al., 2018, p. 2). The "Natural History" profile describes participation that leads to some kind of evidence for observations made, yet without the evidence being shared, meaning any combination of types of participation that included Documenting but not Recording. The "Environmental Education" profile describes a participation pattern in which youth engage in Exploring, Observing, and/or identifying, or any combination of these types of participation, without Documenting or Recording. Participation in this category can also be found in environmental education and public engagement events such as nature walks, pond dipping, or rock pooling activities, without any data collection for monitoring or research purposes.

Phase two: exploring learning through participation individual settings

We selected 22 FY across three longer-term and field-based monitoring programmes. We collected field observations (n=73), pre-participation surveys (n=22) and post-participation surveys (n=17) as well as post-participation semi-structured interviews (n=22). The interview recordings and field observations were transcribed and uploaded to Dedoose for analysis. Survey analysis was conducted in spreadsheets, focusing on the open-ended survey questions. Two researchers analysed the data, following principles of thematic analysis to explore and code data (Braun & Clarke, 2006). Coding involved a priori codes based on the three ESA dimensions for the top-level and sub-level coding, further defining these codes through the content of the data. The coding also included the participation steps towards creating a contribution to authentic research as set out in Phase 1. For example, for the top-level category "ESA 1: understanding science content and practice", sub-level coding included "youth perceptions of the purpose or goals of the CCS project and the data they collected", among other sub-codes.

In addition to the longer-term field-based FY participants, 64 young volunteers of Zooniverse completed an online survey. The survey included closed-ended questions about demographics and prior science experiences and open-ended questions about learning designed to identify evidence about the three ESA components and how these are expressed in online CCS. Descriptive (frequencies) and inferential (correlations) statistics were used in the analysis. Open-ended questions were coded using the strategies previously described for the data of FY from the longer-term monitoring programmes.

Phase three: comparing learning through participation across settings

We selected 37 FY across four field-based and online longer-term CCS settings, collecting and examining post-participation surveys (n= 29) and semi-structured interviews (n= 25). A researcher led the analysis with the support of other analysts using the same codebook employed for phase two. The coded data became the content of text analysis tables or matrices (Kuckartz, 2014) and data triangulation (Flick, 2018) to search for patterns and differences of ESA development in FY.

RESULTS AND DISCUSSION

Actual participation vs potential participation

Our results show that not all youth undergo the same participation patterns. Most FY (67 out of 81) engaged in at least one step necessary to generate biological records. Participation in Exploring (48 FY), Observing (57), and Identifying organisms (45) was much more common than participation in Documenting (28) and Recording (12). The participation of 39 FY fell under the category of the Environmental Education profile, 19 FY under the Natural History profile, and the Citizen Science profile was the rarest (12 FY). The Citizen Science profile was rare, meaning only very few youth contributed data to a CCS project themselves. This is concerning because participating in the data submission step of a CCS project is a crucial aspect of youth participation in BioBlitzes because a) only recorded data can be used for scientific research and b) interaction and ownership of scientific data has been proven important for youth development of agency (Harris et al., 2020). The high proportion of youth participation profiles that do not include Recording reveals that the authentic research element of CCS and its potential effect on individual outcomes and scientific citizenship development are not yet fully used by or available to youth in BioBlitzes.

Science learning in longer-term monitoring programmes

All long-term programme participants (n=22) developed scientific knowledge, ESA 1. In particular, they learned about the taxa or biodiversity topics, gained scientific skills and practice, and an increased understanding of the norms of scientific research. We found that for most youth, using scientific tools, having repeated experiences in real scientific research, and understanding the purpose of data collection supported the development of environmental science content and practice. Along with these learning outcomes and processes, 20 FY developed their identity with science through participation in the programmes (ESA 2), positioning themselves in specific roles within the project, such as “finder”, “leader”, or “explorer”. Connecting their effort to collect data with the scientific goals of the programmes also fostered recognition of their own expertise with science. Further, we found 16 FY described small moments of agency with environmental science through CCS ongoing participation. The evidence suggests that FY perceived their work in the programmes as activities they could use to expand on or build upon their interests and personal inquiries about biodiversity.

Science learning in Zooniverse

Young people reported knowledge of how CCS works (ESA1), changes to their science identity, in particular, their performance and competence (ESA2), and science perceptions (ESA2), and reported developing new roles by coming up with questions they would like an answer for (ESA2). Half of them shared or taught others about their experiences, evidencing the development of expertise in environmental science (ESA2). The lack of ESA3 is noticeable in the survey responses.

Table 3. The expressions of environmental science agency (ESA) that were identified in focal youth (FY) participants of online citizen science projects hosted by Zooniverse.

Expressions of ESA	Survey items and frequencies	Expressions of ESA	Survey items and frequencies
ESA1: Draws on prior knowledge and science skills	Did any other things you have done before help you do the tasks on Zooniverse? (School classes, Other courses, Volunteering, Reading etc) ***Yes=34, No=30***	ESA2: Science identity – Performance	By doing activities on Zooniverse, I got better at learning science or doing science. ***Yes=39, Don't know=12, No=13***
ESA 1: Perception of how Citizen Science works	Do you know what happens with the work you do on Zooniverse? ***Yes=54, No=10***	ESA 2: Shares knowledge/ teaching others	While taking part in Zooniverse I have the chance to teach others something I learned. ***Yes=31, No=33***
	I came across the term 'Citizen Science' (and know how to explain it correctly) ***Yes=42, No=22***	ESA2: Increase Value or Gaining new value/interest	I feel participating in Zooniverse changed the way I think about science. ***Yes=40, No=24***
ESA2: Science identity and competence	I feel like a scientist while taking part in Zooniverse projects. ***Yes/Sometimes=55, No=9***		I feel participating in Zooniverse changed the way I think about the natural world. ***Yes=36, No=28***
	By doing activities on Zooniverse, I am confident about my ability to do science, in or out of school/university. ***Yes=36, Don't know=18, No=10***	ESA2: Takes on Roles or developing a new role	When I was taking part in Zooniverse, I came up with questions I wanted to get an answer for. ***Yes=42, No=13, Don't know=9***

The presence of ESA1 (at least one expression) was significantly correlated with "like learning science out of school" ($r=.383$, $p<.01$, $N=64$), while the presence of ESA2 with visiting online science platforms ($r=.311$, $p=.05$), museums, etc. ($r=.303$, $p=.05$), going outdoors ($r=.334$, $p<.01$) and 'like learning about science' ($r=.387$, $p<.01$). The more the ESA expressions reported (or the strongest the ESA), the more participants talked about science out of school ($r=.351$, $p<.01$), visiting museums, etc. ($r=.494$, $p<.01$), and going outdoors ($r=.277$, $p=.05$).

Overall, prior science experiences were significantly related to the presence of ESA as well as the strength of it, that is, the number of ESA expressions we identified in a participant's data. FY with an interest or previous experiences in science were more likely to gain learning benefits from taking part in Zooniverse. In contrast to a male predominance in adult volunteers, there was a rather fair representation of female youth in this study. Who can take part in which CCS projects (National Academies of Sciences, Engineering, and Medicine, 2018) should be heavily considered to enable diverse community groups to take part and benefit from it, including the marginalised ones and those with fewer to access science experiences.

Learning across field-based and online Community and Citizen Science settings.

We found that the patterns of ESA learning in youth across all the settings (Table 4) prominently shows learning of topic-specific science knowledge and scientific methods science skills, ESA 1. For example, a Bioblitz participant described how she gained topic-specific knowledge, *'I learnt how to recognise animals that looked similar to [other] animals. I learnt from a member of staff that water snails don't have their antennas at the top like land snails, instead, they are at the bottom.'* (Clara, 11 years old, post-survey). Similarly, a participant from Zooniverse said, *'Well, the sage-grouse, I've never even heard of them before. I think when we started looking at them, I didn't even know where they lived. Then we looked at it, and we found out that they live in… Texas and the Great Plains'* (Lloyd, 13 years old, interview). In terms of ESA 2, we identified FY perceived their competence with scientific activities such as documenting findings and identifying organisms. These expressions of competence included feeling like a scientist or like 'doing science'. One of them said, *'Just taking pictures of nature makes me feel like I was "doing science".'* (Victor, 10 years old, post-survey). For ESA 3, we identified signs of FY agency among a small number of FY. FY of the field-based settings and iNaturalist described actions they pursued to continue exploring nature and identifying organisms. From the fully online setting, one FY from Zooniverse described his CCS experience inspired his independent research projects.

Table 4. Environmental science agency (ESA) evidence of focal (FY) from field-based and online community and citizen science (CCS) settings.

CCS settings	ESA 1	ESA 2	ESA 3
Bioblitzes at three NHMs, field-based short-term events	ESA 1.1 ESA 1.2 ESA 1.4	ESA 2.1 ESA 2.2 ESA 2.3	ESA 3.1
Longer-term programmes at three NHMs, field-based	ESA 1.1 ESA 1.2 ESA 1.3 ESA 1.4	ESA 2.1 ESA 2.2 ESA 2.3	ESA 3.1
iNaturalist	ESA 1.1 ESA 1.2 ESA 1.4	ESA 2.1 ESA 2.2	ESA 3.1
Zooniverse	ESA 1.1 ESA 1.2 ESA 1.3 ESA 1.4	ESA 2.2 ESA 2.3	ESA 3.1

ESA 1.1 - Developing or increasing basic knowledge of scientific methods, using tools to explore, observe, classify, and/or document data.
ESA 1.2 - Increasing or developing topic-specific knowledge and/or science knowledge.
ESA 1.3 - Understanding or expanding ideas about the norms and nature of science.
ESA 1.4 - Understanding the scientific purpose of their actions and data generated through CCS.
ESA 2.1 – Perceptions of competence with scientific work.
ESA 2.2 - Increasing or reinforcing confidence in science.
ESA 2.3 - Becoming experts; sharing knowledge, teaching others, etc.
ESA 3.1 - Using CCS experience for independent nature-based explorations.

CONCLUSION

Our study revealed that the actual participation differs from the potential participation. The Citizen Science profile was rare, meaning only very few young people contributed data to a CCS project themselves. However, the different learning settings all provided opportunities for youth to become 'legitimate participants' of science by sharing environmental science knowledge, tools, and norms common in scientific practice (Lave & Wenger, 1991). Our findings show youth-focused CCS programmes can contribute to youth development of aspects of ESA. Evidence shows that using disciplinary content and tools to generate data according to rules and norms shared by scientific communities (ESA 1) may foster youth understanding of how to take part in science, especially if young people are supported to recognise their individual effort to the collective engagement representing the scientific goals of the research (Harris et al., 2020). The latter provide organisation and coherence to science practice by enhancing explanatory power and scientific reasoning (NASEM, 2018). Moreover, generating data and working with data was closely related to youth's sense of competence and confidence in science across all the settings (ESA 2), further corroborating some key results from Ballard et al. (2017) on youth's science identity ownership and agency development. Additionally, taking roles and identifying one's own expertise within the environmental science discipline is part of sustaining their participation and prompting their agency (Ballard et al., 2017; Phillips et al., 2018). We found little evidence of agency (ESA 3) and only in FY from the long-term field-based settings.

Implications for Community and Citizen Science Practice

Our findings have implications for the design of CCS programmes. We need to better support young people in participating in the actual CCS activity by 1) expanding opportunities to engage with scientific tasks and tools, making a range of roles available, 2) putting youth in a position where their work has meaning as they contribute and collaborate with science communities, 3) scaffolding ways to use new knowledge and skills to foster individual and collective change and 4) implement recruitment strategies that engage diverse youth, including those with limited or no prior experiences with CCS.

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BIOLOGY EDUCATION, RIGHT TO HEALTH AND DEMOCRATIC EDUCATION

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This text discusses proposals and approaches of health education in the curricula of biology school subject. We challenge traditional and conservative perspectives on school education to argue that the right to health education is part of building democratic education and society. This problem is situated in a recent Brazilian educational framework, in which conservative political tendencies have placed a broad conception of education and the formation of the students in confrontation with reductionist visions of a purely instructive and moralising education. Based on Biesta's proposal for democratic education, the text focuses on teaching the human body as capable of carrying visions of human rights, health, and education. For that, two data sources were used to support our analysis: biology textbooks and narratives of science and biology teachers over three decades. Dialoguing with the categories Biesta (2010) proposed, there is the predominance of the qualification function in all textbooks analysed, suggesting that the textbooks prioritise technical education, focused on the information of concepts and techniques. Teaching roles to sex education show generational marks updated by teachers to face the challenges of their times. These marks show the effort of these teachers to assume a democratic commitment to their students in each generation. Such an effort seems to break with the biologist, hygienist, behavioural and moralising impositions that accompanied sex education in Brazil. The results argue for integrative and interdisciplinary actions, emphasising the school environment and in line with students' social and cultural needs.

Keywords: Health education, sex education, democratic education

INTRODUCTION

In this text, we examine proposals and approaches of health education in the curricula of biology school subject. Two data sources were used to support our analysis: biology textbooks and narratives of science and biology teachers over three decades. The study assumes that perspectives on school education poses challenges to consider the right to health education as part of building democratic education and society. This problem is evident in the recent Brazilian educational framework, in which conservative political tendencies have placed a broad conception of education and the formation of the students in confrontation with reductionist visions of a purely instructive and moralizing education. In this conception, the role of school education would be reduced to conveying decontextualized and disconnected teaching contents of the issues raised in society. In Brazil and Latin America, the advancement of the conservative movement denounces school themes and practices, like sex education, considered opposed to the views of family and religion of groups that integrate this movement. We question whether this conservative agenda deprives students of the right to education in its broader perspective and the right to health, knowledge, and values as school education are committed to collective health principles.

Shiratori et al. (2004) argue that health promotion represents a form of objectification of fundamental human rights since they manifest themselves in the conscious and responsible self-determination of life itself. Human rights education would be a way of guaranteeing them. Understanding education as a right in itself and considering it fundamental to access to other rights, this educational perspective seeks the full development of citizenship and the promotion of a society with social justice. Fernandes and Paludeto (2010) call attention to the moral and ethical values that permeate the discussion about education focused on human rights, pointing to them as intrinsic to the educational process, since "it is not a question of how to teach or teaching, but what principles education is based on" (p. 238). Hernández-Sánchez et al. (2019) point out that there are few approaches to health education that dialogue with the field of education to encompass a multidisciplinary and participatory approach. They emphasize the school's potential and its surroundings as spaces of society that are conducive to health promotion. In this sense, we understand the school education as one of the bodies that work to promote this right, mainly because it is in this institution that students can have access to information and discussions about the right to health, the different senses about which is to be healthy and their rights and duties. With this regard, the curricular appropriation of health in science and biology school subjects is this text's primary focus. Thus, the purposes of science education are crossed by citizenship education and, therefore, meet the defences of health and education as human rights.

To discuss health education as human rights, the study dialogues with the contribution of Gert Biesta (2010). Biesta argues that any discussions about what a democratic education would be should present articulated proposals regarding the three functions of education:

- qualification (the process of conferring knowledge and skills that allow students to have abilities in different areas)
- socialization (the many ways in which education inserts individuals into social, political, and cultural orders)
- subjectivation (the function that provides processes of individualization of the subjects by the education)

These three dimensions overlap and cannot be hierarchical, so they are a composite question regarding the purposes of education. Biesta warns about the severe reduction of the aims of education due to the overvaluation of the qualification function. Such functions are always outcomes that the educational system plays, and even in proposals that deny one or two of them, they happen and produce their effects on individuals and society. For these reasons, the author advocates a deepening of the discussions about the aims and purposes of education, intending to favour maintaining the status quo and social injustices if we do not do so.

Indeed, in the teaching of science and biology, sex education is an example of these school themes located at the interface between biology and human, political, cultural and social issues mainly addressed to the particularities of the student population. In a widely publicized text, Paulo Freire (1998, p.41) states that the biology teacher cannot disregard that the themes he or she teaches are rooted in these issues. Some authors approach this proposition, such as Simonneaux and Simonneaux (2012), to defend the inclusion of socially acute questions (SAQ) - open questions in the context of unstructured problems that integrate knowledge in human sciences. Alternatively, as Gil and Eugênio (2018) prefers, "sensitive topics" – topics dealt with in the school environment that imply the confrontation of values and interests and can cause constraints in decision-making – or even "friendly content", as assumed by Teixeira, Oliveira and Queiróz (2019), in defence of human rights-oriented education. With some similarity, Moreira and Candau (2007) defend the idea that curricula are a space in which the social anchoring of content is explicit and shows its social construction and historical and cultural roots. When these liaisons are absent or denied, contents tend to be understood as indisputable, neutral, or timeless. These themes expose curricular boundaries in biology, as they do not have a strict sense of biological knowledge as the only reference.

In this text, we choose sex education as a sensitive topic that reveals itself as an essential instrument for promoting the right to health education and the right to health in itself. This theme has been crossing school spaces and times, being present in textbooks and causing generations of teachers to approach it within their classes.

METHODS

Sexuality has been treated mainly in science and biology classes when the human body contents are present in the curriculum. Guerellus and Martello (2014) point out that since the beginning of the 20th-century, sexuality has been present in schools when the sexual orientation of that time concerned only the biological dimension and fought masturbation practices and STI. Throughout this century, as sexuality acquired a social problem dimension and was treated as a public health issue, the school environment was favourable for implementing public policies related to these issues. Although we live in a new century, health concerns, while linked to other contexts and assuming other meanings, pose challenges for educators and researchers. On the one hand, these challenges are set due to the persistence of many socio-environmental constraints; on the other hand, new cultural problems challenge the school to re-examine its curricula. Over many decades, science and biology school subjects' goals have been challenged to include the attendance to the specific demands of the students. Among these purposes, the emphasis relies on promoting health in the scope of schooling. Guided by this understanding, the present text focuses on teaching the human body contents as capable of carrying visions of human rights, health and education. For that, the research explores this science and biology curricular component in Brazilian textbooks and teachers practice over the last three decades.

Biology textbooks

To the study, ten Brazilian biology textbooks, published from the 1990s to 2010, containing proposals for the study of the human body were selected. We used as a criterion of selecting the books those that could be considered representative of the curricular traditions of biology teaching. Thus, we combine two criteria: (i) books published since 1990 that continue to be published in the present decade, indicating that different generations of teachers would have used them; (ii) books officially recommended by the Brazilian government. By crossing these criteria, the textbooks by Sonia Lopes, César and Sezar and Sérgio Linhares were examined (Table 1).

Table 1: Biology textbooks selection.

CODE	YEAR	TITLE	AUTHORS	PUBLISHING COMPANY	ISSUE/EDITION
TB1	1999	BIO	Sônia Lopes	Saraiva	SINGLE/1st
TB2	2008	Biologia	Sônia Lopes and Sergio Rosso	Saraiva	SINGLE/1st
TB3	2002	BIO	Sônia Lopes	Saraiva	1/1st
TB4	2013	BIO	Sônia Lopes and Sergio Rosso	Saraiva	2/2nd
TB5	1997	Biologia 2	César da Silva and Sezar Sasson	Saraiva	2/4th
TB6	2007	Biologia	César da Silva and Sezar Sasson	Saraiva	2/7th
TB7	2013	Biologia	César, Sezar and Caldini	Saraiva	2/1th
TB8	1995	Biologia Hoje	Sérgio Linhares and Fernando Gerwandsznajder	Editora Ática	2/7th
TB9	2003	Biologia Hoje	Sérgio Linhares and Fernando Gerwandsznajder	Editora Ática	2/11th
TB10	2012	Biologia Hoje	Sérgio Linhares and Fernando Gerwandsznajder	Editora Ática	1/1st

The overall analysis of the chapter's human reproduction contents considered Biesta's three educational purposes in the textbooks and the extent to which they can serve a democratic educational perspective as a student right. Both text and images were probed - expressions, examples, images, exercises and complementary readings - that allowed to classify them according to each category: qualification (contents that show biological knowledge and skills required to students, such as anatomic, physiological and other information about diseases); socialization (suggested ways in which education inserts individuals into social, political, and cultural orders, such as the role of men and women, reproduction and sexual pleasure, birth control, individual or public health); subjectivation (processes of individualization and identities, regarding sexuality, gender, control over the bodies, sexual violence).

Science and biology teachers' narratives

The research used four cohorts of generations of science and biology teachers to understand the processes by which sex education has been worked in schools concerning social and professional contexts over 30 years, based on the studies of Goodson (2019) and Magalhães (2014). We chose to include four generations of science and biology teachers related to the historical moment of their initial training (Chart 1). Teachers' selections for the interviews followed the period of their profession: the ones who had at least five years of professional experience and others who had been in the profession for between 5, 10, 20 and 30 years. The interviews were carried out through online meeting programs, as they occurred during the

Covid-19 pandemic throughout 2020. All teachers authorized the recording and use of the interviews to develop this research and, to protect their identities, we used fictitious names.

Table 2: General information about the teachers interviewed.

Generation	Fictitious names	Age	Professional career time	Subject taught at school	University	Graduation year
I	**Clara**	61	33	Biology/Science	UFRRJ	1986
II	**Carlos**	55	28	Biology	UERJ	1992
	Ernesto	47	24	Biology	UERJ - FFP	1997
III	**Rosa**	37	10	Science	UERJ - FFP	2005
	Ana	37	10	Science	UFF	2005
IV	**Leila**	33	5	Biology	UERJ-FFP	2010
	Vladimir	29	6	Science	UFF	2014
	José	26	5	Biology / Science	UFRJ	2015

After transcribing, reading, and re-reading the interviews, we analysed the narratives, seeking to find the motivations described by the participants to understand possible changes related to generational factors. Thus, three categories emerged that express the sources of changes in teaching human reproduction, namely: (i) social issues, (ii) personal experiences, (iii) students' demands. All these categories relate to teachers' generations: social demands gain more visibility over the years, and the teachers integrate them into everyday school life; the experiences and life stories are reviewed by the teachers and modify their knowledge and practices; the pupil's demands modulate the way teachers select and organise their lessons at classrooms.

BIOLOGY TEXTBOOKS ANALYSIS

Dialoguing with the categories that Biesta (2013) proposed, the qualification function predominates in all textbooks analysed. Approaching it technically highlights aspects of the anatomy and physiology of the human reproductive system, both in images and texts, suggesting that the textbooks prioritise technical education targeting the information of concepts and techniques. In addition, there is also a concern with public and individual health in all the textbooks. This concern fits the socialisation function since health became part of the Brazilian school curriculum in the last century to prevent diseases resulting from industrialisation, urbanisation, and lately, the AIDS epidemic. In other words, the inclusion of approaches that relate to broader social problems is associated with the function of socialisation, as it refers to a model of the desired society. Equally, there is a concern with the issue of family planning, likewise birth control policy. Thus, the issues most obviously related to socialisation and subjectivation are in the STIs and contraceptive methods sessions. These sessions address collective and individual health and birth control issues as part of culture and politics. Finally, the discourses on the bodies indicate the subjectivation function. It is possible to observe, among other aspects, a difference in the approach of the female body to the masculine one.

By mobilising these three concepts – qualification, socialisation and subjectivation - proposed by Biesta, the analysis highlights the challenges of establishing relationships between other broader concepts such as democratic education. In this sense, democratic education integrates health as a fundamental right and a purpose of the school discipline biology, even though not all three categories are addressed simultaneously. In the textbooks analysed, different conceptions of health, already identified in the traditions of biology teaching - biomedical, hygienist/behavioural, socio-environmental, and cultural – are mixed. This interrelated way, as shown in the textbooks, is evidence of the tensions between knowledge, values, and customs in the school curriculum. The debate posed by the conservative threats in Brazil and Latin America reduces educational aims to merely informational and fulfil moralising purposes. Such a reduction not only compromises the recognition of health as a right, but it also strikes head-on the principle of education as a right. Therefore, as the analysis shows, educational functions of socialisation and subjectification are emptied, and the emphasis relies on qualification. In this sense, such reduction of educational aims moves away from a perspective of democratic education because it emphasises qualification at the expense of the two other functions – socialisation and subjectivation – since all of them are essential to emancipation. Considering the prominent role of science and biology curricula in school education in disseminating notions of health, we regard the composite conception of health as a fundamental right that is potent for the construction of citizenship in a perspective of Democratic Education. Hernández-Sánchez et al. (2019) indicate, in a survey of health education trends in schools in Latin America, that health promotion in schools is necessary under a perspective capable of integrating more traditional approaches of the biomedical tradition with a view of human development, citizenship and the participation of subjects in the care of themselves and the community. The lack of integration between the teaching contents and the students' living world is a limitation since it reduces the potential of the curriculum to strengthen the construction of citizenship in a perspective of democratic education in the terms proposed by Biesta (2010).

SCIENCE AND BIOLOGY TEACHERS' NARRATIVES

For this analysis, we use the contributions of Biesta (2013) to develop the three categories early mentioned: (i) social issues, (ii) personal experiences, and (iii) student demands. The first category highlights the socialization function since social issues related to sex education were prioritized in the narratives of the interviewed teachers. It suggests that the answers to these questions align with this function proposed by Biesta. As can be seen in the excerpt from the interview with Rosa:

> […] I will present the reproductive system to discuss the issue of sex and the relationship between men and women. The social roles that these two, these two figures, have in society when they have a child. At that time, I was very focused on the issue of teenage pregnancy. So, yeah, I intended to lead to a reflection on the unequal roles between men and women in society and because of that, yeah, I had to debate about it (Rosa - Generation III).

The teachers' narratives, when examined in generational terms, show that at the beginning of their careers, the concern with information happens without much criticism, especially by teachers of generations I and II, which differs from the teacher of generations III and IV, who assumes the teaching warned by the juxtaposition of sex education with social issues. It does not mean that teachers from generations I and II were not sensitive to these issues. Probably for the generations III and IV, the deconstruction of the qualification function occurred not only because teaching experience developed but also because social pressures destabilized the established sex education biomedical biases. Considering that teachers narrate their experiences in the present, the purpose of socialization does not exclude that of qualification but uses it to expand the possibilities of achieving its ends. Therefore, it shows that teaching exhibits a mixture of these purposes without prioritizing them.

Regarding the second category, (ii) personal experiences, teachers' narratives show that sexuality results from multiple individual and collective experiences. Thus, when students and teachers arrive at school, they already carry their sexual values. Students construct these values throughout school experiences, within their culture, and according to the family and social group each belongs to (Maia & Ribeiro, 2011). Such reflections also include teachers whose personal experiences influence how they approach the subject in the classroom. Thus, pressures outside the school influence the ways to teach sex education, but personal experiences also influence this. In other words, the life history of teachers is a crucial factor in understanding the way teachers teach sex education content.

Both Rosa's and José's reports imply considering, as stated by Tardif (2002), that teachers' professional knowledge is temporal and situated: they develop over time and are subject to the contexts in which their practices occur. The following highlights this aspect:

> So, I like to discuss socio-cultural issues. It's my teacher profile. Today I don't see myself as a teacher who always wants to fill the guy with content to pass the National Exam and go! Go away. No. So that's what I told you. I work by creating a pretext for social discussions because sometimes if I arrive at my classroom right away asking (cultural issues), it could create some problems for me. (José - Generation IV)

As we have seen, teachers structure their knowledge about teaching and their social roles in a way that is rooted in their life history. Based on it, they solve the school contextual requirements and build their ways of teaching. This structuring is constituted temporally by crossing teachers' personal experiences in their practices: making decisions regarding the approaches to teach sexual themes and the re-readings they make of the curricular materials. Their identity processes are built on these choices and on assessing the risks they may run. In dialogue with what Biesta (2013) proposes, we understand that educational purposes are also filtered by these personal experiences and the contexts in which they teach.

Regarding the last category, (iii) student demands, many teachers highlighted that the inclusion of topics related to sex education is greatly influenced by the students themselves, who demand, in different ways, information and discussions about the theme. Such demands refer to information about the changes inherent to puberty, questions about gender and sexuality, and doubts about sexual relationships, as highlighted by teachers from different generations such as Ernesto, Vladimir, Carlos, Clara, and Rosa. These generations received influences from the social contexts marked by panic regarding sexual practices, resulting from the HIV epidemic or cultural factors. Even in different generations, these reports show that working on sex education means listening to students' demands. Therefore, meeting these demands is an intergenerational trait that outlines the way of teaching and can even go against personal values.

We are working on this in the eighth year, worked before and continue to work, the reception of students for this topic, their curiosities, their interest is enormous, very great, it is my classes that yield the most, that students show interest and desire, so their reception is fantastic. (Vladmir - Generation IV)

Therefore, we assume that teachers produce curriculum and the school subject they teach through inventive modalities or "ways of doing it" (Carmo & Selles, 2018), which in the case of this work fall on sex education. In different generations, these ways of doing were updated by social dimensions, influenced by values and personal experiences and produced responses to students' demands. Thus, the ways of doing express teaching knowledge that contributes to curriculum production and it can be shared collectively in generational cohorts. Thus, the analytical categories result from teachers' narratives in dialogue with the contributions of curriculum studies, teaching knowledge and educational purposes. It allowed us to understand that curricular approaches to sex education integrate teachers' experiential knowledge in social and pedagogical contexts, and they are subject to educational purposes and temporal constraints.

FINAL COMMENTS

The analysis indicates that purposes other than just qualification are met even on a smaller scale in the ten textbooks. Thus, it is possible to admit that cultural artefacts such as contraceptive devices shown in these textbooks to teach the anatomy and physiology of human reproduction can favour themes such as gender, sexuality, and cultural and social representations. The purposes of teaching biology and sexual issues can be addressed beyond anatomical and physiological information, as teaching does not depend solely on what is prescribed in the written curriculum. Teachers constantly mediate the information in textbooks to explore other aspects they judge as relevant to students. It can prevent us from essentially attributing the custody of curricular traditions to textbooks or assigning exclusively to them the socialisation and subjectivation functions.

Finally, teaching roles to sex education show generational marks updated by teachers to face the challenges of their times. These marks show the effort of these teachers to assume a democratic commitment to their students in each generation. Such an effort seems to break with the biologist, hygienist, behavioural and moralising impositions that accompanied sex education in Brazil. Although the number of teachers participating in this research does not allow us to generalise, their narratives are indicative of richer and fuller possibilities of working on sex education, sensitive to the risks that the student population runs as a result of sexual violence, gender and gender prejudice and cultural definitions. These practices gathered in narratives produce a collective teaching memory that can encourage resistance to attacks by the new conservatism and design more promising social futures for students.

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HOW PRE-SERVICE TEACHERS APPLY EDUCATION FOR SUSTAINABLE DEVELOPMENT DURING THEIR PRACTICUM

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Through Education for Sustainable Development (ESD) students can attain knowledge and positive attitudes to face holistically environmental, societal, and financial problems. Teachers must therefore be able to teach on such complicated, multifaceted, and complex problems. Many studies have shown that teachers who had ESD training during their initial studies, are much more likely to include it in their teachings. We developed and delivered teaching interventions on ESD to pre-service Early Childhood teachers using houses as a paradigm to analyse the components of SD and their interrelatedness. To investigate the pre-service teachers' ability and willingness to teach about ESD during their practicum, we gave the students the possibility to choose ESD among several other subjects. About one third of them chose to apply this thematic. They developed 145 interactive student-centred activities, provoking the pupils' creativity and high involvement, while tackling the societal component of the houses, their environmental impact, and rarely addressing their financial impact. The practicum proved to lead to expansive learning cycles for the pre-service teachers. Furthermore, our analysis demonstrated that the theme "houses" is a suitable paradigm to approach ESD holistically through its three dimensions.

Keywords: Society and Environment Education, Sociocultural Theory, Initial Teacher Education (Pre-service)

INTRODUCTION

Education for Sustainable Development

The critical problems humanity is facing today, e.g., the pandemic, the climate change, plastic pollution, etc. are issues of Sustainable Development (SD). These problems require high priority and collective efforts. To achieve change, people must obtain knowledge, as well as positive attitudes (Edwards et al., 2020).

Teachers can play an important role in this direction supporting their students to acquire knowledge and positive attitudes. Therefore, it is necessary to include ESD in all educational levels starting at early childhood (Bascopé, Perasso & Reiss, 2019). For teachers to be able to teach about SD, they must have sufficient knowledge (Andersson 2017), positive perceptions about the importance of ESD, positive attitudes towards it (Büssing, Schleper & Menzel, 2018), and they must be equipped with the appropriate teaching approaches. Many studies found that teachers' limited knowledge of sustainability issues is due to lack of teaching and training during their studies (Kennelly, Taylor & Serow, 2012).

Practicum

Students are trained to become teachers through their university studies and through their practicum. Many researchers argue that the practicum is the most beneficial, and practical aspect of teacher education (White & Forgasz, 2016), as it allows teachers to combine theory and practice, a perception often shared by future teachers (Graham, 2006). The practicum is not always described as a positive experience. Some students describe it as a difficult situation, or as an inconsistent and frustrating experience. It is often experienced as a discontinuity between the requirements of schools and of what they were taught during their studies (Grudnoff, Haigh & Mackisack, 2017). In addition, schools are not very receptive to young teachers and their learning needs (El Kadri & Roth, 2015).

Framework and research questions

To inquire about the knowledge, perceptions, and attitudes of pre-service teachers, we used a questionnaire. The findings showed that the pre-service teachers had insufficient knowledge about ESD, understanding mainly its environmental dimension. Despite that, they expressed a need for learning and training on SD and revealed a positive attitude towards ESD (Maidou, Plakitsi & Polatoglou, 2019a). These findings led to the development of teaching interventions (TI) on ESD. As a paradigm we used the thematic "houses" to introduce the pre-service teachers holistically to the dimensions of SD. We examined some environmental and economic impacts of houses, their societal importance and analysed them as financial entities. The TI proved to have positive outcomes on the pre-service teachers' knowledge, perceptions, and attitudes towards ESD, as shown by the post-test using the same questionnaire (Maidou, Plakitsi & Polatoglou, 2020), where improvements of all aspects of SD could be observed. Since the aim of the TIs was the support and encouragement of the pre-service teachers to teach about SD, in the present study we focus on the activities they developed for their practicum, the teaching approached they used, and their evaluation of the outcomes.

The research questions were: 1. Do the pre-service teachers cover all three dimensions of ESD in their practicum teachings? 2. Do they use interactive and student-centred teaching approaches? 3. Did the practicum function as the second stimulus leading to the completion of an expansive learning cycle? 4. Is the thematic 'houses' suitable to teach about SD?

METHOD

In this study we analyse the expansive learning cycles of pre-service teachers who decided to teach about SD using the thematic 'houses' in their practicum. They were placed in groups of two in various pre-schools. Their actions formed various learning cycles during the design and implementation of their teaching scenarios, which could potentially be expansive (Engeström & Sannino, 2010). These learning cycles gave direction and led the pre-service teachers to a new practice, which includes their working methods and learning strategies (Postholm, 2014), and might become part of an expansive learning process. To investigate the expansive learning circles of the pre-service teachers, we used their reports, where they described the activities, they carried out, the means they used, and the evaluation of the implemented activities. The participants were pre-service teachers of the Department of Early Childhood Education at the 6th or 8th semester. Given that they could choose between more topics for their practice in the subject Science Teaching, we can assume that all participants were interested in the subject SD and considered it important. 31 pre-service teachers chose to apply ESD during their practicum. They were placed in groups of two. Because one group consisted of three members, and another group encountered difficulties in their cooperation, the participating pre-service teachers handed in 16 reports.

These reports were analysed using the Thematic Analysis (Braun & Clarke, 2006; Nowell, Norris, White & Moules, 2017). More specifically, we applied the theoretical Thematic Analysis (Braun & Clarke, 2006) to get an insight into how the pre-service teachers designed and conducted their teaching activities, the means they used and the teaching approaches they applied, followed by their evaluation of the outcomes of their activities, the difficulties they encountered and their feedback on their placement experience.

RESULTS

Teaching approaches

All the groups of the pre-service teachers used interactive teaching approaches. They designed activities for the pupils to speak, paint, play games, pantomime, or role play. Through discussions they familiarized themselves with the pupils and thus promoted the development of their communication skills. Drawing and painting was also used by all groups. The applied activities and their percentage frequency are shown in Fig. 1. They utilized group work, experimentation in small groups, field work, etc. In total 145 activities were created by the pre-service teachers.

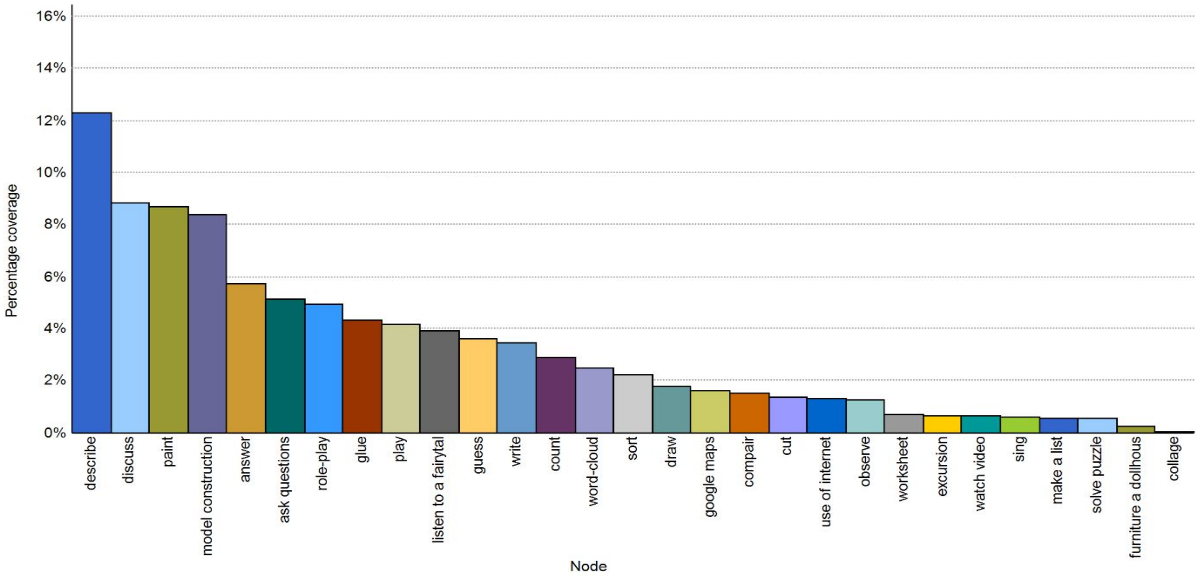

Figure 1. The designed and performed by the pupils' activities and their percentage frequency.

The societal dimension of houses

The pre-service teachers designed 220 activities concerning the societal dimension of houses. Many activities (N=38) were related to the rooms of a house, such as their name, objects that people keep in specific rooms or activities people perform in certain rooms. Activities with houses-styles at different parts of the world were chosen by many groups and applied in many variations (N=34). For example, the pre-service teachers used a map, and placed houses of different types and structures on their respective places on the world map thus connecting places with building types and styles (Fig. 2). In another similar activity, pupils were asked to draw copies of different house-styles from various places. There was also an activity where the pupils connected people from different cultures with a specific house-type, after an introduction on different lifestyles and clothing, and cultural and climatic conditions of the places where these people live. In this way, the pupils connected the houses (forms and functions) with cultures and places.

Figure 2. Pictures of houses from around the world placed on a map.

32 activities were designed on the house-type. Pupils were asked to describe their homes as one-story, two-story, or multi-story buildings. Many pre-service teachers' groups continued this task by asking the pupils to describe what they or their family members do in specific rooms (N=20). These activities were performed either as discussions or as representation with pantomime or by role plays. Many pre-service groups discussed why we have homes (N=19), enabling pupils to express themselves and realize the usefulness of homes. Activities around the timelessness the houses/shelters were also performed quite often (N=16). Some groups depicted the creation of settlements by arranging many houses together such as the activities of Fig. 3, where pupils were also asked to connect the houses with roads and add buildings necessary for the community, as a school, playground, shops, etc.

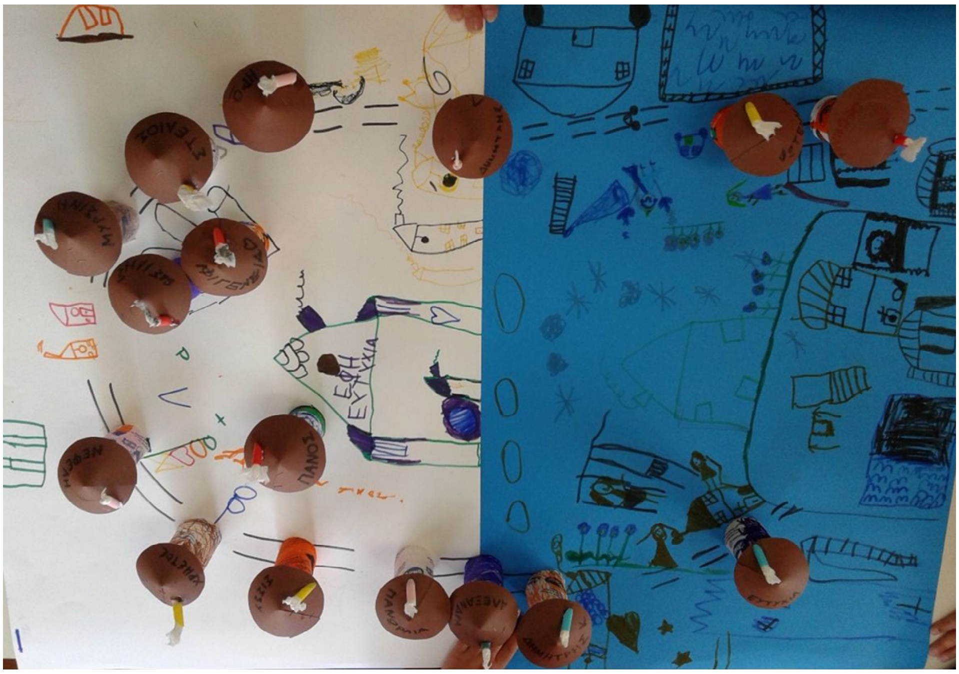

Figure 3. Pupils construct a settlement by adding houses and public buildings.

For some activities pupils were requested to name the elements that constitute a house, such as walls, windows, etc. (N=12). Sometimes they were compared to other types of houses from different cultures (N=15). Some groups of pre-service teachers also used houses in the arts (N=9), such as songs about houses, paintings, poems, proverbs, and fairy tales to engage pupils in activities around houses. Some groups also talked with the pupils about the professions involved in the construction of houses, and how houses are built.

Environmental dimension of houses

The environmental aspects of houses included 35 orientation exercises, 34 activities around building materials and their properties, 33 activities were on the introduction of the apparent sun-path to the young pupils and how it changes due to earth's motion around the sun. Furthermore 20 activities included the impact of the climate on the form of buildings, 13 activities were on sustainability (e.g., renewable energy sources or green cities), while the Socrates' house was used as a teaching tool 5 times, the surrounding of houses 4 times and renewable energy sources were used in 3 teaching scenarios.

The adaptation of houses to the climate of a region was a theme included in 20 teaching scenarios. Climate and local conditions are factors that affect the shape of traditional houses around the world. To exhibit this phenomenon the pre-service teachers used sometimes the comparison of traditional island houses and houses from mountainous areas in Greece (Fig. 4). The characteristic white houses with a flat roof or the houses of the mountainous areas with the sloping roof are examples of adaptations to the climatic conditions.

Figure 4. Use of traditional architecture to showcase the influence of the climate on the form and function of buildings.

To investigate the orientation of houses some pre-service teachers introduced the cardinal points on the horizon and observed the apparent sun-path with the pupils. In some activities the pupils were asked to work in groups of two, one was standing while the other one drew the standing pupil's shoes' outline and the shadow they cast. After one hour, they should repeat the process. The pupils were surprised to find out that the shadow had changed, and the standing ones tried to adjust their body to fit into the former shape of their shadow. The pre-service teachers explained about the apparent sun-path and asked the pupils to stand again upright to draw the new position of their shadow. An analogous activity was performed by another group of pre-service teachers using a dollhouse (Fig. 5).

Figure 5. Using a dollhouse to show the apparent sun-path and how it changes withing an hour.

To explain the different apparent sun-path during summer and winter, some pre-service teachers used a torch and a house model, explaining that the sun rises only twice exactly at East and sets in the West, and that this occurs at the spring and autumnal equinoxes. During the summer the sun rises Northeast and sets Northwest reaching its highest apogee at noon of the summer solstice. On the contrary, during winter the sun rises Southeast, reaches a much lower apogee at the winter solstice, and sets Southwest (Maidou, Plakitsi & Polatoglou, 2019b). Each pupil was encouraged to repeat the process and display the sun-path with the torch

Financial dimension of houses

The financial dimension was referred to only twice in a very brief way. It occurred in a teaching scenario about renewable energy sources, which were mentioned as a cheap energy source that doesn't harm the environment. The second time it was used in a socio-economic context while discussing the picture of a palace, which was described as a home for the rich.

Pre-service teachers' evaluation of their activities and feedback from their practicum

The pre-service teachers designed 145 activities for their practicum and applied them during their placement. Of these, 22 activities were not related to the topic houses, while 1 activity was a misconception, as this pre-service teacher group used a wrong teaching approach and explanation on the role of building materials. In their reports the pre-service teachers described the activities they planned, the purpose of the activities and evaluated the teaching result in the classroom. Most activities were mentioned in a positive manner when they led to positive outcomes, sometimes they got even better results than expected, and sometimes the pre-service teachers were not satisfied with the result of some activities.

The pre-service teachers aimed at specific outcomes while designing their teaching activities, among which they mentioned: to develop the pupils' communication skills, their critical thinking ability, active listening, etc. Some groups introduced the scientific method to the young pupils, while one group formulated the relationship of buildings with SD.

The pre-service teachers described the outcomes of their activities in positive ways when the pupils seemed to understand, when the pupils participated actively in the activities, when they managed to motivate the pupils to express themselves creatively, and when the pupils collaborated among themselves and showed mutual support.

In addition, they sometimes expressed anxiety about the activities they planned and reported that their outcomes were not as good as the pre-service teachers expected. These experiences were connected to the planning of the activities without knowing the class, which had the risk of planning too difficult activities. Some pre-service teachers faced discipline problems. Many pre-service groups expressed worries of not being able to catch the pupils' interest. A few pre-service teachers had to deal with pupils who did not want to participate in the activities. One group reported problems in their collaboration with a school-based teacher and one group faced problems in their collaboration.

In general, the pre-service teachers' overall experience of their placement was quite positive. One group mentioned: *This experience was unprecedented for us. In the practicum, we realized that the function of the teacher is based on pre-planned activities, as well as on the improvisation and readiness to adjust. We developed very good relations with the school-based teachers and the pupils, and we feel satisfied with our results (Anna, Maria)*.

DISCUSSION AND CONCLUSIONS

The pre-service teachers realized the importance of ESD and therefore included this subject in their teachings. They used interactive and student-centred teaching approaches, which are considered by many scholars to be the most relevant teaching approaches for ESD (e.g., Tomas, Girgenti, & Jackson, 2017). They encouraged the pupils to express themselves in many ways such as talking, painting, playing, pantomime, etc. When the pupils had difficulties, the pre-service teachers guided them with questions or invoked the pupils' former experience, trying to remain supportive of their learning experiences.

Our research confirmed that placing the pre-service teachers in groups of two can support their learning through collaboration and dialogue in accordance with Brown and Roth, (2002) and Sorensen (2014). We corroborated the results of Engeström (1987) and Brown and Roth (2002), that placement in pairs empowered students by allowing them to share their uncertainties and thus achieve better results. One couple experienced a problem in their collaboration, as in a similar case described by Brown and Roth (2002). Specifically, one pre-service teacher complained that her colleague did not collaborate actively in the design of the activities. Therefore, this pre-service teacher decided to do all the work on her own, a fact that made her anxious as she had to make all the decisions on her own and in addition, she had to carry out all the activities without support. In addition, the pre-service teachers were free to design the sustainability scenario they wanted to implement. This led to the development of their self-efficacy, which is consistent with previous findings of other studies (El Kadri & Roth, 2015).

Furthermore, the thematic 'houses' we chose for the teaching interventions proved to be a suitable example, as it contributed to the involvement of the pre-service teachers during the teaching interventions, because it is related to their daily life. In addition, it also seemed appropriate for the young pupils, as it is a familiar topic for them, thus enabling the pre-service teachers to build on the pupils' prior knowledge.

During the short-term placement of the pre-service teachers, they faced tensions and contradictions, stemming from the subject of ESD, which is complex and multifaceted. What they had learned during the teaching interventions had to be transformed for the young pupils' level. They had to prepare activities and material for a class they have not met before. They had no previous teaching experience, so they had to base their teaching scenarios on the theoretical knowledge gained from their university studies.

All the participating pre-service teachers started an expansive learning cycle (Engeström, 1987), starting from the design and followed by the application of the activities. The expansive learning cycles began with the Question on what and how to teach about SD using the topic houses. This was followed by the Analysis phase, between the team members during the preparation of the activities and between the students and the researchers. Then came the Modeling phase of the teaching scenarios and the Examination of the model. The pre-service teachers continued with the Application of the model during the practicum. The pre-service teachers conducted the Reflection on the process during the writing process of the reports. The expansive learning cycle of the pre-service teachers did not reach the final phase, namely that of the Consolidation of the new practice.

From the overall results of the students' practicum, it appears that the students completed all phases of an expansive learning cycle except for the final phase, that of the Consolidation of the new practice. This might well be expected by new teachers, which apply a new teaching scenario for the first time. This stage is not even achieved by experienced teachers, as knowledge and teaching practices change over time and teachers have always to adapt their teaching scenarios to the current conditions. That is especially true for ESD, as it is not a body of knowledge that can be acquired (Wiek, Withycombe, Redman & Banas Mills, 2011), but a complex subject that is constantly evolving. For teachers to be able to teach sustainability topics, universities must include sustainability courses in their study programs and in addition to support teachers through lifelong learning.

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GEOLOCALIZATION TOOLS IN CHEMISTRY EDUCATION: IDENTIFYING LOCAL WATER ISSUES WITH GOOGLE STREET VIEW

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This study analyzed the potential of the Google Street View geolocation tool in a Chemistry education activity based on the environmental problems surrounding the living contexts of 25 junior public high school students in Rio de Janeiro. Toward this end, a qualitative investigation was carried out, in which students, using the tool, recorded images related to the theme of water identified across the pathways between their homes and the school, and constructed narratives based on the selected images. Students were able to point out the lack of basic sanitation, flooding, pollution, waste, and lack of water as the main socio-environmental problems in their surroundings. Few students (n=5) were unable to find the image they had in mind using Street View. Nevertheless, it proved to be a useful tool for identifying the socio-environmental problems that affect their living conditions and to motivate students to relate water problems to Chemistry Education.

Keywords: Context-based learning; Environment; Dynamic Visualization Tools.

INTRODUCTION

We live in a globalized and connected world where conceptions of space and time have changed as a consequence of ubiquity in cyberspace and its computational resources. Connectivity offers countless possibilities, such as instant access to information and communication with people of different classes, ethnicities, and locations. These processes are becoming increasingly integrated between what is virtual and what is physical, defining hybrid spaces in most activities in our society (Mantovani, 2016). The use of digital information and communication technology associated with a contextualized teaching approach can arouse interest and facilitate understanding of scientific concepts and promote a closer relationship between students and learning Chemistry (Martinho & Pombo, 2009). According to Gilbert (2006), the function of context is to assign meanings to the learning of Chemistry, which becomes relevant to the students' lives.

Faced with the potential of remote communication, teachers and students around the world were able to maintain the teaching-learning process despite the social isolation imposed by the pandemic of COVID-19. Even in countries where Internet access is unequal, digital platforms and social networks have been widely adopted. Evidently, some adaptation, training, and re-planning were necessary. In this changing scenario, research on Chemistry Education which had started face to face in a public high school was remodeled in order to adapt to the remote modality.

The purpose of this article is to analyze the potential of the geolocation tool Google Street View in a study that sought to reframe the teaching of Chemistry from a socio-environmental perspective, contextualized in the surroundings between students' homes and their school.

CONCEPTUAL FRAMEWORK

Teaching Chemistry based on Science-Technology-Society and Environment (STSE) perspective supports changes in the traditional educational paradigm by promoting a broader view of social implications of science and technology, and also greater students' participation in the learning process. It also contributes to scientific literacy and to critical citizenship education, preparing students to position themselves and intervene in society (Santos & Schnetzler, 2010; Acevedo-Díaz, 2009; Mansour, 2009).

A map is a visual and graphical representation of a place, of a landscape, with different types and shapes, depending on what you want to show. In addition to visualizing a landscape, a map also carries a socially produced reality, therefore, with numerous social, economic, and political aspects related to that representation (Nunes, 2016). With the introduction of georeferencing, geolocation, and spatial capture technology, the ability to view maps has brought cyberspace closer to geographic space, where the environment can also be visualized in three dimensions (3D). Maps' visualization tools, such as those made available by Google (Google Maps, Street View, Earth) reproduce real scenarios, and can be used as means to search and to record images of routes, contexts, and locations, emphasizing socio-environmental or architectural aspects (Dodsworth & Nicholson, 2012; Kang *et al*. 2018; Teixeira, 2019).

Not many Sciences Education studies in the Brazilian context have addressed environmental education using these map tools. Teixeira (2019) used Google Maps to help deaf students learn about hydrographic basins. Map tools have also been adopted in the study of kinematics, and also to assist students in the construction of collaborative maps (Nascimento, 2016). The use of these tools in education enables the implementation of active methodologies, which place students at the center of the learning process and favors problematization, criticism, and reflection about the contents.

METHODOLOGY

It is a qualitative study which focused on students' perceptions and productions and on researchers' observations of an educational activity that aimed at identifying environmental issues in the school surroundings.

Twenty-five high school junior students and their Chemistry teacher worked in partnership with the researchers of this study. Before the pandemic period, students have identified water as a recurrent problem in their living surroundings, and in most areas of the city.

Due to the COVID-19 pandemic, the Google Street View geolocation tool was adopted as a strategy for students to register images related to environmental issues about water, identified in the pathway between their homes and the school. In addition, students were invited to construct a narrative exposing the motivation for choosing the images, as well as their perceptions of the use of geolocation tools. To carry out this activity, students discussed the proposal and received guidelines for using the tools.

RESULTS AND DISCUSSIONS

Most students (n = 20) were able to use the Google Street View and obtain their images. The other five students reported having difficulty capturing them, because despite knowing the location and already having in mind what they wanted to photograph, when using Street View, they did not find the image they expected. This may have happened because, although images are frequently updated, they are not always consistent with the period when the changes happen. In addition, some streets inside poor communities are difficult to access and are not included in the tool collection. Concerning these limitations, one of the students reported: *"So, there is an open sewage in the middle of the trees that doesn't appear right in the image I've registered* [...]". Some students pointed out that they had difficulty due to problems with the cell phone and another complained about the lack of an image that could be related with the theme.

On the other hand, most images captured by students reveal that the Google Street View is an effective tool for raising environmental issues in different locations. One student expressed that: "*It is impressive to see a clean river become a ditch, all dirty and polluted because of human beings who increasingly pollute the environment*". In the image, there was a sewer ditch common to her neighborhood and which was also present in the material of other students. Some students' narratives related the local river with health risks, due to mosquitoes, diseases, and physical security, to social issues, such as floods, and environmental issues, such as pollution and water waste.

Using Google My Maps, we have created a map with students' images. Each point in the map represents one of the locations from which the images were generated. Locating students' images in the map allowed them to have an enlarged view of their context and of the socio-environmental situations identified.

Based on students' recorded images and narratives, it was possible to identify several problematic situations related with water in their way between their homes and school. They were floods/flooding (n=9), diseases/vectors (n=14), waste/lack of water (n=6), basic sanitation (n=10), pollution (n=18), garbage (n=15), social impact (n=8), and others (n =5). Based on the recurrence of problems related to water quality, students, the teacher, and researchers collaboratively decided to study the different aspects related to water and sewage treatment to approach, in a contextualized way, contents about substances, mixtures, and separation of mixtures methods in Chemistry classes.

FINAL REMARKS

The use of geolocation tools in the Chemistry classroom has shown positive results by providing students with an overview of the environmental problems related with their surroundings. It also has facilitated contextualizing Chemistry with students' living conditions, incorporating social and environmental aspects into scientific knowledge. In addition, students showed interest in the way the classes were conducted, in the use of technology, in being agents of their learning, and in the search for representative images of their living surroundings. Despite the limitations that Google Street View presented in some cases, this tool proved to be adequate to relate the teaching of Chemistry with critical environmental education, in a contextualized way to the students' daily lives. Therefore, it is interesting to explore the use of geoprocessing tools in different ways in Chemistry classes and in other science related disciplines.

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CHALLENGES OF SCIENCE COMMUNICATION IN A MOBILE MUSEUM

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Science museums are asked to become agents of social inclusion. However, this is a demanding mission in very large countries with a huge racial, economic and social diversity, such as Brazil. In Brazil, mobile science museums, besides the dissemination of science, foster sociocultural inclusion of underserved populations. The success of this project depends, in part, on how science is communicated in the museum space. This study aims to identify mobile museum coordinators' impressions on the challenges involved in the type of science communication intended by the institution and to get their reflection on how museum educators' practices can be improved. Data was collected by semi-structured interviews and the analysis was drawing on Lakoff's (1987) Idealized Cognitive Model (ICM), which assumes that our knowledge is organized into a network of concepts in an idealized way. Results suggest that there is a clash between the institutional ICM and the museum educators' ICM concerning science communication: while the former is horizontal so that a social mission can be achieved, the latter is vertical and neglects the social mission of the museum. Reasons for this clash include the non-affiliation of the museum educators with the institution, and the low academic and professional diversity of museum educators who hold traditional model of communication. While budget is one of the main obstacles to align the institutional and museum educators' ICMs, museum coordinators believe that developing museum educators' identity with the museum could enhance science communication. For that, they suggest relocate funding in order to developing projects in which museum educators participate.

Keywords: Idealized Cognitive Model, science communication in mobile museums, museum coordinators

INTRODUCTION

Studies have shown that those who typically visit museums are well-educated, white, urbanized, fluent in decoding the museum frames, and from medium/high economic and cultural level (Burton & Scott, 2007, Maggi, 1998). The need to diversify and broaden museums' audiences has been part of museums' agendas (Sandell, 1998). As many advocate, these institutions have a role in promoting social inclusion at an individual level (i.e. museums can trigger positive outcomes, e.g. self-esteem, confidence, creativity, sense of belonging), at a social level (as their collections and programs can be a vehicle towards cross-cultural understanding (Kreps, 2003)) and at a community level (e.g. museums can support communities in developing skills to increase control of their life and the development of the neighbourhoods) (Sandell, 2003).

Becoming an inclusive institution is a challenging task for museums as there are many barriers to overcome. At an institutional level it is not enough to provide free access (Dawson, 2014); unattended audiences need to feel they fit in, to experience a sense of rightfully presence

(Barton et al., 2021). According to Sandell (2003), moving towards inclusion requires, among other aspects, *committed leadership* which implies dynamic leaders who are willing to support novel inclusive projects, to assume risks, and to bring together different institutional sectors towards a common end; *guidance on best practices*, i.e., staff needs training and development to implement best inclusive practices and to shift deeply beliefs and attitudes; *democratization of museum practices*, which is fostered when museums engage communities in decision-making processes, rather than taking decisions for their projects based on internal aims and agendas; *flexible working practices*, being proactive by responding quickly to communities' needs; *the nature of the workforce* which entails recruiting staff with a wider range of experiences (e.g. a deeper knowledge of potential audiences) and skills (e.g. finding routes into the communities).

Working towards inclusive museums is a major challenge in very large country with a huge racial, economic and social diversity, as Brazil (CGEE, 2015, 2019). In Brazil the majority of museums (47%) are located in big cities in the Southeast, which constrains a democratic access to science (CGEE, 2015, 2019). Southeast corresponds to 1/10 of the Brazilian total area, with 85,1 million inhabitants, i.e., over 40% of the total population. Initiatives, such as mobile science museums, were created to foster sociocultural inclusion to those that frequently experience exclusion (Gonzalez & Guimarães, 2021). Despite being projects of major institutions, e.g., edified museums, these mobile museums are more than simply their extensions. They travel to a diversity of places, where they meet a diversity of underserved audiences who hold singular stories and lived experiences (Gonzalez & Guimarães, 2021). Consequently, science communication towards inclusion is of high demanding in the mobile museum space.

Front-line museum educators play an essential role in putting in action the mobile museums social agendas, through science, and, in particular, through the way they communicate scientific issues. The one-way communication mode cannot correspond to that agenda because, in this mode, there is a remote possibility of engaging in conversation as a joint activity. That is, one in which museum educator and visitor share knowledge and are agents of co-production of knowledge. A two-way communication mode, as has been arguing by several authors (Gilbert, 2013; Rennie, 2013; Stocklmayer, 2013), would perform this communication much more efficiently. It would give voice to the public, from whom emotions and viewpoints are elicited, memories triggered, imagination stirred (Weil, 2007) through open ended dialogues. In these dialogues, knowledge grows as a result of a need-to-know from the participants in a conversation (Pedretti & Iannini, 2020). In this way, the idea of museum and science as alien may undergo change and begin to be perceived as being an important facet of their lives.

There are, nonetheless, many challenges in putting into practice the two-way communication successfully. For example, the absence of the typical mobile museum visitor (Gonzalez & Guimarães, 2021) suggests that museum educators need to spend time to know well the diversity of audiences, so that there is an initial common ground for starting a conversation (i.e. "a set of background facts, assumptions and beliefs the participants presupposed when they entered a conversation" (Clark, 1996, p. 43). Furthermore, the two-way communication mode may not be successful in engaging the visitor, by establishing dialogue, eliciting experiences and concerns, if this dialogue does not aim at a genuine exchange of meanings. Educators need to "place their own 'self'" into the frame of questioning in interaction with others (Wynne, 2006, p. 219).

The singularities of mobile museums suggest that their challenges of science communication cannot be simply inferred from the theoretical frames employed in edified museums (Gonzalez & Guimarães, 2021). Through the lived experiences of mobile museum coordinators, this study aims to identify the impressions of mobile science museums' coordinators on the challenges involved in the type of science communication intended by the institution and to get their reflection on how museum educators' practices can be improved.

METHODOLOGY

The context of the study is a mobile museum in Brazil. This mobile museum is a truck that carries scientific exhibitions, science-related activities, and staff (namely museum educators) in a vehicle to underserved populations. Upon arrival, the exhibition area is expanded to the outside of the truck and stays there for about one week. The mobile museum has already visited 7% of all Brazilian municipalities.

Data was collected by interviewing three mobile Brazilian museum coordinators. They were all frequent travelers, affiliated with the same mobile museum, well trained and specialized in science communication, with a long experience in interacting with mobile museum audiences, and deeply committed with the project. After formal consent for audio-recording the interviews in a place chosen by them, the interviews were fully transcribed. The analysis draws on Lakoff's (1987) Idealized Cognitive Model (ICMs). ICMs are linguistic models of categorization. Through language, it is possible to access our conceptual system, and understand how concepts are organized. According to ICMs, our knowledge is organized into a network of concepts in an idealized way, i.e., the knowledge represented is a conceptualization which is based on recurring direct or indirect experiences, i.e., constrained by speakers' assumptions and expectations about the world they interact with (Cienki, 2007), rather than representing all possible realities.

The identification of ICMs required an analysis of the physical and socio-cultural space of communication, i.e., the conceptualization of visitor, the museum, the museum educator, and knowledge that emerges in the museum coordinators discourses. This implied an analysis of keywords and properties (i.e., lexical references such as nouns, verbs, adjectives, etc. with the specification of the elements, sub-elements and their relationship). For example, for the element museum educator, amongst the identified keywords is "teacher" in relation to which certain properties were also identified, e.g., "knowledge holder". These network of keywords and associated properties construct the ICM (Evans et al., 2007). The analysis of the data in this way sheds light on the reason behind some of the identified challenges in communicating science towards social inclusion.

FINDINGS AND DISCUSSION

The identified ICMs

The identified ICMs suggest that there is a dissonance between the institutionalized science communication mode and science communication mode put in practice. The institutional science communication principles on science communication encompass three elements: the communication that takes place, the museum educator and the visitor. The educator is characterized by someone who listens to visitors, values visitors' knowledge and creates bridges between the exhibitions and the visitor; the visitor, on the other hand, is seen as someone with a participatory contribution and one which is also enriching; and the communication is a two-way communication and is horizontal. Through this dialogue, knowledge is reconstructed. Underpinning this model is something, which is the core of the museum project: its social mission. This social mission is characterized by giving underserved audiences access to science, but not in the sense of giving them the norms of science. Rather, the visitor is welcomed, heard, and his/her voice considered. In other words, the mobile museum provides a space for those voices to be heard and for the visitor to be an agent in the co-production of meaning. Consequently, the visitor is treated as an equal partner in the conversation, becoming, therefore, empowered in the process (Figure 1). Some examples[8] from which this ICM emerged are:

"We invest in a communication model through which the local issues/worries are, as far as possible, valued, listened to and resignified during the communication of science." (MC1)

"The visitor is not a mere spectator; s/he will bring his/her knowledge and enrich the visit." (MC2)

"Our main objective is to make the public become interested in science and to reach people who do not have access to science." (MC2)

"We will not give up. To go on with all the problems and constraints involved is more important than to stop. It's our social mission (…) to get to these places is necessary." (MC1)

On the other hand, the dominant ICM which is constructed by the perceptions of the museum coordinators on museum educators' practices and on visitors' role is the one-way communication mode. In this mode, the elements museum educator, visitor and communication are organized as in Figure 2.

The characteristics of the museum educator is that he/she explains everything, hence, it follows the school teacher canonical model. In addition, the museum educator has a compartmentalized understanding of science, is very verbally dominant and often disregards social contexts. In this dominant ICM, the visitor is perceived as unaware that his/her opinion matters, is not really prepared to speak, and accepts a one-way communication mode. The communication that takes place between the museum educator and visitor is vertical. One aspect that contrasts with the institutionalized ICM is that there is no social mission underpinning this model. Some examples from which the elements and relationships for constructing this ICM are:

> "That professorial posture was useless; [the educator] is used to teach that class to secondary school pupil." (MC1)

[8] All the data, including the examples presented in this paper, were analyzed in Portuguese, not in the English translation.

"There are educators who are the only ones that speak…..There is no point in throwing a ton of information at visitors," (MC2)

"Museum educators need to be sensitive [to the reality of many places we visit which may be very different from our], so as to be able to perceive the place where they are." (MC1)

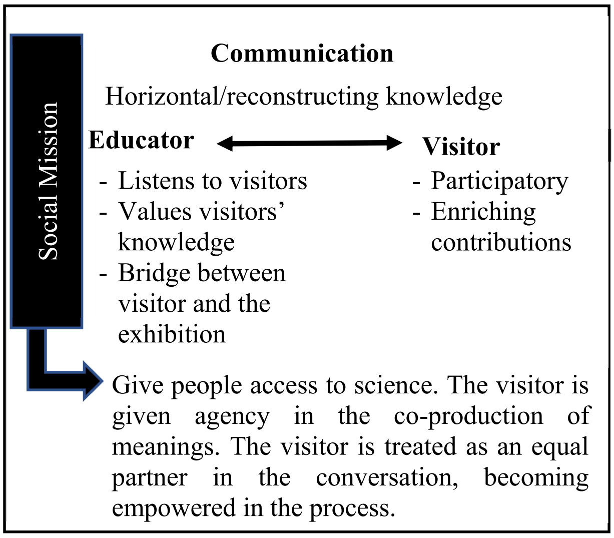

Figure 1. Institutional science communication ICM

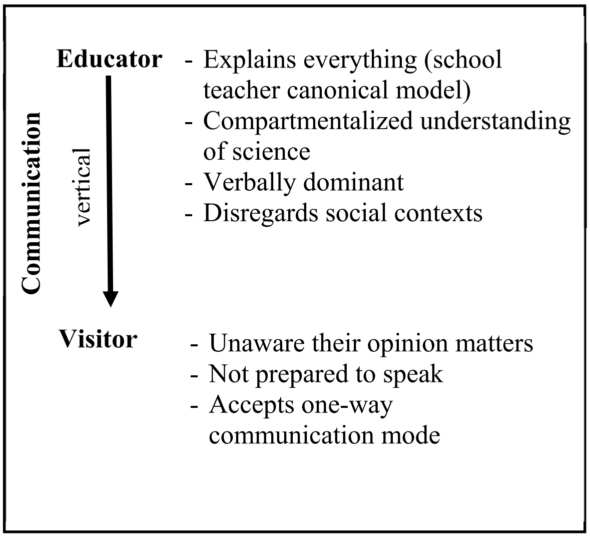

Figure 2. ICM underlying museum educators' science communication

Towards the institutional ICM: reasons for ICMs clash and overcoming it

Considering the reasons for the clash of the identified ICMs, the interviews revealed that one of the main reasons is concerned with the museum educators' lack of affiliation with the museum. This lack of affiliation, in turn, leads not only to a lack of awareness of the social mission that drives the mode of science communication, which is intended by the institution, but also to a restricted academic and professional diversity of people who applies for a temporary and often seasonal job as museum educators, as MC3 explains:

"Nowadays, our mediators[9] are basically prospective teachers and graduate students […] In a mobile museum in Australia, similar to our museum, they hire a team of museum educators for one entire year. We cannot offer that! Rather, we have a database of museum educators, and we count on their interest and availability to travel. Some do travel frequently, but others don't. We don't keep in touch with the latter on a regular base. This is one of our difficulties... The irregular participation of museum educators compromises their development, their study, their commitment with the museum." (M3)

Most of the workforce are undergraduate students and teachers, many of whom have deeply entrenched a transmission mode of communication. MC3 expresses this idea by saying: "Many of our mediators are graduate students. They bring to the mobile museum the model of tutorial classes". Finally, despite museum educators have a one-week intensive period of training before travelling, which is delivered by the committed museum coordinators, the museum educators'

[9] Mediators is term employed by museum coordinators to refer to front-line museum educators.

ICM has not been restructured through the training. Museum coordinators point out that this is, in part, due to a lack of continuous training that could promote change, but also because the practice of these museum educators in the mobile museum is sparse, as MC1 said:

"During training they develop mediation strategies (…), but there is no ready-made recipe for practice. There is that dimension of training that occurs in day-to-day, when s/he clashes with a situation that needs to be solved (…). There is no point in having that posture that s/he uses with high school student, when s/he faces a kindergarten group, who do not have high for a given exhibit." (MC1)

On the top of these obstacles is the short budget available for running the science museum, as MC2 mentioned: "We need to have a balance in the qualifications of the staff, because graduates receive more than undergraduate students. We have a budget for the year. If I only select graduates, the budget will finish before expected."

Overcoming the clash between the institutionalized ICM and museum educators' ICM on science communication is not an easy task as there is a need to change museum educators' ICM so that it becomes aligned with the institutional ICM. This implies a reconceptualization of the museum educators' network of concepts, attitudes, competences, identities, etc. For museum coordinators one way of doing this is relocating funding to small pilot projects to enhance educators' commitment to and ownership of the museum's actions, as the following citation illustrates:

"We called some museum educators that are frequently travelers to collaborate with us in the preparation of new exhibits or script (…) I can pay to these museum mediators for 5 days, not for traveling, but to build the script. The idea is to think of strategies like this, so that I can have some mediators engaged. Why do I believe this works? Because if s/he does not engage at this level, s/he is just a dude who is hired once a month to make a trip, to play with the equipment. I need to find out who is really motivated for science communication." (MC3).

CONCLUSION

The identified ICMs show that museum coordinators conceptualize the mobile museum as having a social mission, in which museum educators have crucial role to play. This means that science communication is horizontal, attends to visitors' interests, and assumes that museum educators and visitors are equal partners in a conversation. Despite the museum coordinators' ideological beliefs, museum coordinators' perception is that the museum educators' practices are not aligned with the institutionalized ICM. Indeed, the dominant museum educators' ICM is based on a vertical mode of communication, which mirrors the school teacher's canonical model of communication.

One of the main reasons for this clash is related to the non-affiliation of the museum educators with the institution, which results in a low academic and professional diversity of those attracted to be museum educators (mainly teachers, prospective teachers and undergraduate students), and constrains their availability for travelling. Hence, museum educators do not develop a sense of commitment with the project, and are unlikely to become familiarized with the several set of visitors' profiles, as visitors change from place to place (e.g., their cultural standards, dialects, conceptualizations of the mobile museum, their perception of role of the museum educator as well as their own role). These represent obstacles for inclusion as a sense of commitment with the museum project (e.g., McLain, 2017) as well as knowing the audiences well are requirements for good communication (Stocklmayer & Rennie, 2017)

Furthermore, because museum educators are mainly teachers and students, the traditional model of communication is deeply entrenched and very difficult to reconstruct in the short training courses for museum educators that are offered. While budget is one of the main obstacles to align the institutional and museum educators' ICMs, museum coordinators are willing to relocate funding in order to developing projects in which museum educators participate. The value of these projects has been reported in the literature (e.g., Bailey, 2003). However, to be effective, this approach needs to go beyond episodic collaborations. This learning involves participation in "community of practices" (Lave & Wenger, 1991), i.e., through collaborating in socially organized practices (e.g., by developing exhibits and/or educational programs), museum educators engage in a process of enculturation. This process involves learning the scripts of the mobile museum, its missions and values and is believed to develop museum educators' identity, as Bailey (2003) suggested.

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ANALYZING CLIMATE CHANGE DESCRIPTIONS IN SECONDARY SCIENCE TEXTBOOKS

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The role of education in understanding the current state and causes of climate change, and in responding accordingly, is increasingly recognized. To effectively conduct climate change education, it is necessary to analyze climate change descriptions in formal education textbooks, and to consider problems arising from contradictions with the latest scientific knowledge. The purpose of this study was to clarify the contents of climate change in Japan's secondary science textbooks and to examine problems related to learning. Contents on the observational facts and causes of climate change were extracted from lower and upper secondary science textbooks. Regarding observational facts on climate change, "atmospheric warming" and "increase in the atmospheric concentrations of greenhouse gases" were described in all analyzed textbooks. However, descriptions on "ocean warming" and "decrease in the amount of snow and ice" were limited to some textbooks. An inaccurate explanation of the greenhouse effect was observed in some of the lower secondary science textbooks. Regarding "impact of human activities on climate change," the lower secondary science textbooks did not establish the human influence on climate system. These results suggest the need for improved descriptions of the current status and causes of climate change in textbooks. It is imperative to discuss the contents and learning methods of the science of climate change in formal education.

Keywords: Climate Change, Science Education, Secondary School

INTRODUCTION

Education is increasingly recognized as an essential element for understanding the current status and causes of climate change and to strengthen appropriate responses accordingly (Mochizuki & Bryan, 2015; UNESCO, 2019). Climate change education must be based on scientific knowledge of climate change. However, descriptions of the science of climate change in some secondary science textbooks could be potentially misleading to students (e.g., Choi, Niyogi, Shepardson, & Charusombat, 2010). Additionally, since significant time passes from the writing and editing of textbooks to their first use, contradictions may occur between their contents and the latest scientific knowledge on climate change. Descriptions on global warming and greenhouse effect has been examined on some of Japan's secondary science textbooks (Jung, 2010). This study examines in detail the descriptions of climate change in Japan's secondary science textbooks and the problems that arise in the prescribed learning from any contradictions with scientific knowledge, in order to facilitate an appropriate understanding of the science of climate change.

METHOD

The objects of analysis were science textbooks for the 3rd grade in lower secondary schools published by five publishers and the "Basic Earth Science" textbooks in upper secondary

Table 1. Analyzed textbooks.

Subjects	Authors and year of publication	Publishers
Lower secondary science in Grade 3	Arima et al. (2016)	Dainippon Tosho
	Hosoya et al. (2016)	Kyoiku Shuppan
	Okamura et al. (2016)	Tokyo Shoseki
	Shimoda et al. (2016)	Gakko Tosho
	Tsukada et al. (2016)	Shinko Shuppansha Keirinkan
"Basic Earth Science" in upper secondary science	Isozaki et al. (2018)	Shinko Shuppansha Keirinkan
	Kimura et al. (2018)	Tokyo Shoseki
	Morimoto et al. (2018)	Jikkyo Shuppan
	Nishimura et al. (2018)	Daiichi Gakushusha
	Ogawa et al. (2018)	Suken Shuppan

Table 2. Japan's secondary science textbooks' coverage of observational facts on climate change.

TS: Tokyo Shoseki; DN: Dainippon Tosho; GT: Gakko Tosho; KS: Kyoiku Shuppan; KR: Shinko Shuppansha Keirinkan; JS: Jikkyo Shuppan; SS: Suken Shuppan; DG: Daiichi Gakushusha. Yes=Covered and No=Not covered. Yes*=Figure only.

Categories \ Textbooks	Lower secondary science in Grade 3					"Basic Earth Science" in upper secondary science				
	TS	DN	GT	KS	KR	TS	JS	KR	SS	DG
Atmospheric warming	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Increase in the atmospheric concentrations of greenhouse gases	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ocean warming	No	No	No	Yes	Yes	No	Yes	No	Yes	Yes
Decrease in the amount of snow and ice	Yes	No	No	No	Yes*	Yes	Yes	No	Yes	Yes
Sea level rise	Yes*	No	No	No	No	Yes	Yes	No	Yes	Yes
Changes in extreme weather events	No	No	No	Yes	No	No	Yes	No	Yes	Yes

schools published by five publishers (Table 1). All contents on observational facts and causes of climate change were extracted. Referring to the synthesis of the fifth assessment report by the Intergovernmental Panel on Climate Change (IPCC, 2014), the contents were classified into eight items—"atmospheric warming," "increase in the atmospheric concentrations of greenhouse gases," "ocean warming," "decrease in the amount of snow and ice," "sea level rise," "changes in extreme weather events," "greenhouse effect" and "impact of human activities on climate change"—. The existence of the descriptions of each item was examined on each textbook. Furthermore, the descriptions were compared with the latest scientific knowledge on climate change, and the difference was examined.

RESULTS

Table 2 shows the items in each textbook for the observational facts on climate change. "Atmospheric warming" and "increase in the atmospheric concentrations of greenhouse gases" were described in all textbooks. Descriptions of other observational facts were limited to some

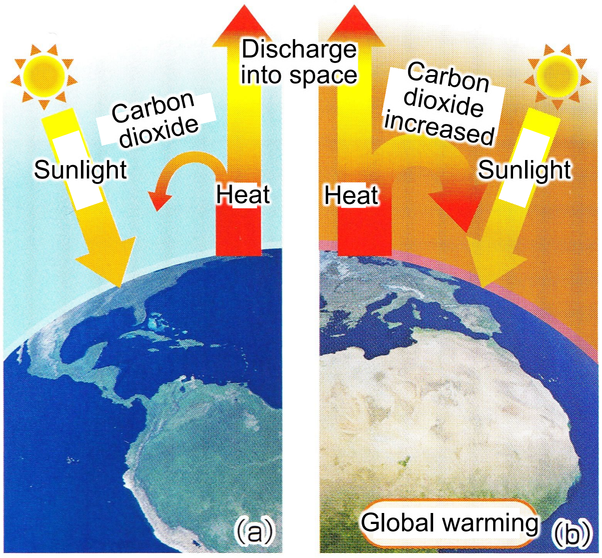

Figure 1. Conceptual diagram illustrating the mechanism of global warming (Shimoda et al., 2016).

"Heat is released from the surface warmed by sunlight. Some of the heat is absorbed into the atmosphere and sent back to the surface, raising the temperature (Figure 1a). As atmospheric carbon dioxide increases, more heat is absorbed into the atmosphere and sent back to the surface, resulting in higher temperatures than in Figure 1a (Figure 1b)." (Shimoda et al., 2016).

textbooks. While one textbook addressed the current state of climate change considering various phenomena, such as the atmosphere, oceans, snow, and ice, one textbook only dealt with the phenomena of the atmosphere; furthermore, the contents differed greatly across textbooks.

Global warming refers to the long-term warming of the Earth's climate system. All upper secondary textbooks pointed out long-term increases in global average surface temperatures over the last 100 ~ 150 years and described them as global warming. All lower secondary textbooks also pointed out an increase in global temperature. However, the period of the warming was not clearly indicated. For example, "In recent years, the temperature of the earth has been rising. This is referred to as global warming." (Arima et al., 2016).

Greenhouse gases and the greenhouse effect were adequately explained in all upper secondary textbooks. However, in four lower secondary textbooks, only the gases discharged by human activities were mentioned as greenhouse gases, and water vapor which has the largest greenhouse effect in the present atmosphere was not described. In some textbooks, conceptual diagrams and explanations of the greenhouse effect were scientifically inappropriate. For example, "As shown in Figure 1, carbon dioxide in the atmosphere prevents the flow of heat discharged from the earth to the outer space, and warms the atmosphere and the ground surface. This effect is referred to as the greenhouse effect, and the gases with the greenhouse effect is referred to as greenhouse gases." (Shimoda et al., 2016). As shown in Figure 2 (IPCC, 2007), most infrared radiation emitted from the earth's surface is absorbed by the greenhouse gases and clouds. In Figure 1a, however, it is explained that some of the heat released from the earth's

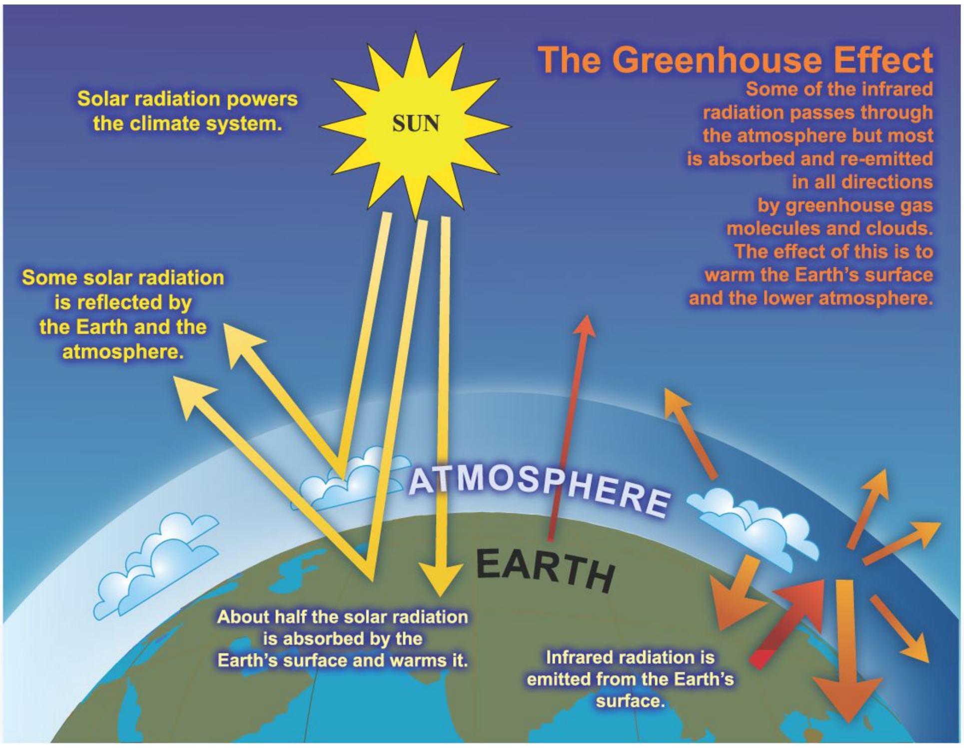

Figure 2. An idealized model of the natural greenhouse effect (IPCC, 2007).

surface is absorbed into the atmosphere. The selective absorption and radiation of the greenhouse gases were not touched upon, and this may lead to misconceptions about the greenhouse effect among students. This issue in the descriptions of the greenhouse effect was also pointed out in the United States secondary science textbooks (Choi et al., 2010).

Regarding the impact of human activities on climate change, the IPCC (2014) report concluded that human influence is extremely likely to have been the dominant factor behind observed warming since the middle of the twentieth century. This relation was adequately explained in upper secondary textbooks, but descriptions in lower secondary textbooks suppressed the impact of human activity. For example, "Carbon dioxide generated by burning fossil fuels is considered to be one of the causes of global warming." (Tsukada et al., 2016).

DISCUSSION AND CONCLUSIONS

As shown in Table 2, half the textbooks do not describe ocean warming. All lower secondary science textbooks newly edited and published in 2021 do not describe ocean warming (Table 3). Because the heat capacity of the ocean is much larger than that of the atmosphere, the impact of ocean warming on the climate is large. The decrease in the amount of snow and ice is also considered to raise sea levels and accelerate the warming of the climate system through ice-albedo feedback. Additionally, extreme weather events are closely related to the frequent occurrence of natural disasters. To better understand the current state of climate change, it is necessary to improve the description of climate warming.

Table 3. Same as Table 2 but for Japan's lower secondary science textbooks newly edited and published in 2021.

TS: Tokyo Shoseki (Kajita et al., 2021); DN: Dainippon Tosho (Arima et al., 2021); GT: Gakko Tosho (Shimoda et al., 2021); KS: Kyoiku Shuppan (Murofushi et al., 2021); KR: Shinko Shuppansha Keirinkan (Ohya et al, 2021)

Textbooks / Categories	Lower secondary science in Grade 3				
	TS	DN	GT	KS	KR
Atmospheric warming	Yes	Yes	Yes	Yes	Yes
Increase in the atmospheric concentrations of greenhouse gases	Yes	No	Yes	Yes*	Yes
Ocean warming	No	No	No	No	No
Decrease in the amount of snow and ice	Yes	No	No	No	Yes*
Sea level rise	Yes	No	Yes	No	No
Changes in extreme weather events	No	No	No	No	No

In particular, there were issues in the descriptions of global warming, greenhouse gases, and the greenhouse effect in lower secondary textbooks. This may be explained by the fact that learning contents on climate change in lower secondary schools are not determined in detail in Japan. As pointed out by Choi et al. (2010), meteorology and science education researchers and textbook writers should actively discuss the contents and methods of learning about climate change.

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7TH GRADE OF GREEK STUDENTS' LATENT KNOWLEDGE ABOUT THE CARBON FOOTPRINT CONCEPT

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The raise of greenhouse gas emissions (GHGs) in the atmosphere causes global climate change. A modern approach describing human contribution to GHGs is through the energy (ENF) and carbon footprint (CF) concepts, which are by far the most significant contributors of the ecological footprint (ECF). This research explores secondary school students' latent knowledge about the CF concept by using a specially developed questionnaire with images. For each of the 12 images included, depicting everyday products or services, three questions were set regarding the (a) energy use throughout their life cycle, (b) the extent of the effect (positive or negative) to the environment from this energy use, and (c) the ways of this impacting. Participants were 188 7th grade students from the greater metropolitan area of Thessaloniki, Greece. Results highlight that students do not comprehend the CF concept. It was recorded that very few of them realize that energy is needed before (raw materials) and after (final disposal) product or services' main use. Even though students seem to understand the negative effect of energy use on the environment, there was a lack of understanding of the concept of neutral or negative CF. Furthermore, the energy consumption, the GHGs emission, the burden on human health and the excessive use of natural resources were considered as the most negative impacts on the environment caused by the energy use throughout the life cycle of the depicted products. On the contrary, the facilitation of human life, the coverage of water needs, the energy and oxygen supply, and the non-depletion of natural resources are considered as positive effects of energy use during their life cycle. Hence, the observed lack of understanding related to the CF concept should be addressed through the revision of the secondary curricula and the training of pre- and in-service teachers for the implementation of relevant projects.

Keywords: Carbon Footprint, questionnaire image tool, 7th grade students

INTRODUCTION

Human activities significantly contribute to the increase of GHGs in the atmosphere, which accelerates the global climate change (Alderson, Cranston & Hammond, 2012). Two main approaches describing human emissions of GHGs are the energy (ENF) and the carbon footprint (CF) concepts (Boruche et al., 2013). ENF was originally introduced as a sub-indicator of the Ecological Footprint (ECF) (Wackernagel & Rees, 1996) and represents the amount of forest area that would be required to absorb CO_2 emissions from fossil fuel combustion and electricity generation, and it is measured in global hectares (gha) (Fang, Heijungs, & De Snoo, 2014). In general, Ecological Footprint includes a total of five basic categories of human resources consumed, as well as the waste generated from this consumption (energy, housing and infrastructure, timber and paper, food and fibber, and seafood) (Borucke et al., 2013). Although in the Ecological Footprint methodology only CO_2 emissions are taking under consideration, that part of Ecological Footprint it is reported as Carbon Footprint. In addition, it is the only land type, out of the five included in the Ecological Footprint, which is exclusively dedicated to the detection of waste product, namely carbon dioxide (CO_2) (Wiedmann & Minx, 2008), and in 2017 it was by far the most significant contributor of the Ecological Footprint, accounting 61% of it (GFN, 2022).

On the other hand, there is another approach of CF, that it is measured in units of mass (kg, t, etc.) equivalent to carbon dioxide (tCO_2e) (Hammond, 2007; Cucek, Klemes, & Kravanja, 2012) and takes into account the six Kyoto Protocol greenhouse gases: carbon dioxide (CO_2), methane (CH_4), nitrogen monoxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulfur hexafluoride (SF_6) (Boruche et al., 2013). In addition, CF measures the total amount of GHGs produced directly or indirectly by an activity from individuals, populations, countries, organisations at different stages of a product's life (Galli et al., 2012). In fact, CF is consisted of two parts: (i) primary and (ii) secondary, and both should be taken into account (Trappey et al., 2011). The primary footprint is a measurement of direct GHGs emissions from the burning of fossil fuels in daily activities, such as household energy consumption, with the consumers having direct control of these emissions (Trappey et al., 2011). The secondary footprint is associated with the production of products and their final disposal (Trappey et al., 2011). Moreover, although that no specific gases are mentioned, either directly or indirectly, in the questionnaire, in this study the approach of including all six GHGs of Kyoto agreement in CF is considered.

When reviewing the scientific papers referring to the ECF, ENF or CF, the following three main levels of their measurement are observed: (a) The first refers to the ECF, ENF or CF of countries (e.g., Galli et al., 2014), (b) the second to cities and urban areas (e.g., Baabou et al., 2017) and (c) the third to educational units (universities and schools) (e.g., Li, Tan, and Rackes, 2015; Fernandez et al., 2018). Furthermore, in the field of education, the issues for reducing or increasing footprints (ECF, ENF, CF) refers to the following areas: energy (e.g., Lin, 2016; Li, Tan, & Rackes, 2015), products or services (e.g., Sudas & Ozelturkay, 2015; Collins et al., 2018), transportation (Lin, 2016; Collins et al., 2018), water supply (e.g., Li, Tan, & Rackes, 2015; Lin, 2016), food (e.g., Gottlieb et al., 2012; Utaraskul, 2015) and wastes (e.g,. Gottlieb et al., 2012; Li, Tan, & Rackes, 2015).

However, there is a lack of studies focusing on the understanding of the energy and carbon footprint concepts by the wider society, since current research either approaches this issue indirectly, through the study of the wider ecological footprint umbrella (e.g., Fernandez et al., 2016; Collins et al., 2018) or it is limited to the measurement of the ecological footprint of students and/or of their schools (e.g., Li, Tan, & Rackes, 2015; Utaraskul, 2015). Nevertheless, none of these studies explores the ways in which learners comprehend the concept. Consequently, aiming to fill this gap, the present research aims to explore the level of students' latent knowledge about the CF, through the use of energy in the various stages of everyday products or services' life cycle, as well as the extent and ways that this use of energy impacts the environment. The exploration, in this study, of students' latent, instead of explicit knowledge, relies on their comprehension of the energy use rather than on the GHG emissions, which is actually the meaning of CF concept (Borucke et al., 2013). This latent knowledge approach was adopted mainly because the age groups under study were not familiar with the concept in focus (i.e., CF). In particular, students have limited knowledge about greenhouse gases processes in the atmosphere, and footprints (ECF, ENF, CF) gain limited or no space at all in the formal school curricula. In addition, the carbon and energy footprint concepts are still underrepresented in the media and in the public debate. Though, ordinary citizens are very unaware of it. Based on the above, the research questions that guided our study were the following:

1. What is 7th grade students' level of latent knowledge about the concept of CF?
2. Which is the 7th grade students' perceived degree of energy use impact on the environment?
3. Which are the 7th grade students' perceived ways that environment is affected from the energy use throughout the life cycle of products and services under study?

METHOD

Participants

Participants in this study were 188 students (54% females, 46% males) of the 7th grade (13th years old), from the greater metropolitan area of Thessaloniki, northern Greece. Students were purposefully selected from schools located in the east, centre and west sides of the city. None of them had been exposed before to any teaching about CF.

Research tool

The research tool was a questionnaire with images that facilitated the collection of both qualitative and quantitative data. Questionnaires of this type have been effectively used in science (DeWaters & Powers, 2012), biology (Schmelzing et al., 2013) and geography teaching (Schnotz et al., 2017) as well in sustainability education (Liampa et al., 2017). The questionnaire consisted of 12 images, each one representing an everyday product or service. These images were organized in six (6) domains corresponding to the following six main areas of interest regarding CF (2 images/domain of CF, Table 1): (i) energy use directly from use of fossil fuels (Wright, Kemp, & Williams, 2011; Trappey et al., 2011), (ii) energy use indirectly from fossil fuels (Galli et al., 2012; Trappey et al., 2011), (iii) energy use from non-fossil fuels (Patel, 2006), (iv) energy use corresponding to the country global trade share (Galli et al., 2008; Abdallah et al., 2012), (v) negative CF (CO_2 and other GHGs absorption) (Galli et al., 2008), and (vi) absence of CF concept (non-existence of CF). The last CF domain does not exist in bibliography, but it was included in this research aiming to control participants' ability to distinguish situations where CF exists from those which does not exist.

Table 1. CF domains in correspondence with the image in the questionnaire

A/A	CF domain	Image in questionnaire
1	Energy use directly from fossil fuels	Laptop Air-condition (heating- cooling)
2	Energy use indirectly from fossil fuel	Bottled water (Not used) Mobile phone (Not used)
3	Energy use from non-fossil fuels	Landfill site Livestock farm
4	Energy use corresponding to the country global trade share	Transportation Bananas from Ecuador
5	Negative CF (CO_2 absorption)	A tree Renewable Energy Sources
6	Non-existence of CF	Natural water source Thermal springs

For each image included in the questionnaire there was a set of three questions concerning (a) the situations in which energy is used at all stages of the illustrated products' life cycle, (b) the extent (positive/negative) in which the use of that energy affects the environment, rated in a scale from -4 (fully negative) to +4 (fully positive) with zero being the balance point, and (c) explanation and examples of this effect (Figure 1).

1. Laptop

1.a. Where is energy used in all stages of its life?

1.b. How does it affect the environment at all stages of its life? *(circle what you think is right for you)*

Positive:				Neutral	Negative:			
Too much	Very	Enough	Little	Not at all	Little	Enough	Very	Too much
4	3	2	1	0	1	2	3	4

1.c. Explain how this is made. *(Give 1-2 examples, if you like, to explain your opinion)*

Figure 1. Example of the research tool, where a combination of picture and text is used

The key stages of the questionnaire development process included the theoretical framework and literature review, as well as the conduction of exploratory semi-structured interviews with students having similar characteristics to the participants of the main research. Moreover, feedback and comments from secondary teachers and university educators were also gathered regarding its internal coherence, objectivity, clarity, usefulness and practicality. Finally, a pilot study of the questionnaire in two classes with 42 students was also carried out.

Data collection and analysis

The questionnaires were distributed voluntarily and anonymously, without any audio or video recording of students. They were informed about the purpose of the research and they needed a maximum of two teaching hours for its completion. Data collection was carried out from November 2019 to May 2020. Raw data were entered to Excel for the necessary grouping and analysis.

For brevity and clarity reasons, in the analysis and presentation of results, the life cycle of products and services was divided into three main phases: BEFORE (raw materials, construction, transportation), main USE and AFTER use (final disposal).

RESULTS

Results from the first set of questions (1a-12a), regarding the use of energy in the various stages of products or services, indicate that very few students realize the energy used before (raw materials) and after (final disposal) the main use period of a product or service (Figure 2). In addition, the great majority of them (84%) realize the energy consumption in the stage of actual use of the product or service.

The substages of construction (mainly in the 1st and 2nd domain of CF) and transportation (mainly the 3rd and 4th domain of CF), in the Before stage, are the less acknowledgeable among students. In regard to the two last domains of CF, no student seems to comprehend that there may be a negative CF or that there can be situations without CF.

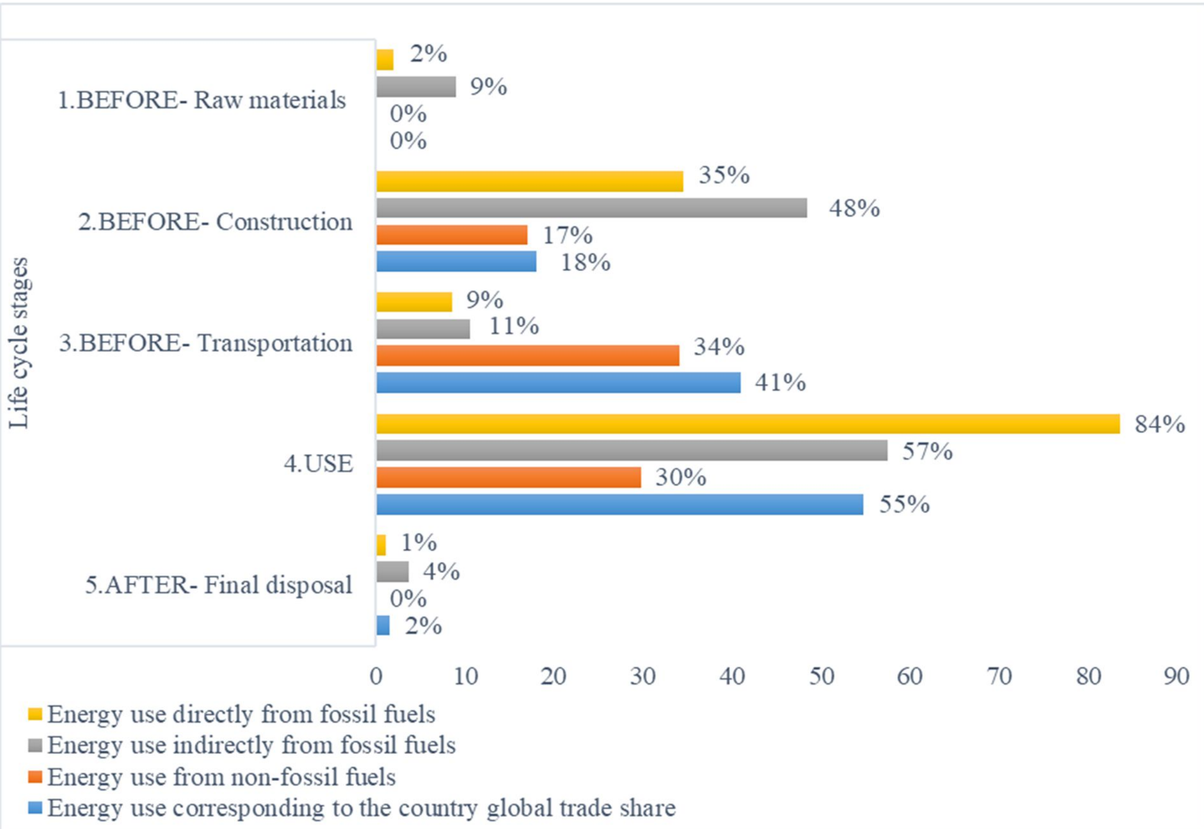

Figure 2. Percentages of students mentioned energy use in the various life cycle stages of a product or service

At the second set of questions (1b-12b), students were asked to rate the effect on the environment from the energy consumption, using a 0±4 scale (Figure 3). The overall mean effect on the environment, including the five out of six CF domains, was 0.43, indicating a positive but rather very week impact on the environment. In this set of questions, we take under consideration only the first five (5) CF domains (Figure 3), as only in that cases energy is directly and/or indirectly used in the illustrated products or services, and in the sixth CF domain we have no CF.

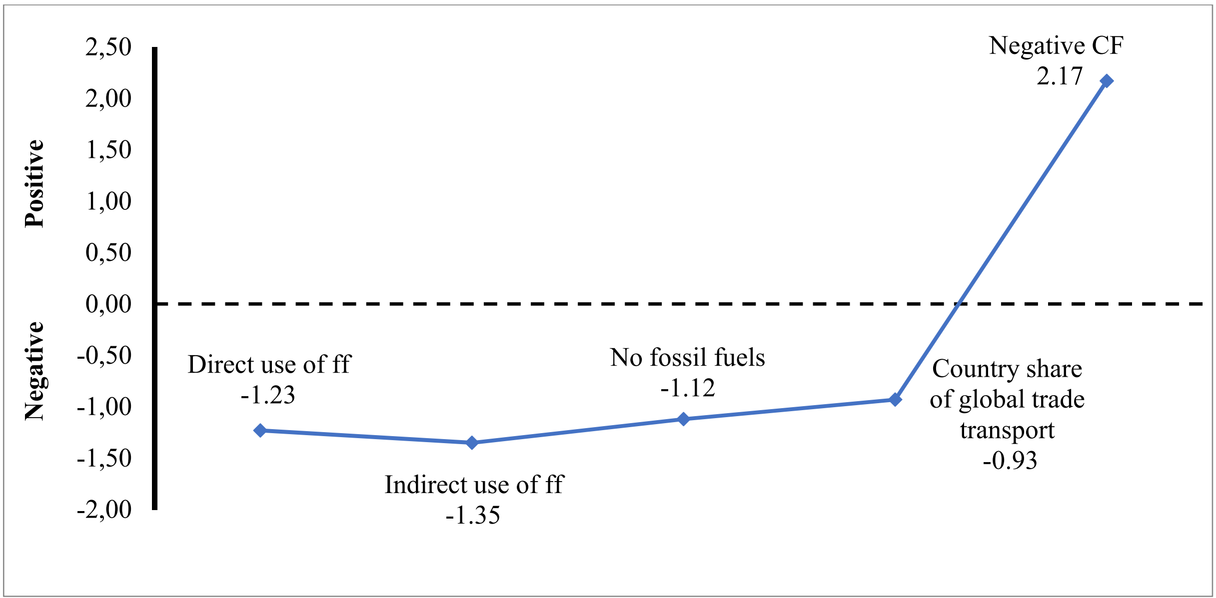

Figure 3. Perceived degree of energy use impact on the environment, by CF domain

The third set of questions (1c-12c) is the explanation of the effect on the environment rated in the previous set. Energy consumption (86%), gas emissions (67%), the dumping of products without recycling (33%), the burden on human health (32%), the extended use of natural resources (29%), the deforestation (10%) and soil pollution (4%) were identified by students as the main ways of negatively affecting the environment. On the contrary, the facilitation of human life (12%), the facilitation of human transportation (11%) and the energy creation from Renewable Energy Sources (RES) (3%) were mentioned as the most positive contributions for the environment (Figure 4).

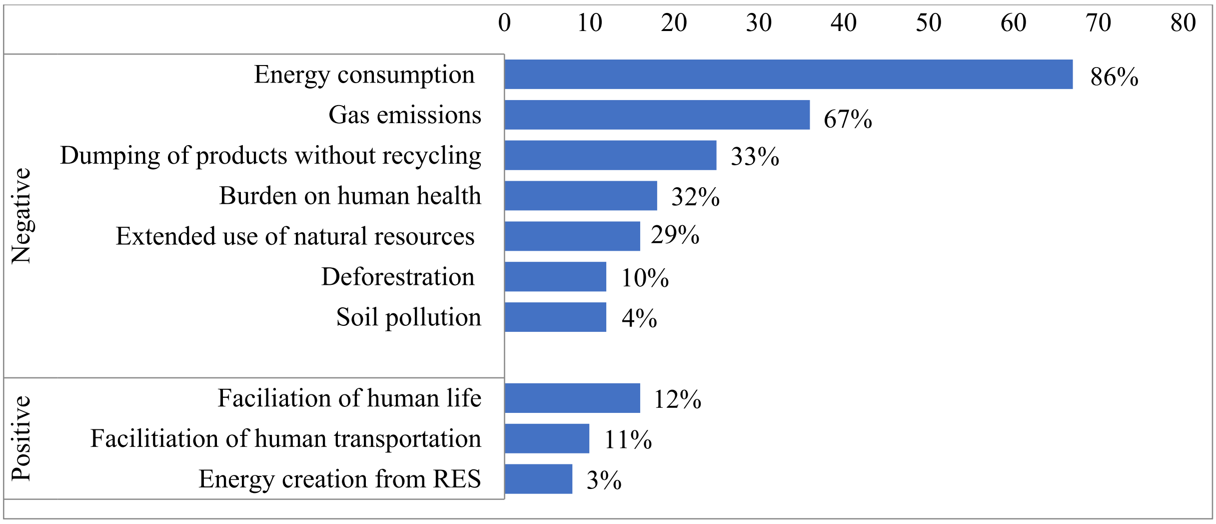

Figure 4. Perceived ways in which energy use affects the environment

CONCLUSION

In respect of the first research question, the participants in our study seem to have several difficulties in understanding aspects of the CF concept. Moreover, while the use of energy in the main stage of the life cycle of a product or service has the highest rate of recognition among students, very few of them recognize that energy is also needed in the stages Before (raw materials) and After (final disposal) the main stage. Furthermore, no student understands that some products or services may have a negative CF or that there are situations with no CF.

In the second research question, the average degree of environmental impact for all CF domain was almost zero. Finally, regarding the third research question, energy consumption and gas emissions were the most adverse environmental consequences, while oxygen supply and the coverage of water needs being the most positive impacts on the environment emanating from all CF domains throughout the life cycle of the products or services.

Due to the significance of the CF concept, there is a need to enhance our efforts on this topic and promote the idea of energy sustainability in the educational agenda and in the school curriculum. Moreover, the CF concept is a useful tool for selecting appropriate measures to deal with the environmental impact of students and their schools (Li et al., 2008). In addition, it is possible, through the adoption of CF, to directly compare the research results from several schools, and make useful conclusions. However, more research is necessary in order to further explore the understanding of the CF concept by students and raise their awareness, change their everyday activities and turn them to more sustainable ways of life.

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IMPROVEMENT OF A CLIMATE CHANGE CONCEPT INVENTORY

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The anthropogenic climate change confronts humanity with unprecedented challenges. Understanding the scientific principles behind climate change is a prerequisite to reach higher acceptance of measures and to motivate individuals to climate-friendly behaviour. Concept inventories serve to reliably evaluate the understanding in large scale studies. Several such concept inventories for the topic of climate change have been developed. However, up to date, there is no climate change concept inventory (CCCI) available in German, so either a new instrument needs to be developed or an existing one needs to be translated, adapted, and tested. Our study goes both ways. For the first pilot study with 338 high school students, we translated and adapted an already existing test instrument developed by Jarrett & Takacs (2020). Based on these results, interviews were conducted with 8 students to further elaborate the results. The analysis revealed that the test-instrument needs further improvement: One the one hand, the Australian CCCI does not cover all relevant concepts. On the other hand, the analysis reveals several psychometrical shortcomings that need to be addressed. In this contribution, we elaborate on how we further developed the test instrument, and present results from the quantitative pilot study as well as from 40+ qualitative interviews.

Keywords: climate change, conceptual understanding, diagnostic tools

BACKGROUND

The anthropogenic climate change confronts humanity with unprecedented economical, ecological, and social challenges (Schreiner, Henriksen, & Kirkeby Hansen, 2005; IPCC, 2018). For school students, it is a relevant topic, as for example the global "Fridays for Future movement" shows. Although, more developed knowledge about climate change does not necessarily lead to more climate-friendly behaviour (e.g., Hornsey, Harris, Bain, & Fielding, 2016), understanding the scientific principles behind climate change is a prerequisite to reach higher acceptance of measures and to motivate individuals to climate-friendly behaviour (e.g., Bord, O'Connor, & Fisher, 2000).

Concept inventories serve to reliably evaluate the understanding in large scale studies to elicit misconceptions and to distinguish them from lack of knowledge (Schecker & Gerdes, 1999). Over the last years and decades, several such concept inventories for the topic of climate change have been developed (e.g., Keller, 2006; Arslan, Cigdemoglu, & Moseley, 2012). However, up to date, there is no climate change concept inventory (CCCI) available in German, so either a new instrument needs to be developed or an existing one needs to be translated, adapted and tested. Additionally, past research on student understanding of climate change has repeatedly and dominantly found that students show a confusion of climate change with the ozone hole (e.g., Niebert, 2010). With the Montreal Protocol being 35 years old and the ozone layer slowly recovering, it seems questionable whether this is still a dominant understanding. So, a re-measurement of the current understanding and potential discovery of current misconceptions seem necessary. Furthermore, new research methods have entered science education such as Rasch analysis, so a psychometric update of existing CCCIs seems timely as well. All in all, work on conceptual understanding of climate change seems timely (Tasquier & Pongiglione, 2017; Höttecke & Allchin, 2020).

Our research aim is to develop an up-to-date and psychometrically reliable CCCI in German language, derived and translated from existing CCCIs and existing literature on student understanding of climate change, with added new content and tested and improved for psychometric refurbishment. Target population are German speaking teenagers ($8^{th}/9^{th}$ grade upward) and young adults. At the ESERA conference 2021, we presented the complete new CCCI and first empirical findings. These findings are based on the quantitative pilot study and 40+ qualitative interviews. In this contribution we show how we improved the test instrument, present results from the pilot studies and give an outlook.

PILOT-STUDY WITH AN ALREADY EXISTING AND TRANSLATED CCCI

As a first step, an existing Climate Change Concept Inventory (CCCI) developed in Australia (Jarret & Tackacs 2019) was translated into German and administered to n = 338 school students at the beginning of High School in different school types in the province of Styria (Steiermark) in Austria (Schubatzky, Pichler & Haagen-Schützenhöfer, 2020). The instrument consisted of 30 multiple-choice questions in ten thematic areas: Concept 1: carbon cycle and fossil fuels; Concept 2: electromagnetic spectrum; Concept 3: interactions between greenhouse gases and electromagnetic radiation; Concept 4: climate variability; Concept 6: greenhouse gases in the atmosphere; Concept 8: feedback processes; Concept 9: equilibrium of energy; Concept 10: conservation of energy. The R-package TAM was used to obtain linear values for the item difficulties. For the analysis, three of the 30 items had to be excluded: One item was formulated misleadingly, one item showed an unsatisfactory outfit-value (>1.2) and another item showed a negative correlation with the total score. The person reliability of the test instrument was determined using a weighted likelihood-estimation and has a value of .68 for the high-school student sample. Figure 1 shows the distribution of item difficulty and person ability. As one can see, items from the translated Australian CCCI were in general too difficult for the Austrian high-school students, especially items from the concept areas “carbon cycle and fossil fuels”, “electromagnetic spectrum”, and “interactions between greenhouse gases and electromagnetic radiation”. Turning the attention again to figure 1, one can see in the diagram for the person ability some light grey shaded, short columns with higher ability than those of the high school student sample. These are the person abilities of a small contingency sample consisting of university physics education students around the third undergraduate semester. That population shows as expected a higher person ability than the high school student sample. As further remarks, the translated Australian CCCI shows a somewhat un-balanced item-concept distribution, and based on the literature and expert interviews, some important concepts such as the distinction between weather and climate are missing.

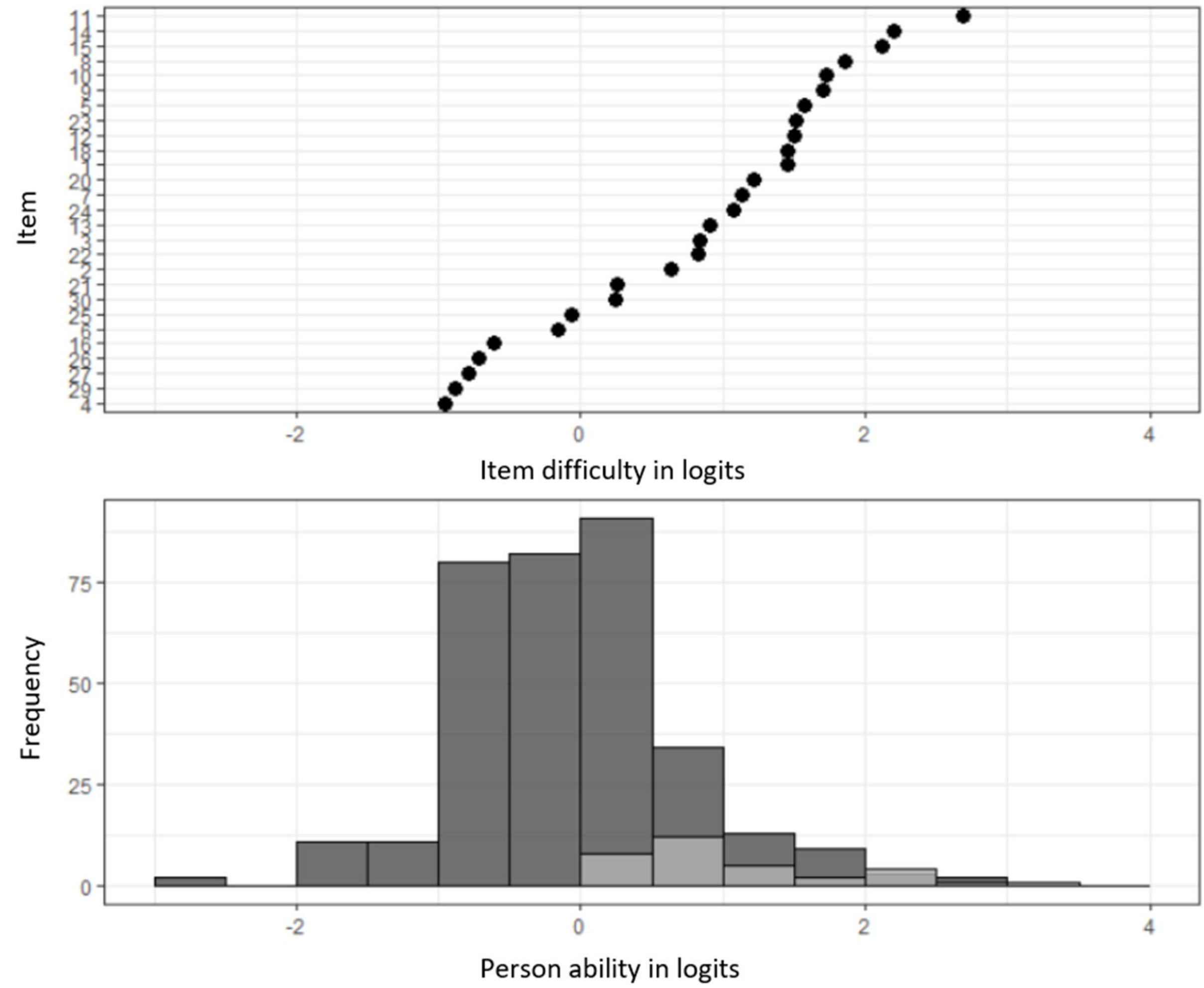

Figure 1. Item difficulty and person ability for the pilot study sample with the translated CCCI (n = 338 students ranging from grade 9 to grade 12)

DEVELOPMENT OF A REFURBISHED AND IMPROVED CLIMATE CHANGE CONCEPT INVENTORY

After the pilot study with the translated Australian CCCI it was decided to fundamentally develop a refurbished and improved CCCI. The procedure was similar to common Concept Inventory developments (Nelson et al., 2007). First, to develop a fitting multiple-choice instrument, a literature review and expert interviews were conducted.

Thus, the following five defining concepts elementary to understanding climate change were identified:

- (a) facts about the atmosphere,
- (b) distinction between climate and weather,
- (c) the greenhouse effect,
- (d) climate as a system,
- (e) carbon cycle.

As an example, this is the conceptualisation of the greenhouse effect in four steps:

- Visible light from the Sun penetrates the Earth's atmosphere nearly undisturbed, possible interaction with white clouds and reflecting surfaces
- Absorption of visible light from the Sun at dark surfaces on Earth, thus warming of these surfaces, and re-emission as a different radiation (infrared radiation)
- Partial absorption of this infrared radiation coming from the Earth's surface by greenhouse gases in the atmosphere
- Re-emission of infrared radiation through greenhouse gases, thus enhanced radiation onto the Earth.

The next development step was to formulate open questions, which were administered to 40+ interviewees to generate common distractors and attractors in the language of the interviewees. The group of interviewees consisted of a contingency sample of high school students and university students. Distractors and attractor extracted from the interviews were arranged in items (ranging from three to six distractors), providing about 3-6 items per concept.

This is an exemplary item for the question "Which statement best describes the greenhouse effect on earth?", loosely translated from German into English:

a) Solar radiation gets through the atmosphere and warms the earth's surface. Solar radiation reflected from the ground is reflected back to the earth by greenhouse gases in the atmosphere. So, the earth warms up more.
b) Greenhouse gases damage the ozone layer in our atmosphere and thus create the ozone hole. More solar radiation can reach the earth through the ozone hole and therefore the earth warms up more.
c) Greenhouse gases in our atmosphere concentrate the incoming sun rays. The earth is warmed up by the concentrated rays of the sun.
d) Solar radiation gets through the atmosphere and warms the earth's surface. Thermal radiation from the earth gets absorbed by greenhouse gases in the atmosphere and radiates back to earth. So, the earth warms up more.

The correct answer is d). In fact, in guided interviews seven out of 18 interviewees (9^{th} grade school students to beginning university years) showed ozone hole conceptions in connection with the greenhouse effect. After further inquiry, one to three of the seven interviewees stuck to a conceptualization similar to answer b). In later interviews conducted for testing the understandability of the questions and their corresponding answers with ten mostly new interviewees again between 9^{th} grade and beginning years of university answer b) was chosen two times.

Another loosely translated exemplary item regarding the carbon cycle concept is as follows:

When fossil fuels, such as coal, are burned, carbon (C) enters our atmosphere in the form of carbon dioxide (CO_2). Can this carbon (C) from the carbon dioxide (CO_2) be absorbed by a plant at some point?

a) Yes, when it rains, the carbon (C) enters the soil in the form of carbon dioxide (CO2) and is absorbed by plants there.

b) Yes, the plants can absorb the carbon (C) from carbon dioxide (CO_2) through photosynthesis.

c) No, carbon dioxide (CO_2) and the plants do not come into contact because the gaseous carbon dioxide (CO_2) rises to the top of the atmosphere.

d) No, the carbon (C) from burning fossil fuels is artificially produced and cannot be absorbed by plants.

The correct answer to this question is b). Distractor d) for example refers to a known student conception of "natural vs. man-made CO_2 (Niebert & Gropengiesser, 2013), where students think that CO_2 emitted by burning has a different structure than CO_2 emitted by respiration. In ten guided interviews with 9th grade students, who were specifically targeted towards the concept of carbon cycle, three students argued along the "natural vs. man-made CO_2"-concept. Furthermore, two students mentioned the idea that CO_2 emitted by fossil fuels does not participate in the "natural" carbon cycle since it raises in the atmosphere and can therefore not be absorbed by plants, since it is out of reach.

DISCUSSION AND OUTLOOK

As an exemplary result for the open-ended interviews, it can be concluded that even in the year 2021 among the interviewed German speaking teenagers and young adults some hold on to an ozone hole conceptualization to explain the greenhouse effect. Additionally, student conceptions about the carbon cycle documented in existing literature (Niebert & Gropengiesser, 2013) were also mentioned in our interviews.

To summarize the state of the work, open-ended items were developed for all five concepts a) to e), and 40+ one-on-one interviews were conducted with the targeted population of teenagers (8th/9th grade upward) and young adults. The generation of distractors (3 to 5 distractors per item) is done, and 6-8 items were developed per concept.

To give an outlook, in autumn 2021 the current version of the CCCI was administered to a larger sample study to evaluate psychometric values of the improved CCCI with special focus on item functioning as well as matching of the test with the target population. The main study is subsequently planned for 2022.

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IMPROVING STUDENTS' UNDERSTANDING OF ECOLOGICAL FOOTPRINT WITHIN THE CONTEXT OF EVERYDAY LIFE

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Higher Education Institutions can play a major role in shaping societies towards more sustainable pathways, but such initiatives still need to be enhanced and further developed. Towards this effort, a 3-year ERASMUS+ project was organized, through a strategic partnership among four European Universities and an international Non-Governmental Organization. The project has two main goals: (i) the development of educational materials for the universities' community (students, educators, administrative staff, and university managing authorities) regarding the teaching of sustainability through the Ecological Footprint (EF), and (ii) the development of an EF online calculator for universities. This study aims to assess the learning effect of the developed educational materials on 22 students from two of the four universities involved in the project: University of Aveiro (UA, Portugal), and Aristotle University of Thessaloniki (AUTh, Greece). The module lasted 12 teaching hours and was delivered face-to-face to UA undergraduate students (n=13) and, due to COVID-19 restriction measures, via a synchronous, distance learning mode to AUTh master students (n=9). The Ecological Footprint Diagnostic Instrument (EFDI) tool was used with students a week prior to the teaching and a week after, to assess their understanding of the EF concept by covering 3 tiers: i) Content, ii) Reasoning, and iii) Confidence. Results showed an increase in all mean scores for both groups of students. Differences between pre- and post-teaching results were statistically significant in both universities for the Content tier, in UA for the Reasoning tier and AUTh for the Confidence tier. Taking into consideration the combined Content and Reasoning tiers, no significant differences were recorded neither for UA nor for AUTh, while for the combined three tiers (Content, Reasoning and Confidence), only AUTh students presented significant improvement. Findings are very encouraging in promoting sustainability education in higher education through the teaching of Ecological Footprint.

Keywords: Conceptual understanding, Higher Education, Questionnaire survey

ECOLOGICAL FOOTPRINT

The Ecological Footprint concept (EF) is a valuable resource accounting tool that assesses human pressures on the environment. It links everyday activities with the environmental burden caused by human needs (Baabou et al., 2017). It measures the biologically productive land and water area that an individual, a city, a country, a region, or humanity requires to sustain its consumption and to absorb the waste it generates, using prevailing technology and resource management practices (Wackernagel & Rees, 1996).

From the early beginning, the concept of EF gained great attention among the educational community aiming to benefit from its potential. EF method was used from early childhood education (McNichol et al., 2011) to secondary (Gottlieb et al., 2013) and university students (Lambrechts & Van Liedekerke, 2014), as well as in the preservice teachers' education (O'Gorman & Davis, 2013; Fernandez et al., 2016).

Also, several teaching interventions have been implemented to educate different groups of learners on the concept of EF, its characteristics and its practical use in everyday life. In particular, McNichol et al. (2011) studied the EF of an early learning centre, by identifying and exploring opportunities for early childhood sustainability education through interdisciplinary research. Results indicated that the EF consumption categories which had the greatest impact on the overall Footprint were food (61%) and transport (22%). This study also revealed that the introduction of the EF concept in early childhood education may be an effective way to educate children, staff and parents on the links between their food consumption, land usage and the environmental impact.

In secondary education, Gottlieb et al. (2013) studied 130 high school students from the city of Haifa, Israel, and revealed that the incorporation of the EF as an educational tool may provide some predictive indicators of Pro-Environmental Behaviour (PEB). It also showed that applying the EF as an educational tool produced statistically significant differences in Perceived Behaviour Control (PBC), Personal Norms (PN), and Behavioural Intentions (BI). In Collins et al. (2018)'s study, the individual EF was calculated by a total of 20 postgraduate students from UK and 31 high school students from Italy to explore the environmental consequences of their current consumption behaviours and the effects associated with selected changes in their daily consumption. The results showed that the average EF per student was higher than the world average due to their activities mainly associated with Food (40%), Goods (22%), Services (17%) and Mobility (13%). In addition, students could identify possible changes in their day-to-day consumption habits after receiving the educational message from the first round of EF calculator implementation.

In the area of tertiary education, Ryu and Brody (2006) examined the impacts of a graduate course on sustainable development using EF assessment. A total of 50 graduate students (22 students from the study group and 28 from the control group) from Texas A&M University, USA, participated in the course. The results showed that environmental education is associated with behaviours' change since students who knew and attended environmental courses reduced their EF during the three-month study period (from 7.9 to 6.8 gha). In addition, the categories that negatively influence EF were products and services, housing, food, and transport, while the key determinants of the EF were determined in the socio-economic factors (e.g., residence, age, and the distance from university). The implemented teaching techniques, i.e., Place-Based Learning (PBL), proved to have a very positive role in increasing environmental behaviour, and students who learn with the use of PBL teamwork techniques were more likely to reduce their environmental Footprint. Similarly, Conway et al. (2008)'s study developed EF scenarios on the University of Toronto at Mississauga campuses and reported that students' involvement with EF helped them to become familiar with statistical research and teamwork (collaboration), and despite the limitations of EF, to better understand environmental issues.

Another informative application of the EF is given by Collins et al. (2020)'s study, in which a survey was run to assess the usefulness of Global Footprint Network's (GFN) personal Footprint calculator in enhancing individuals' understanding of their environmental impact and lifestyle choices and empowering them to frame the scale of the problem. Answered by 4,245 individuals from 10 different countries, this survey shows that most of the calculator users are young individuals, aged between 18 to 34 years old (54%), who mainly used the calculator within an educational context (62%). The results showed that the calculator was considered a valuable tool for knowledge construction (91% of respondents), and to motivate action (78%), but with a lower impact, on actual changes to their life and reducing their personal Footprint (only 23% indicated this benefit).

In the field of pre-service teacher education, O'Gorman and Davis (2013) used the EF method with pre-service early childhood teachers at Queensland University of Technology, Brisbane, Australia to help them to address sustainability issues in their lifestyles and to engage them in learning and teaching for sustainability. The findings highlighted that EF is a tool for changing personal habits and consumer choices, by enhancing environmental concerns through engaging younger children in hands-on activities. Also, it showed that the use of a discussion forum had enabled students to adjust their attitudes and efforts to reduce negative environmental consumer habits. Likewise, Fernández et al. (2016) studied the effect of teaching the EF within a multidisciplinary project that was carried out in 119 Primary School alumni teachers from the Universitat Internacional de Catalunya (UIC) in Barcelona, Spain. The goal of the project was to engage participants to analyse and try to reduce their EF. The study concluded that EF could be used as an attitude indicator, leading to changes in the participants' consumption routines.

However, in all these studies the main focus was on the individual's EF reduction as well as on the realization of the environmental consequences of their daily activities rather than on the actual understanding of the EF concept itself. Therefore, the present study aims to assess the learning effect of the developed educational materials on higher education students' understanding of the EF in two universities involved in the EUSTEPs project: University of Aveiro (UA, Portugal), and Aristotle University of Thessaloniki (AUTh, Greece).

THE EUSTEPs PROJECT

Higher Education Institutions (HEIs) can play a major role to improve societies' sustainability, which in turn should not only be taught but also practiced within campuses. To this end, a 3-

year ERASMUS+ partnership was created in 2019, involving four European Universities: Aristotle University of Thessaloniki (AUTh), Greece; University of Aveiro (UA), Portugal; Universidade Aberta (UAb), Portugal; University of Siena (UNISI), Italy; as well as an International Non-Governmental Organization, Global Footprint Network (GFN), USA. The project is designed to educate European university students and the wider academic community (including educators, administrative staff, and university managing authorities), on the complexity of sustainability and its interdisciplinary nature in an engaging and captivating manner. Using a learning-by-doing approach, the project aims to enable the diverse academic community to recognize and learn the full complexity of the economy-society-environment relationships. To this aim, the analysis of the everyday life of each participant was adopted to create and develop moments of reflection and awareness.

The project has two main objectives: (i) the development of different educational modules customized for the four target groups of the project, and (ii) the development of an online calculator, aiming to assess the EF of universities. The developed educational module for students is interactive, innovative and applicable at the European level and intends to teach sustainability in the context of everyday life. It is comprised of seven topics, which mainly focus on three thematic areas: i) Ecological overshoot, sustainability concept and the Sustainable Development Goals (SDGs), ii) EF and its implications and applications to sustainability debates, and iii) the link between sustainability and HEIs. Among the seven topics, four of them constitute the core content, and the other three being optional, with a duration ranging from six (core) to 12 hours (extended). Since the educational materials were in the development phase, all engaged universities implemented the extended version of the module, taught in their national languages between March and April 2020.

METHOD

A pre/post research design with no control group was the general research design followed in this study.

Participants

Fifty-two (52) students engaged from the four participating universities. However, since only two universities (UA and AUTh) collected data from both testing periods (pre and post), the results are presented here based on a total number of 22 students (27% males and 73% females). From those, 13 participants were 2nd semester, undergraduate students from UA, Department of Social, Political and Territorial Sciences, and nine were 2nd semester master students from AUTh, Department of Primary Education. The study took place during the spring semester of the 2019 – '20 academic year (February – May 2020). None of the participants had been exposed before to any teaching related to the EF.

Research tool

The Ecological Footprint Diagnostic Instrument (EFDI) was the main research tool which was already developed, tested, and applied by Liampa et al. (2019) to assess undergraduate primary teachers' understanding of EF in Greece. EFDI is a 3-tier test, namely a closed-form, multiple-choice instrument, comprised of 13 questions relating to the concept of EF. Each question consists of 3-tiers; i) the Content (1st) tier that assesses content knowledge, ii) the Reasoning (2nd) tier that assesses explanatory knowledge related to the first tier, and iii) the Confidence (3rd) tier that differentiates the lack of knowledge from misconception by using a certainty response index regarding the first two tiers. More specifically, among the 13 questions, three questions had Content and Confidence tiers (questions 1–3, no Reasoning tier was included), one question had nine multiple-choice items (question 4), where possible answers were 'it increases', 'it reduces', 'it depends', 'it has no effect', and the remaining nine questions had all three tiers (questions 5–13). The answering scale in the Confidence tier included the following six options: 'Just guessing', 'Very unconfident', Unconfident', 'Confident', 'Very confident' 'Absolutely Confident'. In this study, EFDI was applied online through Limesurvey, a week prior and a week after the teaching of module to the target group of students.

Data analysis

The collected data was quantitatively analysed using SPSS v.25. Due to the small number of participants and the unbalanced distribution of scores, the non-parametric Wilcoxon Signed Ranked exact test was used for the analysis. As there was a different number of questions in each part of the EFDI and different answering scales for the three tiers, all scores were converted to percentages of the theoretical maximum scores for comparability among data. For all testing, the limit of p=0.05 was set.

RESULTS

Descriptive results and trends

Initial students' scores, in both groups of students (AUTh, UA), were above average (>50%) in the two individual tiers of Content and Reasoning, and these scores were further increased after the EF teaching (except for the UA students in the Reasoning tier who increased their scores from 37% to 50%).

The comparative analysis of the three individual tier scores (pre- and post-questionnaires), showed that in all, except one case, Content knowledge scores were higher than the other two tiers' scores (Reasoning and Confidence). The only exception was the scores of UA students where their initial (pre) Content score (58%) was lower than the initial Confidence one (63%). However, when all participants were analysed as one group, Confidence scores were always the highest among the three tiers, both before (63%) and after teaching (72%), indicating that the perceived accuracy of their answers was relatively higher than the actual one.

On the contrary, for both groups of students, Reasoning tiers (namely the justification of the answers given to the content knowledge; 1st tier) gain always equal or lower scores than the other two tiers, both before (UA=37%, AUTh=60%) and after teaching (UA=50%, AUTh=75%). This result indicates the relative difficulty of the particular type of tier (reasoning / explanation of why the answer in tier 1 was correct).

Moreover, the trend of dropping achievement scores, when the learning demand for students is increasing, it is also apparent and to the next two scores, where the combination of two and three tiers was considered. In particular, in the first combination, if the answers of both Content and Reasoning tiers were correct, then the final answer for a specific question was considered correct. In the second combination, an answer was considered correct if the answers of both Content and Reasoning tiers were correct and participants were either 'Confident', 'Very confident' or 'Absolutely confident' for the accuracy of their answers. Based on these definitions and for both groups, even they were treated separately or combined, the two tiers combination scores were always equal or lower of those of the individual tier scores, and the three tiers combination scores were always lower than the combination of the two tiers. This was the case both before and after teaching.

Effect of the teaching module

Regarding the effect of teaching the educational module, our analysis showed an increase of correct responses in the post scores, for both student groups (UA, AUTh). This improvement is the case when the three individual tiers were examined independently, and when their combinations were in focus. In particular, in 10 out of the 15 comparisons significant differences were recorded (see shaded cells in Table 1). More specifically, UA scores significantly increased in the individual tiers of Content (16% progress, p=0.007) and Reasoning (13% progress, p=0.045). Concerning the results of AUTh, students presented significant progress in the individual tiers of Content (17% progress, p=0.008) and Confidence (11% progress, p=0.020), as well as in the combination of the three tiers (i.e., Content & Reasoning & Confidence, 33% progress, p=0.031).

Table 1. Mean percentage scores in EFDI domains per university

	Content (1st tier)		**Reasoning (2nd tier)**		**Confidence (3rd tier)**		**Content & Reasoning (1st & 2nd tiers)**		**Cont & Reas & Conf (all 3 tiers)**	
	PRE	**POST**	**PRE**	**POST**	**PRE**	**POST**	**PRE**	**POST**	**PRE**	**POST**
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
UA & AUTh (n=22)	61 (15)	78*** (11)	46 (23)	60* (22)	63 (10)	72** (9)	45 (22)	58* (24)	32 (18)	52** (23)
UA (face-to-face) (n=13)	58 (17)	74** (12)	37 (20)	50* (17)	63 (11)	69 (7)	36 (19)	46 (20)	30 (17)	40 (18)
AUTh (distance & synchronous) (n=9)	67 (10)	84** (6)	60 (20)	75 (21)	64 (8)	75* (11)	58 (21)	75 (21)	35 (20)	68* (20)

*p <0.05, **p<0.01, ***p<0.001

When participants from both universities were analysed as one group, statistically significant progress was recorded in the scores of the individual tiers and the scores of their combinations. In particular, for all participants, the Content tier scores were increased by 17% (p=0.000), the Reasoning tier score by 14% (p=0.018), the Confidence tier score by 9% (p=0.003), the two-tier combined score (i.e., Content & Reasoning) by 13% (p=0.021) and the three-tier combined score (i.e., Content & Reasoning & Confidence) by 20% (p=0.004).

DISCUSSION AND CONCLUSIONS

Results indicate a medium-level score (~50%) of the initial understanding of the EF concept for both groups of students. However, the quality and depth of this initial understanding were poor as it is exhibited by the low combined two tiers and the three tiers students' scores. Moreover, the high potential of the educational module to develop students' understanding of the EF was also demonstrated by the significant differences that were recorded, in both groups, in the two-thirds of the comparison cases (10 out of 15, see table 1). Thus, these findings are very encouraging in the promotion of sustainability education in higher education through the EF teaching. The latter, in combination with the promising outcomes from the implementation of EF teaching in most educational levels, may lead to a substantial turn to more sustainable patterns of living. Therefore, teaching EF may be proved as a valuable tool in achieving the one-planet goal.

In reverse, the small number of participants in each group, their different academic backgrounds and levels of study (undergraduate and master), and the potential cultural differences are some of the limitations of the study. Especially the number of participants seems to be crucial, as when all 22 participants were analysed as one group, all differences were significant (Table 1). Further research is needed, with a larger number of students, to have more reliable findings regarding the effectiveness of the module.

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CONTRIBUTION OF EARLY CHILDHOOD EDUCATION TO A SUSTAINABLE SOCIETY: INFLUENCE FROM HOME IN PRESCHOOL CHILDREN'S UNDERSTANDING AND PRACTICES OF COMPOSTING IN FRANCE

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This paper examines the influence of parental composting practices on the understanding of organic matter processes among five-year-old children. We used semi-structured interviews with parents and young children to determine details of parental composting practices on the one hand, and children's knowledge and misconceptions about the organic matter cycling in a composter on the other. We collected data from samples in neighbourhoods with different socioeconomic characteristics in two different French cities. Results show that young children are capable of developing an understanding of biowaste decomposition in the context of composting, and that formal teaching of composting in preschools could promote better scientific knowledge of the concept and get children involved in environmentally responsible everyday practices related to waste management.

Keywords: Early Childhood, Informal learning, Sustainable Development education

INTRODUCTION

Background

Education can empower children by equipping them with the knowledge, values and skills to make informed decisions about environmental issues (Kaga, 2008). There is, therefore, growing interest in children's learning between the ages of 3 to 6, and a considerable body of educational research focusing on early science education is related to the environment (e.g., Palmer, 1995; Davis, 2010). Despite this trend, however, French curricula for preschools give little space to scientific concepts, the carrying out of experiments or initiation in inquiry-based science.

It is notable that children's science learning begins long before they enter formal education, and that young children acquire their initial ideas through everyday life experiences (Allen, 2014; Gomes & Fleer, 2017). Preconceptions can be described as young children's initial ideas based on previous experiences, developing occasionally into alternative frameworks and representing obstacles for learning (Kambouri, 2015; Delserieys et al., 2018). Initial ideas and obstacles concerning matter decomposition have already been studied in the context of formal schooling at the preschool level (Leach et al., 1996; Ergazaki et al., 2009) and also with older pupils (Hellden, 1995). Being a rather complex concept, the understanding of organic matter decomposition may be facilitated by everyday activities that bridge the gap from experiences in a familiar setting to the more generalising perspective needed by science. Yet, there is a lack of empirical studies on the opportunities for young children to develop scientific concepts at home (Gomes & Fleer, 2017).

The current study was devised to address this need by investigating the influence of parental composting practices on the understanding of organic waste decomposition among young children. After having long been considered insignificant, home composting is now becoming the leading strategy for the reduction of household organic waste, being the object of a national programme managed by the French Agency for Ecological Transition (ADEME).

Research question

The following question is addressed in this paper: how parental composting practices could have an impact on their children's preconceptions of the organic matter cycling in a compost bin?

MATERIEL AND METHODS

Study sites

This study was carried out in Rennes and Tours, two cities that have similar socio-demographic profiles, but different composting policies. We started from the hypothesis that the city's composting policy would, *a priori*, have an impact on the practices of reducing organic waste at source. It seems to us that Tours has favoured individual composting, whereas Rennes has rather developed collective composting (see figure 1).

Figure 1. Examples of shared community composting areas in Rennes and Tours.

Study sample

The study concerned 48 children and 48 parents, interviewed in eight preschools. The composition of the study group met the following inclusion criteria: lack of prior formal learning activities about waste management, composting and decomposition. We used in this research a judgement sampling which is non-probability.

In each metropole, we chose to collect our data in four areas with different socio-demographic profiles: urban mixed, urban high-income, urban low-income and suburban mixed (see figure 2). Indeed, we hypothesised, *a priori*, that the type of housing could have an influence on domestic waste management practices.

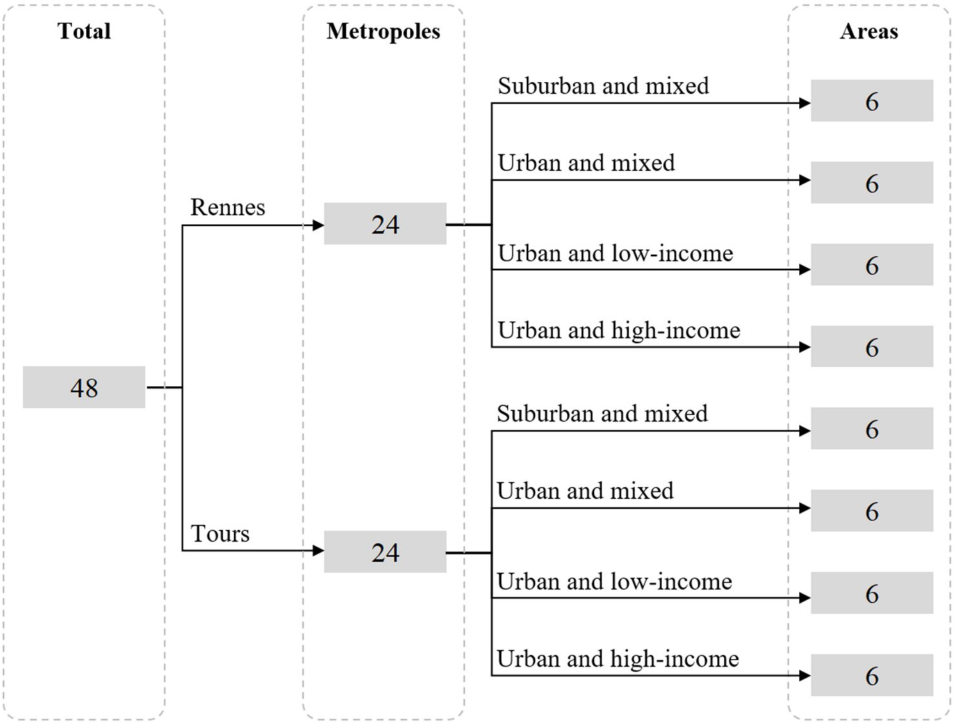

Figure 2. Numbers of children/parents by metropole and area.

Interview protocol

Semi-structured interviews were used with six pupils aged five to six in every selected preschool. One of the activities relied on the observation of five pieces of apples, fruits known to all the children. The child had to classify these pieces from the least decomposed to the most decomposed and then explain their choice. In another activity, various pictures of composters were presented to the children. They were then asked about their knowledge of these objects. During this activity, children were also given the opportunity to observe mature compost in which fruits at different stages of decomposition were visible, as well as two species of detritivores (worms and woodlice). Meanwhile, data on parents' knowledge and home waste management practices were collected through 30- to 60-minute, individual, semi-structured interviews conducted and recorded by the same researcher.

Data analysis

All interviews were manually transcribed and analysed using Sphinx IQ2 software. The analysis of the data collected from the children to categorise their conceptions of the knowledge involved in composting is the subject of a previous article (Marchal-Gaillard et al., 2021). We refer readers to that paper in order to understand in detail our approach to determining the degree of children's understanding of the decomposition of organic waste in the composter.

We nevertheless recall here the main lines of this approach. The analysis of the knowledge involved in the organic matter cycle at different school levels enabled us to determine five key processes that five-year-olds can express through our interview guide (see figure 3).

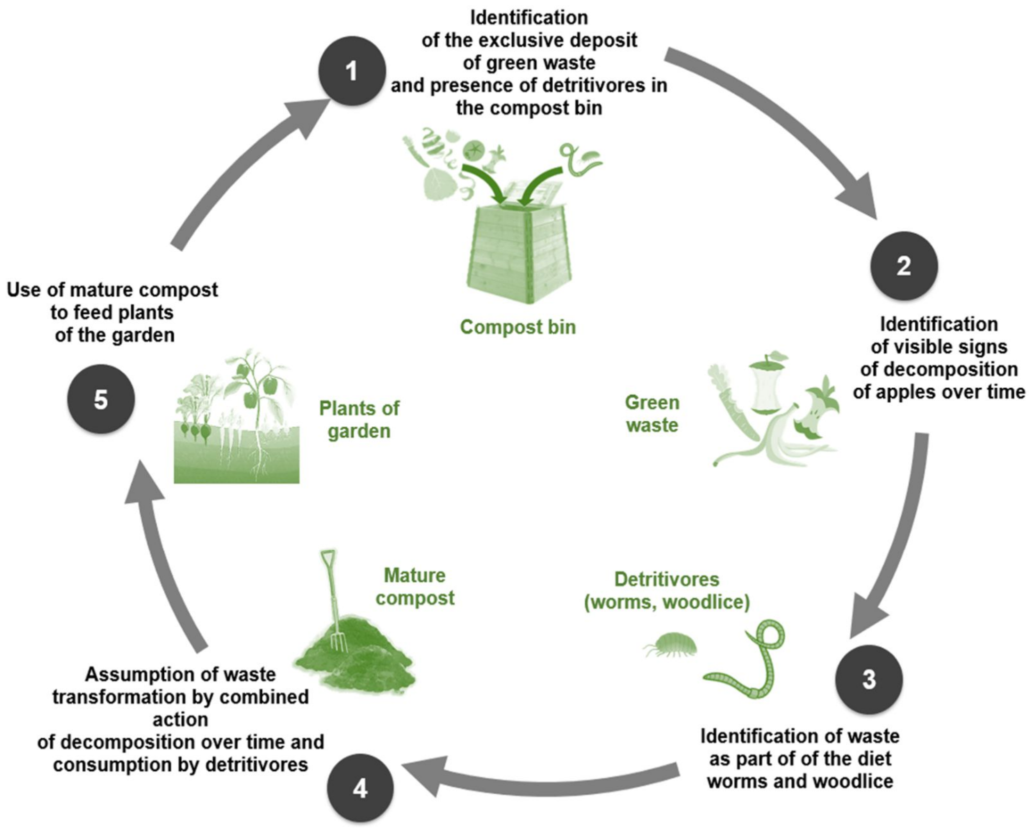

Figure 3. Modelling of the five key processes identified for understanding the cycle of organic matter in the composter in kindergarten.

For each of the key processes of this cycle, we first develop three levels of preconception. These three categories of statements are constructed from the children's responses, and are organised according to their degree of correspondence to the scientific knowledge at stake (see figure 4), reflecting the successive stages of knowledge construction.

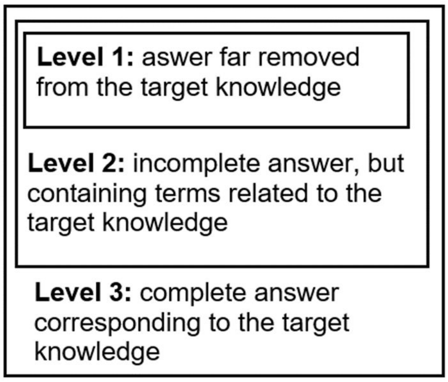

Figure 4. Presentation of the relationship to scientific knowledge for the three levels of preconceptions.

In a second step, we determine a total score for children's understanding of the organic matter cycle in the composter, which adds up the design levels for the target skills.

In this paper, we cross-reference this level of child understanding with environmental and family factors related to the domestic management of this waste. In order to make this cross-reference, we have constructed a tool for analysing interviews with parents in order to characterise their relationship to waste and to develop parental profiles accordingly.

RESULTS

Family properties and modalities of transmission of scientific cultural practices around an everyday object, the composter.

Contrary to what we assumed, place of residence (metropole, neighbourhood and type of housing) does not seem to be a common characteristic of children with equivalent comprehension scores. Indeed, we find children with different places of residence in all groups. On the other hand, we find a high concentration of family properties characterising high scientific cultural capital in the groups of children with high comprehension scores. We also find that the presence of a composter at home is in the majority among children with high scores.

While the overview allows us to describe trends for several family characteristics, it does not allow us to identify any social determinism. For example, when we look at the variable on the parents' scientific studies, we see that some children do not have the general profile presented above. Indeed, the presence of a 'family cultural capital' that has been validated at school (Bourdieu & Passeron, 1970) does not systematically guarantee that it will be transmitted to the children. Although, according to these authors, pupils from higher social categories “make the most” of the cultural capital they have inherited, they do not all seem to benefit from these cultural privileges, as “meshered” pupils may fail at school despite having highly qualified parents (Henri-Panabière, 2010).

Cultural inheritance is not systematic and does not always succeed in finding the right conditions for the 'heir' to inherit (Lahire, 2012). Conversely, other children show a high level of success, while their families lack the cultural capital they could 'inherit' (Lahire, 2012).

We now present two children's portraits that illustrate this lack of determinism.

Unlikely success story: Antonin's portrait

Antonin has a high comprehension profile. Nevertheless, his family characteristics are very different from those of the children in the same group. Antonin lives in a council flat with his mother and brother. Antonin's mother is a hotel cleaner. She has a literary baccalaureate and a beautician certificate. Antonin's father is not involved in the family's life. Antonin's family lives in a flat and does not have a garden, but they do have a balcony and a terrace. Antonin's mother plans to create a vegetable garden there. She also explains that she would like to compost her waste and that she has already tried to do so on the balcony.

Antonin is a very talkative child. When we show him pictures of composters, he immediately recognises the wooden models, which he says he saw in the Peppa Pig cartoon. Peppa Pig is a British animated television series created in 2004 by Neville Astley and Mark Baker, and produced by Astley Baker Davies. Antonin explains, "In fact, it's called compost. We put fruit peel. A little bit of soil, and lots of animals. The fruit in it is all rotten." He says that he has seen these bins in a park as well, and has lifted the lid to see the contents. Watching Peppa Pig certainly helped Antonin to build up his knowledge of composting. We note that the action of breaking up waste by detritivorous organisms, which is not explained in the cartoon, is described by Antonin: "they [worms and sowbugs] eat rotten fruit". But he does not specify that this waste "will turn into soil" (as described in Peppa Pig). His understanding of these cycle processes is incomplete.

On the other hand, Antonin states that the animals went into the bin, whereas this information is not given in the cartoon (in which the worms are dug up in the garden by Peppa and her brother, and then put into the composter).

It seems to us, therefore, that Antonin's curiosity and observation skills are also explanatory factors for his high degree of understanding of the organic matter cycle.

We now present a situation of "improbable failure" in which a child shows a low level of understanding, whereas his family context seems, a priori, favourable to the transmission of knowledge about composting.

An unlikely case of failure: Félicie's portrait

Félicie has a low understanding profile. She does not identify organic waste as part of the diet of worms and woodlice: "Erm... it [woodlice] eats earthworms. Well... uh... [worms] I don't know. On the other hand, birds eat earthworms." In addition, Félicie does not know how to explain what the mature compost will be used for, or where it will be taken.

Félicie lives in a house with a garden, with her two parents and her brother. Her father has no higher education and works at the Tours town hall. Her mother, who was our interviewee, is an operating room nurse. She explains that the family practices composting. She says: "We pile it up and pile it up! We have a big bin outside actually, and we put it in." She explains that Félicie often puts waste in the composter, but she says that her husband is in charge of the gardening, and that he is also responsible for the household waste. The mother puts waste in the composter when it is not raining. But she admits that she hates gardening.

We do not understand why, while Félicie's mother states that her daughter puts waste in the composter, Félicie had not previously recognised the compost bin as an object she has at home. We therefore ask her mother to describe the composter and to send us a photo (see figure 5).

Figure 5. Photo of the composter, sent by Félicie's mother.

Félicie's mother explains: "Our bin is not closed, well it doesn't have a lid. It's a big huge thing that our parents, our grandparents had in the gardens. It's made of plastic. It has a bottom but it's not covered." She says that Félicie only practices composting in the summer, and that the family only puts waste in the composter when there is a large amount of peelings in the kitchen.

Looking at the photo of the bin, we see that the top layer of waste is only fresh peelings, with no visible signs of decomposition. On the other hand, the layer directly below is already very dry. It seems to us that the deposits are very far apart.

Félicie's portrait leads us to believe that composting, as practiced in her family, is a missed opportunity for transmission. Although Félicie shows observation and deduction skills, the absence of observation and imitation of a meaningful parental practice hinders her understanding of the processes involved in composting.

DISCUSSION

In our study, 19 interviewed parents claimed that they had a compost bin at home, but further investigation revealed that the presence of a composter in the garden was probably not a sufficient criterion to categorize all these parents in the same group of individuals practicing composting. Indeed, the location of the composter, the frequency of composting, the use of the mature compost and the involvement of children in the use of the compost bin seem to be important considerations in assessing the practice of the parents.

Although the small size of our sample does not allow us to produce statistically significant results, the trends that emerge lead us to hypothesize about the factors influencing young children's understanding. Parental commitment to waste reduction at the source and the systematic practice of composting seem to be particularly important factors in facilitating children's understanding.

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NATIVE MAMMALS IN SCIENCE TEXTBOOKS FOR PRIMARY SCHOOL: A COMPARATIVE STUDY BETWEEN PORTUGAL AND SPAIN

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The present study analysed textbooks of the 5th year of schooling from Portugal and Spain to check the presence of native mammals of the Iberian Peninsula and of Savannah African mammals. This analysis is the follow up of a study promoted to identify Portuguese and Spanish children's knowledge and live contact with mammals of these two biogeographic regions. In this previous study it was found that native species were more frequently unknown and not seen live, since zoos were the places with more frequent references as responsible for the direct contact with animals. In the present study, it was tried to find whether the textbooks adopted in the schools that participated in the previous study could also be a factor that contributes to children's less knowledge about native fauna, checking the number of figures, drawings and information concerning eleven mammals of both biogeographic regions. Surprisingly, the textbooks from both countries include more pictures of the native Iberian fauna than of the Savannah, but often omit any reference to their biogeographic region of occurrence. Therefore, this omission can also be an explanation for the less familiarity of children with native mammals, reinforcing the role of teaching practice in counteracting this finding. Educational implications of the results are also discussed, since knowledge of animals is one of the factors that can influence a preservationist attitude.

Keywords: Textbooks for Primary School, Iberian mammals, Savannah mammals

INTRODUCTION

The natural environment is a main part of the curriculum in Spain (Boletín Oficial del Estado**,** *Real Decreto 126/2014*) and Portugal (Direção Geral de Educação, 2018). The term natural environment can be defined as a natural place where biological, geological, physical and chemical processes happen. In these processes taking place in the ecosystems, fauna plays an important role.

In the detailed curriculum for the region of Castilla-La Mancha, the nearby ecosystems appear explicitly (Decreto 54/2014) and the same trend can be found in the Portuguese Curriculum, e.g., to characterize some of the existing biodiversity at the local, regional and national levels, presenting examples of relationships between flora and fauna in different habitats (Direção Geral de Educação, 2018). Therefore, nearby biodiversity should be the main scenario to address environmental problems and seem to be central in both countries to better understand the impact of human actions at a local scale, educating in pursuit of sustainability (García Fernández & Sánchez Vizcaíno, 2016). Besides, the environment should be addressed at school from a holistic perspective, integrating all the elements that are part of it (Eugenio Gozalbo, Zuazagoitia Baltar, & Ruiz-González, 2018) and fauna is precisely one of these elements. Thus, the fauna of the nearby ecosystems constitutes a main focus among science contents in primary education.

Concerning fauna, several studies have concluded that children have a greater knowledge and interest about mammals (Huxham, Welsh, Berry, &Templeton, 2006; Patrick et al., 2013). This fact has been explained due to a great human interest towards big animals, which are aesthetically pleasing, with which it is possible to more deeply interact and that share similar needs and interests with humans (Batt, 2009). This interest of humans in mammals seems to be also related to their size, features, cognitive abilities and phylogenetic proximity to humans (Knight, Nunkoosing, Wrij & Cherryman, 2003; Herzog, 2010; Borgi & Cirulli, 2015). Other studies worldwide also found that the younger, and even the adults, tend to not know common species of their region or country, independently of their taxa (Paraskevopoulos, Padeliadu, & Zafiropoulos, 1998; Bizerril & Andrade, 1999; Huxham, et al., 2006; Mateos Jiménez & García Fernández, 2016). This trend appears also among students that live in small cities or in rural areas (Mateos Jiménez & García Fernández, 2016). Recently, Almeida, García Fernández & Strecht-Ribeiro, (2020) compared the knowledge and live experience of Portuguese and Spanish pupils of Iberian and Savannah mammals. In both countries, Savannah mammals were much better known, with a higher frequency of live observations, since these animals were often observed in zoos. This lack of knowledge and contact with local or regional biodiversity can have a great impact on conservation attitudes, since what is not known cannot be valued, and consequently, protected (García Fernández, Sánchez Emeterio & Sánchez Ramos, 2012).

According to Kellert (1996), places where nature is managed like zoos are part of the indirect experience with nature, and are subject to an increase of visitation when compared to the one occurring in natural spaces. Thus, the lower live contact with native fauna could be explained, not only by the absence or lower frequency of native species in zoos, but also by the decline in direct contact with nature (Almeida, Rato, & Dabaja, 2021).

However, to achieve a better explanation for the lesser knowledge of native species found among children, the identification of other factors that can contribute to this situation was considered relevant. Therefore, the present study analysed the inclusion and prevalence in children's textbooks of Portugal and Spain of Iberian and Savannah animals, given that these educational resources are frequently used in teacher's practice and can influence children's knowledge. As Campos (2012) stated, books and textbooks are still an important source of knowledge about biodiversity despite the influence of other resources, like television and the Internet.

METHODOLOGY

A content analysis was implemented, focused on children's textbooks for the 5th year of schooling adopted in the schools where the previous study by Almeida, García Fernández & Strecht-Ribeiro, (2020) was developed. The Science contents of the 5th year in Portugal and Spain are focused on biodiversity, the main reason for the choice of this year of schooling. Seven books, three from Portugal and four from Spain, were part of this content analysis. It consisted in counting the number of photos or drawings of the following animals of the two biogegraphic regions (Iberian Peninsula: badger, bear, fox, genet, Iberian lynx, mongoose, otter, rabbit, red deer, wild boar, and wolf; and African Savannah: black rhinoceros, cheetah, elephant, giraffe, gnu, hippopotamus, hyena, leopard, lion, Thomson's gazelle, zebra) included in the previous study already quoted, and by checking any written information concerning the inclusion of their names associated with the pictures or of their biogeographic region. The digital versions of the textbooks or their scanning allowed the possibility of a previous analysis by each researcher of the two countries, followed by a compared analysis of the results at the end. The counting results of both researchers were similar, and small differences were due to the presence of animals in the opening pages of each unity, where several animals appeared together, sometimes in small figures or drawings, which posed more difficulties in the analysis. Only the global data by each biogeographic region and by country is presented due to space limitations.

RESULTS

The global counting of the content analysis made of the children's textbooks regarding the inclusion of photos, drawings and information about the mammals from the Iberian Peninsula and the African Savannah is included in Table 1.

Table 1. The analysis made of seven children's textbooks of both countries (A, B, C, D, E, F, G) considering the number of images per book (Pict.), information (I) of being native or not, and the total counting of both parameters (T1, T2).

	Portuguese textbooks								Spanish textbooks									
	A		B		C		T1	T2	D		E		F		G		T1	T2
Iberian Animals	Pict.	I	Pict.	I	Pict.	I			Pict.	I	Pict.	I	Pict.	I	Pict.	I		
	22	6	42	5	13	4	77	15	16	1	14	-	11	-	11	-	52	1
Savannah Animals																	T1	T2
	14	5	29	3	10	2	53	8	5	2	10	2	1		-	-	8	4

All the three textbooks adopted in the Portuguese schools have more pictures of the Iberian animals (77) than of the Savannah animals (53). Even so, the animals are often shown on the page which introduces a thematic chapter or to illustrate a certain habitat (generally a field or a forest), without mentioning their names. The three Portuguese textbooks frequently fail to mention whether the animals have native status. Quite often, the pictures are included to highlight certain features of the animals, e.g., type of coat/fur, reproduction, feeding or adaptations to the environment, to indicate whether they are terrestrial or aquatic animals in general, or to explain different taxonomic levels.

The four Spanish textbooks analysed show a higher number of pictures of Iberian animals too (52), when compared to images of Savannah animals (8). Nevertheless, like in the Portuguese textbooks, the pictures don't include information about their native status and the texts tend to omit explanations related to this issue. Pictures are mainly used to explain trophic chains, the concept of the ecosystem, or merely as a decorative element with no clear didactic purpose. It is noticeable that the number of Savannah animals present in the Spanish textbooks is much lower than the Iberian Peninsula animals, the percentage for the Iberian fauna is only 0.2%, but 50% of these pictures are associated with an explanation of their habitat.

DISCUSSION AND CONCLUSIONS

With this study, which follows up a previous one related to knowledge and live experience of Portuguese and Spanish pupils of Iberian and Savannah mammals (Almeida et al., 2020), it was possible to better identify and understand the factors that can explain the low knowledge revealed by children of native species, some of them very common in the Iberian Peninsula. Beside the lack of contact with nature and the prevalence of contact with zoos which privilege exotic fauna, the children's difficulties in the identification of Iberian animals can also be partially related to the lack of reference to native species at school. In fact, and as mentioned in the Introduction section, the national curricula of both countries tend to highlight the importance of the native fauna and the local ecosystems (Direção Geral de Educação, 2018; The Royal Decree of minimum contents in Spain, Ministry of Education, Culture and Sport of Spain, 2014), which can explain the higher presence in the textbooks analysed of Iberian animals when compared to those from the Savannah. In fact, textbook authors normally tried to follow the main recommendations of official documents, even knowing that any document can allow different interpretations.

Although the textbooks adopted by schools include several pictures about the native animals of the Iberian Peninsula, they frequently fail to mention their native status, a common trend in the textbooks of both countries. Thus, it seems that despite the presence of figures, photos and drawings of Iberian mammals in the textbooks, this presence does not seem to be enough to produce a proper learning, and, as a consequence, a higher score in the identification of these animals, and African Savannah animals continue to be better known, certainly due to the influence of other sources of information. Therefore, the textbooks analysed do offer little information regarding the interaction of these animals with the environment in which they live, making it difficult for pupils to understand how these species are interacting with local and regional ecosystems (i.e., resources needed and available) and how they have relations (i.e. trophic relations) with other beings, which is also essential for an adequate knowledge of the ecosystems (García Fernández & Sánchez Vizcaíno, 2016). This lack of explicitness in textbooks can also affect teachers' work in class, since the influence of textbooks in teaching practice has been recognized (Behnke, 2018). Even so, this causal influence needs to be further investigated.

Finally, it is important to state that lesser knowledge and exposure to local, regional or national biodiversity can affect children's awareness about the threats faced by native species (Consoarte-McCreaa et al., 2016), a main reason to justify the importance of the present study.

To counteract this trend, it seems important that teachers, teacher trainers and textbooks writers be aware of this issue and provide the changes needed related to their field of action.

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A REVIEW OF EDUCATIONAL RESEARCH INTO PLASTICS IN AN INTERNATIONAL SETTING

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The excessive consumption and disposal of plastic waste into the oceans is causing severe environmental problems, thus resulting in a need to produce citizens with an awareness of this. This awareness must be promoted from school age onwards, hence this review of the literature to understand the nature of educational research into plastics in an international setting over the past 10 years. Four renowned international science education journals in this field, with good quality indicators, were selected for this literature review and publications therein concerning plastics were analysed. The authors, content, educational stage to which it was directed and methodology used were analysed for each study. Only 1.13% of a total of 6,841 papers were found to concern some aspect of plastics, a percentage that is particularly low. Moreover, no clear increase in the number of publications was observed over the 10-year period studied. An analysis of the authors showed that the typical researcher was a university lecturer in a field other than science education who made a single contribution to the topic and did not usually share authorship with others from different educational levels. Generally speaking, the most widely studied topics were the composition and properties of plastics at a secondary education level, overlooking aspects such as environmental awareness or the impact of plastic pollution on health. A quantitative methodology was used most frequently in these studies. Finally, we can conclude that the educational research carried out over the past 10 years does not appear to be giving an adequate response to the plastics problem, thus making it difficult to produce citizens who are aware of, and are prepared to deal with, this problem.

Keywords: Literature review, plastics, educational research

INTRODUCTION

The use of plastics is currently generating significant debate in our society (Smith, Love, Rochman, & Neff, 2018; Hierrezuelo, Cebrián, Brero, & Franco-Mariscal, 2021). Thus, they have improved our health, sanitation, medicine, communications and standard of living in general (Cook, 2014) due to the fact that they are light and highly resistant to fracture and high temperatures (Lusher, Hollman, & Mendoza, 2017). However, they have high durability results in their build-up on the environment, especially in the oceans. For this reason, large quantities of plastic (so-called Great Pacific Garbage Patch), waste that persists in the oceans, forming large deposits, also generated. This waste is broken down into microplastics, which are ingested by the living beings that form part of our diet. In addition, plastics are synthesised from petroleum derivatives, to which additives are added to improve their properties (Burmeister, Rauch, & Eilks, 2012; Lebreton, et al., 2018). The toxicity of some plastics and their presence in the human body is still a subject for study (Smith, Lov, Rochman & Neff, 2018).

The relationship between chemistry and society is clear (López-Fernández, González-García, & Franco-Mariscal, 2021). The generation of environmental awareness in the general public therefore remains an important aspect. As noted by Jaén and Palop (2011), a change in the general population's attitudes and behaviour must start from a school age. The aim of this study is to present the results of an international literature review in the field of science education to determine recent research into plastics and to obtain an overview of the response of schools to this question.

METHODOLOGY

International science education journals with good quality indicators in the Journal Citation Reports (JCR) and Scimago Journal Rank (SJR) databases were selected and a search was carried out for articles related to plastics published in the period 2010-2019. Specifically, Science Education (SE), Chemistry Education Research and Practice (CERP), International Journal of Science Education (IJSE) and Journal of Chemical Education (JCE) were selected for their indicators which are shown in the table 1.

Table 1. International science education journals indicators.

Journal	Database	Quartil*	Impact factor*
Science Education	JCR SSCI & SCI	Q1	3.50
(SE)	SJR	Q1	5.31
Chemistry Education Research and Practice (CERP)	JCR-SSCI	Q1	2.09
	SJR	Q1	1.03
International Journal of Science Education (IJSE)	JCR-SSCI	Q1	1.51
	SJR	Q1	1.94
Journal of Chemical Education	JCR-SCI	Q2	1.75
(JCE)	SJR	Q2	0.47

*The journal's best position in the decade is shown.

First, a search was made of all the articles published in these journals that contained the word "plastic" or "plastics". To do this, the journals websites' search engines were used. A total of 739 unique publications were found. Subsequently, these articles were read and those that, despite containing these terms, did not deal with the subject of plastics were discarded, making a total of 142 papers. Finally, from the resulting articles, those containing educational research were selected, for a total of 77 unique articles (Figure 1).

The authors, content, educational level to which it was directed and methodology used were analysed for each study (table 2).

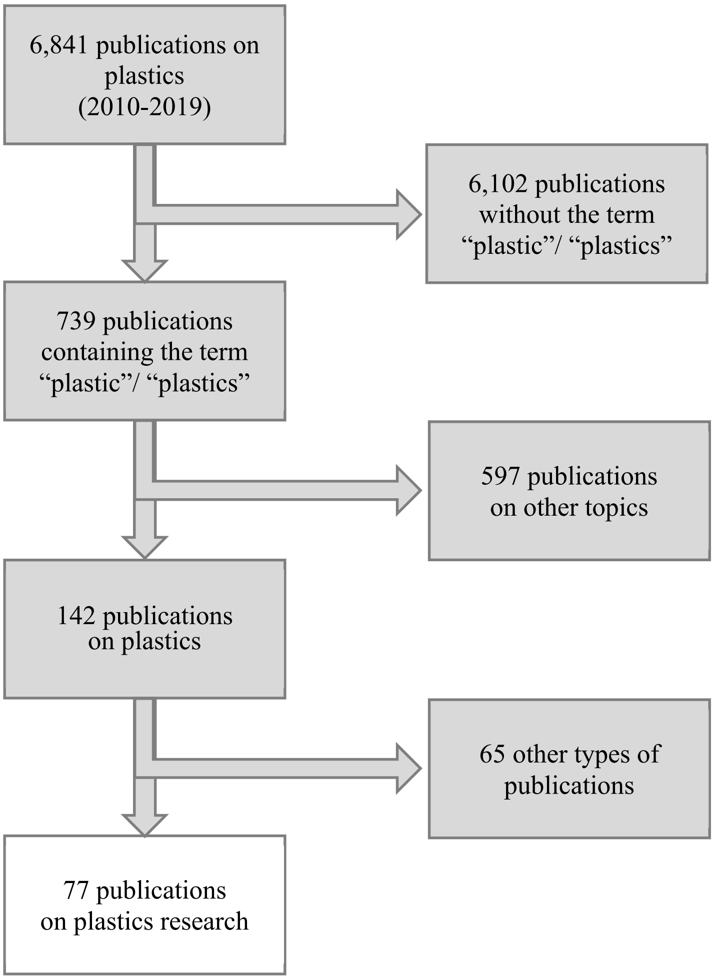

Figure 1. Research selection method

Table 2. Aspects analysed for each study

Topic	Aspects analysed
Plastics-related publications in the past decade	Total number
	Total percentage
	Papers number in each journal
	Papers percentage in each journal
Authorship of the papers	Authors number
	Authors educational level
	Contribution
	Authors mixing
Topics covered	Composition and properties of plastics
	Contamination and environment
	Solutions to the plastics problem
	Awareness and health effects

Educational level	University
	Secondary school
	Elementary school
	Early childhood education
	Others
Methodologies used	Quantitative
	Qualitative
	Mixed

RESULTS

Plastics-related publications in the past decade. Only 77 of the 6,841 studies reviewed in the four journals corresponded to studies concerning plastics. This gave an average of 7.7 studies per year, although they were distributed unevenly, with more such studies being published in 2016 and 2019 (14 papers each year). 2011 was the year with the lowest research about plastics (3 contributions). The years with the highest number of publications are isolated and no upward trend can be observed in subsequent years, as would be expected if the topic of plastics had been consolidated as a field of research in science education. It seems, therefore, that the one-off increase in papers could be due to specific environmental aspects such as climate summits (Figure 2).

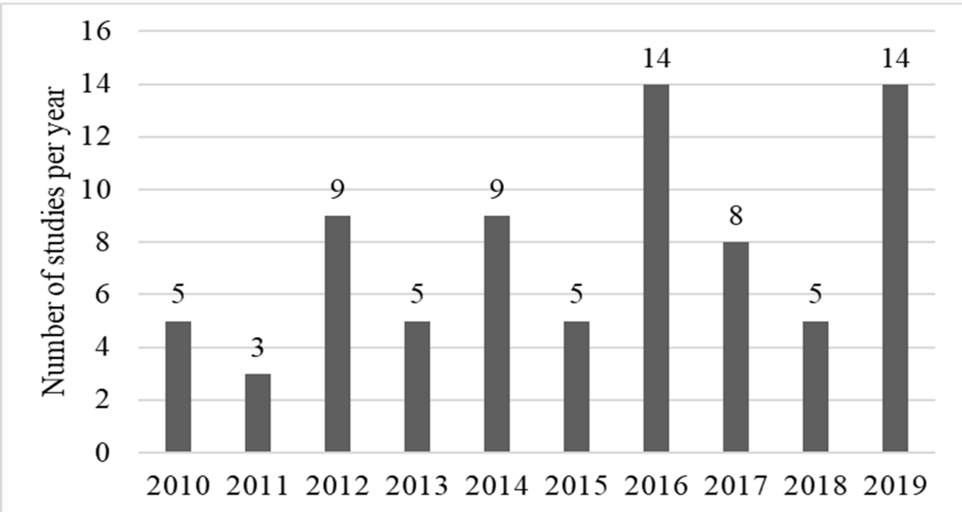

Figure 2. Plastics-related publications in each year in the past decade.

A comparison of the number of studies published by each journal with respect to the total (Table 3), shows that the IJSE published the highest number of papers on this topic (2.4%), although this value is considered to be of little relevance. Although JCE published the second highest number of studies (27), it corresponds to the lowest percentage (0.6%), since is a journal that publishes a large number of papers.

Table 3. Plastics-related studies in each international journal.

Journal	Plastics-related studies	Studies published in journal	%
SE	10	579	1.7
CERP	10	712	1.4
IJSE	30	1236	2.4
JCE	27	4314	0.6

Authorship of the papers. Publications with two or three authors predominate (53%), with the majority being university lecturers from fields other than science education, who do not tend to publish with teachers from other educational levels (Table 4). Moreover, they normally contribute with only a single publication.

Table 4. Characteristics of the publications' authors.

Characteristics		Frequency	Percentage
Authors	One	8	10.4
	Two or three	41	53.2
	More than three	28	36.4
Educational level of authors	Secondary school teacher	6	2.2
	University lecturer in science education	57	21.1
	University lecturer in another field	200	74.1
	Others	7	2.6
Contributions of each author	One article	245	95.0
	Two or three articles	13	5.0
	More than three articles	0	0.0
Mixing of authors	Single author	10	13.0
	Same educational level	53	68.8
	Different educational level	14	18.2

Topics covered. The topics covered are the composition and properties of plastics, contamination and the environment, solutions to the problem, awareness and health effects, as can be seen from Figure 3.

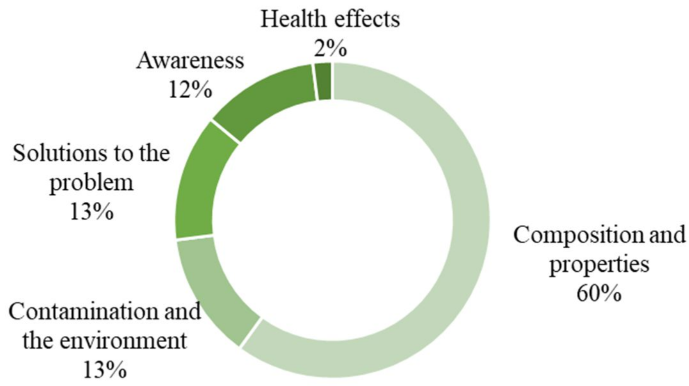

Figure 3. Topics covered in the plastics-related studies analysed.

Educational level. The studies are mainly targeted at the secondary school level (58%), followed by primary school (24%). The levels receiving least attention in plastics-related studies are university, early childhood education and others (Figure 4). The low percentage of publications detected in early childhood education level (2%) requires educational attention since is a fundamental stage for developing environmental awareness in children (Corraliza & Collado, 2015).

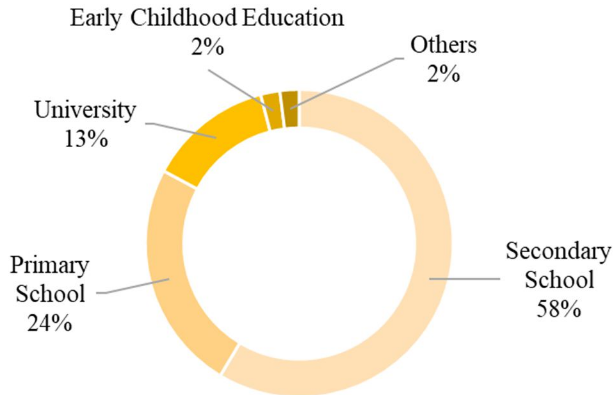

Figure 4. Educational level in the plastics-related studies analysed.

Methodologies used. As can be seen from Figure 5, most studies used a quantitative methodology, followed by qualitative and, finally, mixed.

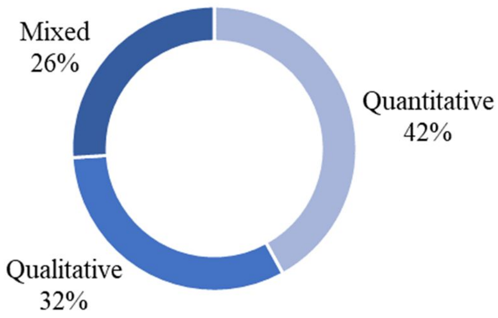

Figure 5. Methodologies used in the plastics-related studies analysed.

CONCLUSIONS

Our findings show that the educational research carried out over the past 10 years (2010-2019) concerning plastics has not overcome this social/scientific problem from a school age in a manner that would be required to produce a citizenship aware of this problem and willing to act. Although some international journals have published research into this topic, the number of studies published is considered to be very low and important aspects such as environmental awareness or the effects of plastic pollution on our health need to be covered to a greater extent. The results of the last decade are not encouraging for an upward trend in the coming years.

As regards the authors, the majority are university lecturers with no direct contact with the children and adolescents who will go on to form future generations. In addition, studies aimed at earlier ages, such as early childhood education, are essentially non-existent despite the importance assigned by some authors to the need to include environmental education from such ages (Corraliza & Collado, 2015).

The plastic problem must be approached from all perspectives. As Van Berkel, Pilot & Bulte (2009) indicate "student activities in mainstream school [...] do not put emphasis in the curriculum on personal, socio-scientific and ethical questions that are relevant to students' lives and society". However, it is essential that current generations live in a manner that does not endanger the opportunities of future generations (De Waard, Prins, & Van Joolingen, 2020) and they take well informed decisions to be taken and actions to be promoted to generate a change of attitude in the population. If we can ensure that the teaching and learning of environmental issues such as plastics is addressed in the classroom in this way through educational innovations and research, the number of publications on this topic will increase (López-Fernández, González-García, & Franco-Mariscal, 2021).

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A CROSS SECTIONAL NETWORK ANALYSIS OF THE PLANT BLINDNESS PHENOMENON

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It is interesting, that even though plants contribute essentially to the life phenomenon upon earth, people don't seem to find them interesting. Humans prefer animals and rarely notice the flora around them. This phenomenon is called plant blindness and it was firstly assigned during the mid-80s. Since then, the phenomenon has been gaining much attention and many researchers have tried to determine it comprehensively. Plant blindness' definition is a combined total of core elements that form a specific "human's relationship to plants" concept. Aim of this study is to focus on these core elements and to highlight possible correlations between them through a network analysis approach. Moreover, by conducting a cross age study, we seek to examine how these correlations alter as students move from primary school to university. One thousand two hundred thirty-seven (1237) primary, middle, high school, and university students participated in this research. Their attitudes and knowledge about plants and animals were assessed through a questionnaire. All statistically significant correlations between the research instrument's factors were considered and were illustrated by using a network analysis software. Different network analysis diagrams were created for every age group. According to the results, some correlations between plant blindness' core elements remain unchangeable as students get older. However, important alterations have been recorded, especially between the primary school and the university students. These alterations probably bring to the limelight the need for a different handling of the phenomenon, accordingly to each educational grade. This is important while researchers record the educational context as a solution to plant blindness through activities that can elucidate plants' importance and make them more interesting to humans.

Keywords: Plant blindness, network analysis, cross-age study

INTRODUCTION

The contribution of plants to human welfare and to the preservation of life upon earth is indisputable. They offer 98% of the planet's biomass and mark the beginning of the life cycle by introducing energy through photosynthesis. Basic and necessary goods of everyday life such as food, clothing, various components for pharmaceutical care and many building materials come partly or totally from plant organisms. Despite all the above, people's attention and interest in plant organisms seems to be limited (Amprazis, Papadopoulou, & Malandrakis, 2019; Batke, Dallimore, & Bostock, 2020; Kubiatko, Fančovičová, & Prokop, 2021; Parsley, 2020). Children prefer to spend more time with animals than plants, students of all grades prefer to study more about animals comparing to plants while in general, people rarely notice the flora around them during their everyday life. This phenomenon was first identified in the mid-80's by James Wandersee, who together with Elisabeth Schussler are considered pioneers in this field (Wandersee & Schussler, 2001). The phenomenon was called "plant blindness" and its "symptoms", as officially recorded in the literature (Wandersee & Schussler, 2001, p. 3), are the following: (a) failing to see, take notice of, or focus attention on the plants in one's daily life; (b) thinking that plants are merely the backdrop for animal life; (c) misunderstanding what kinds of matter and energy plants require to stay alive; (d) overlooking the importance of plants to one's daily affairs; (e) failing to distinguish between the differing time scales of plant and animal activity; (f) lacking hands-on experiences in growing, observing, and identifying plants in one's own geographic region; (g) failing to explain the basic plant science underlying nearby plant communities-including plant growth, nutrition, reproduction, and relevant ecological considerations; (h) lacking awareness that plants are central to a key biogeochemical cycle-the carbon cycle; and (i) being insensitive to the aesthetic qualities of plants and their structures-especially with respect to their adaptations, coevolution, colors, dispersal, diversity, growth habits, scents, sizes, sounds, spacing, strength, symmetry, tactility, tastes, and textures.

Regarding the causes of the phenomenon, the first researchers focused on the lack of intense plant movement (Kinchin, 1999) and the external relevance of animals to the human species (Hoekstra, 2000). The ability to perceive and process plant-related stimuli by the brain is recorded as another cause. Plants being a common part of the visual background and without obvious movement, are not usually among the information that the brain chooses to process (Balas & Momsen, 2014; Wandersee & Schussler, 2001). The phenomenon seems to be even more complex, for it seems to be influenced by social and cultural factors. Balding and Williams (2016) examine plant blindness as a phenomenon of western societies, in which there is no intense connectedness between people and the natural environment. Focusing on the field of education, there seems to be some kind of "zoocentrism" in educational systems worldwide. Curriculum appears to provide a narrower context of knowledge about plants (Amprazis & Papadopoulou, 2018) while more visual or written references to animals comparing to plants are recorded in school textbooks (Link-Perez, Dollo, Weber, & Schussler, 2009). Teachers are also characterized by this kind of "zoocentrism", as they more often use an animal and not a plant as an example when referring to the concept of life in their lessons (Hersey, 1996).

The "zoocentric" orientation of the educational systems mentioned above prompted many researchers to examine solutions to this issue through education. In the literature one can find several studies that describe how educational interventions can reduce the intensity of the phenomenon (Fancovicova & Prokop, 2011; Kissi & Dreesmann, 2018; Stagg & Verde, 2018). These educational interventions are mainly based on highlighting the importance of plants, on outdoor activities and on interdisciplinarity. The results of these studies seem to indeed confirm the effectiveness of educational projects in increasing students' interest for the plant world (Borsos, 2019; Colon et al., 2020).

It should be noted that the phenomenon of plant blindness is more than just a differentiation in the human interest towards plants and animals. It is a phenomenon related to the person's perception of the natural world around him and his connectedness to nature. Above all, the undeniable contribution of plants to human well-being raises questions on recognizing the value of such an important resource. According to recent research, the phenomenon can be linked to sustainability (Thomas, Ougham, & Sanders, 2021) as plants are directly or indirectly linked to the total of 17 Sustainable Development Goals (Amprazis & Papadopoulou, 2020). Therefore, this phenomenon can be described as a social issue and deserves attention from the entire academic community.

Considering all that has been mentioned before, it is meaningful to assess plant blindness' core elements and to highlight possible correlations between them through a network analysis approach. Knowing that, we can define the phenomenon even more comprehensively in order to design educational intervention programs that will reverse this limited interest in plants. The research questions we address here are as follows:

1. What are the correlations between the plant blindness' core elements in every age group;

2. How the correlations between the plant blindness' core elements change as students get older;

It is noteworthy to mention that no cross age and network analysis studies exist regarding the plant blindness phenomenon.

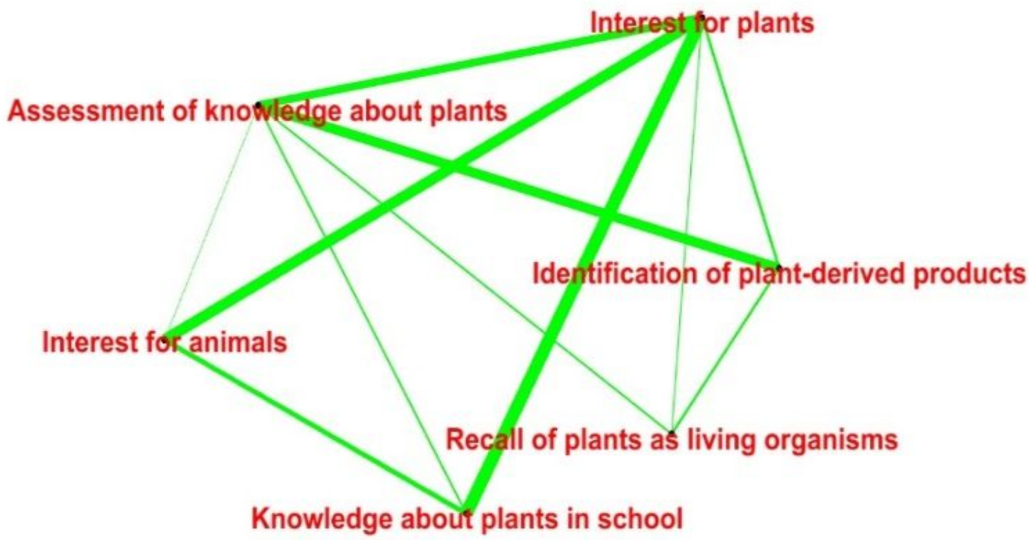
METHODOLOGY

The survey involved 1237 students with the following distribution: 309 sixth grade primary school students (12 years old), 308 students of third grade of middle school (15 years old), 311 students of third grade of high school (18 years old) and 309 students of the fourth year of university (22 years old). A cross-sectional study was chosen as a commonly used methodological approach to clarify whether learners of different age groups share common perceptions and behaviours (Creswell 2012). Cross-sectional studies are widely used in the field of education to examine students' learning attitudes and patterns (Prochaska, Sallis, Slymen, & McKenzie, 2003; Rindfleisch, Malter, Ganesan, & Moorman, 2008). A questionnaire was used as a research tool (Kaplan & Topsakal, 2013). The necessary changes were made to the wording and the content of each grade's research tool version in order to reflect the cognitive level of the participants per age group. For the construction of the questionnaire, all appropriate steps recorded in the research methodology literature were followed (Little, 2013; Teo, 2013). Initially, an in-depth literature review was carried out to examine former studies about plant blindness. Based on the defined theoretical framework, the main factors of the research tool were defined. These factors correspond to the plant blindness' conceptual elements and are the following: a) interest for plants, b) interest for animals, c) background of knowledge about plants, d) spontaneous recall of plants as living organisms, e) identification of products of plant origin and f) quantity of knowledge about plants provided at school. Based on these factors, an interview guide was constructed, and interviews were conducted with students to examine their attitudes towards plants and to make a first assessment of the phenomenon's existence. The interview data were processed to create the first version of the research instrument. This version was given to primary school teachers to give their opinion on its comprehension and general functionality. Teachers' comments led to more changes and afterwards three pilot implementations took place before the questionnaire's final version. The questionnaire's validity was established by a group of experts in biology education. The instrument's internal consistency was also measured, and the value of Cronbach's Alpha was above 0.8 for every grade.

To examine possible statistically significant correlations between the factors of the research instrument, a spearman's rank correlation coefficient test was conducted. In order to characterize a correlation as weak or strong, the following guide was used: 0.7 < rs very strong 0.69 > rs > 0.4 strong , 0.39 > rs > 0.3 moderate, 0.29 > rs > 0.2 weak, 0.19 > rs very weak. The values of these correlations were used to graphically present the relationships between plant blindness' conceptual elements through network analysis (Borgatti, Mehra, Brass, & Labianca, 2009; Rees, Wearn, Vnuk, & Sato, 2009). Network analysis methods are used in cases where it is necessary to analyze and optimize a network of connected and related elements (Brandes, 2005; Butts, 2009). The diagram resulting from the network analysis consists of a set of nodes and lines which is the visual representation of how the elements are connected to a network (Carrington, Scott, & Wasserman, 2005). The open-source software Gephi was used for the illustration of the network analysis by providing specific diagrams. The width of the lines in these diagrams represents the kind of correlation between the factors, as the more strongly two factors are correlated, the wider the line between them is. The absence of directional arrows-endings in the diagrams is due to the two-way nature of the correlations.

RESULTS

In primary school level (Figure 1), a correlation of the factor "Interest for plants" with all the other factors of the questionnaire is recorded. This does not apply to the university grade (Figure 4), in which only few correlations are recorded. In the middle (Figure 2) and the high school grade (Figure 3) "Interest for plants" is linked to several other factors of the questionnaire, but some of these connections are weak. Additionally, by comparing all figures on can conclude that "Interest for plants" is positively linked to "Interest for animals" and to "Knowledge about plants in school" at all age levels. These two correlations do not seem to be influenced by the variable of time. This is not the case for the correlations of the other factors for either the size of the correlation changes or the correlation disappears as the participants move from grade to grade. It is also noteworthy that in middle school grade (Figure 2), the factor "Recall of plants as living organisms" is not related to any other factor.



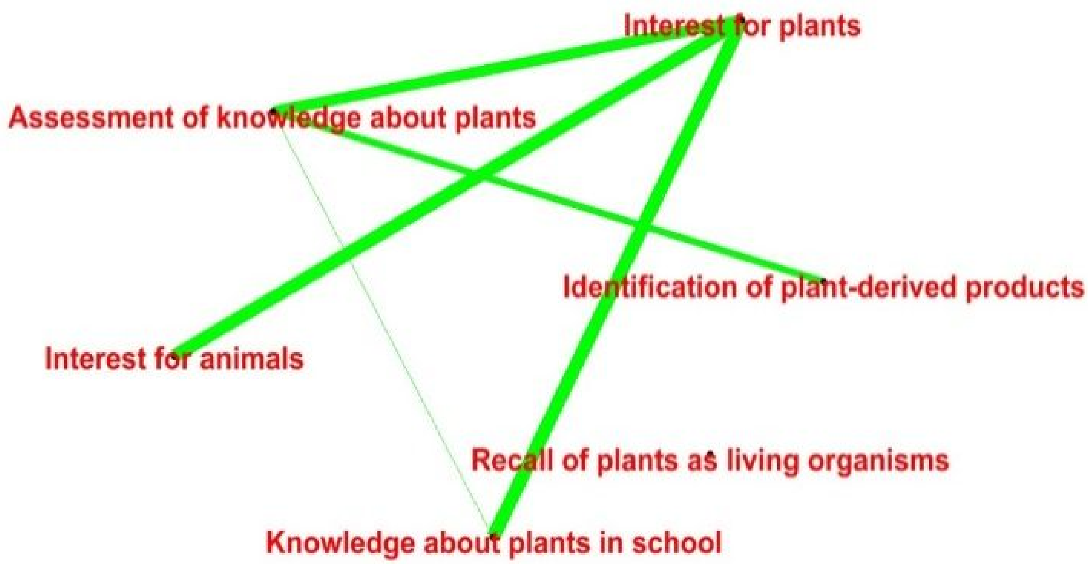


Figure 2. Plant blindness' network analysis for middle school students.

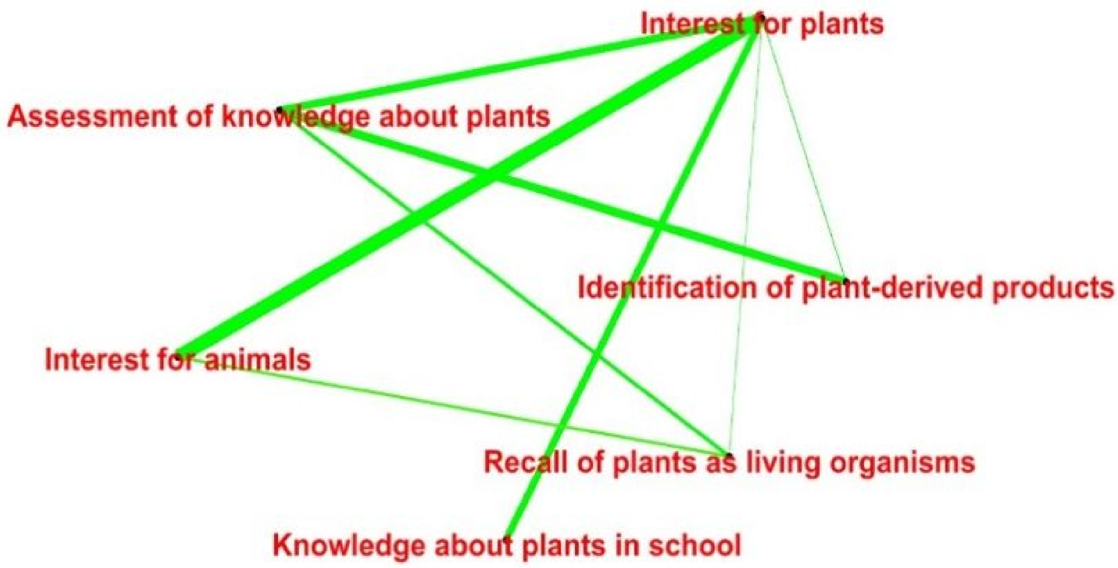


Figure 3. Plant blindness' network analysis for high school students.

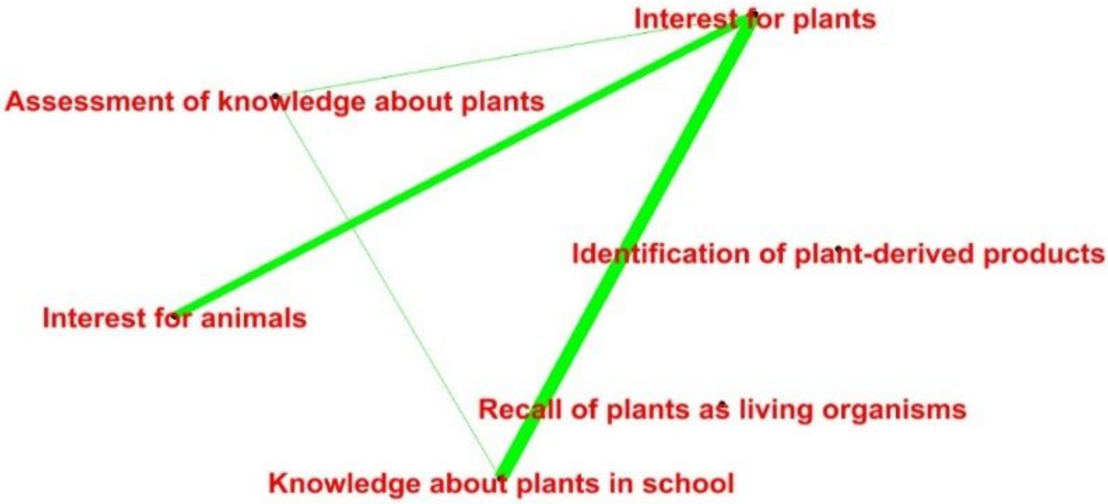


Figure 4. Plant blindness' network analysis for university students.

CONCLUSIONS

Our findings support the general idea of plant blindness being a complex phenomenon that should be examined with caution. Plant blindness may be incorporated, but it cannot be described in its entirety by the concept of "human relationship with plants". This whole issue exceeds the simple liking for flora and extends to areas such as the cognitive background, the perception of the surrounding space and possible misconceptions. Therefore, restricting the phenomenon's intensity requires a holistic approach and a multi-element inclusion. Limited amount of knowledge about plants in the educational context, cultural factors and the presence of alternative perceptions are just some of the factors that must enter the equation when trying to enhance students' interest for plants. The positive correlation between the factor "Interest for plants" and other core elements of the plant blindness can form possible educational approaches to the phenomenon. For example, the strong correlation between "interest for plants" and "knowledge about plants" in primary and middle school students indicates that providing larger amounts of such knowledge we might increase students' preference for plants in that age groups. Accordingly, the strong correlation between interest for plants and interest for animals in the high school network analysis indicates another direction. In that grade, we can probably take advantage of students' innate preference for animals to highlight plants' importance through a more holistic approach to living organisms in the biology education context. Generally, the alterations that have been recorded regarding the network analysis of each age group bring to the limelight the need for a broader perspective through which the qualitative characteristics of the knowledge provided about plants in the school context are determined. Regarding directions for further research, the examination of plant blindness in age groups above 22 years old, is also a key issue that will deepen our understanding about this subject. In addition, it is proposed to examine the usefulness of modern educational approaches such as

"Sustainability-Oriented Learning Ecologies" (Wals, 2009) and "Place Based Education" (Smith, 2002) to increase students' interest in plants.

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SCIENCE TEACHERS AND RESEARCHERS CO-DESIGN A SCHOOL VISIT TO A RESEARCH CENTER

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Research centers offer a unique environment where students have the opportunity to learn about cutting-edge research topics. Though school visits to other settings of non-formal science education have been extensively studied, there is lack of studies regarding visits to research centers, especially from teacher's perspective. This study aims to investigate how science teachers collaborate with researchers so as to co-design the school visits to the research center, in the context of a Community of Learners (CoL) designed for that purpose. 10 science teachers along with 4 researchers participated in the study, which had a one-year duration. All the interactions in the CoL were analyzed and the factors that defined the final structure and content of the school visits were identified, resulting in a visit that was consistent with many recommendations of informal science teaching, such as enhancing social interactions or student involvement, but also consistent with the uniqueness of the setting, such as space constraints or student safety.

Keywords: non-formal learning environments, outdoor education, science education

INTRODUCTION

Nowadays great emphasis has been placed on learning that can take place in organized science venues outside school, as a lot of studies recognize the potential of such places to provide many benefits to their visitors, both in cognitive and emotional level (Dewitt & Storksdieck 2008; Mujtaba et al. 2018). Such places can stimulate the interest and curiosity of the students and provide an incentive for further engagement with science, much more than classroom teaching (Neresini et al. 2009; Pedretti 2002; Salmi 2003).

However, in order to maximize the students' benefits not only at an emotional but at a cognitive level as well, teachers have to recognize the importance of their role and take into account a number of recommendations about best practices that can lead to the effectiveness of visits to non-formal environments as learning experience. For instance, it is suggested that teachers have to become familiar with the setting before the visit, inform their students about the expected learning outcomes, plan pre- and post-visit activities and take advantage of the uniqueness of the setting (Dewitt & Storksdieck 2008).

Despite the fact that numerous studies about visits to science museums and science centers have been undertaken (Anderson & Zhang 2003; Garip & Bülbül 2014; Karnezou et al. 2021; Rennie & Williams 2002), there is lack of studies regarding visits to research centers (Neresini et al. 2009), especially from teacher's perspective. Some conditions under which visits to science museums and science centers take place are quite similar to the conditions during visits to research centers, though the results from these studies also demonstrate the necessity for more efforts to try new methodological solutions and to gather further empirical evidence.

However, there are some crucial differences between research centers and other organized science venues. These settings provide students with the unique opportunity to be engaged with cutting-edge research topics and become familiar with a variety of up-to-date technological applications, which makes the learning of science more attractive (Schank et al. 2009). At the same time, the visitor will not meet any exhibitions or artifacts, as is usually the case in other non-formal settings, such as museums and science centers, but he will meet experimental set-ups. Nevertheless, research centers have usually no specialized educational staff for school visits, so researchers also undertake the school tours. At the same time, a recent study recognized a lack of co-operation between teachers and researchers before or while conducting the school visits to the research center (Giannakoudaki & Stavrou 2019).

Therefore, this study intends to investigate the collaboration between science teachers and researchers, as they design and carry out a school visit to the research center. More specifically, the research question of the study is: "How do teachers and researchers interact in order to co-design a school visit to a research center?".

METHOD

The study, which took place during the school year 2018-2019, aimed to investigate how science teachers cooperate with researchers of Foundation of Research and Technology in Hellas (FORTH), in order to plan and carry out a visit at FORTH focusing on students' understanding of cutting-edge research topics. For that purpose, ten science teachers from various types of high-schools were invited to participate in the study. Initially, as shown in Figure 1, a plenary kick-off meeting took place, where teachers were informed about the context of the study and then they were divided in two groups. Each group of five science teachers, along with researchers from FORTH and science education researchers composed a Community of Learners, which aimed to design the school visit at FORTH. Both groups dealt with cutting-edge science research carried out in FORTH. More specifically, the first group focused on students' understanding of innovative material properties (polymeric and photocatalytic materials) and the second group focused on the effect of light on matter (multi-spectral imaging and optical tomography).

Then each group visited FORTH and was informed by scientists about their research work. Thenceforth, three on-line meetings of each CoL group took place, focused on: clarification of the scientific subject matter, science education research focused on the topics under inspection as well as on visits to out-of-school contexts. Afterwards teachers along with the researchers of FORTH co-designed the final structure and content of the visits and then the school visits took place.

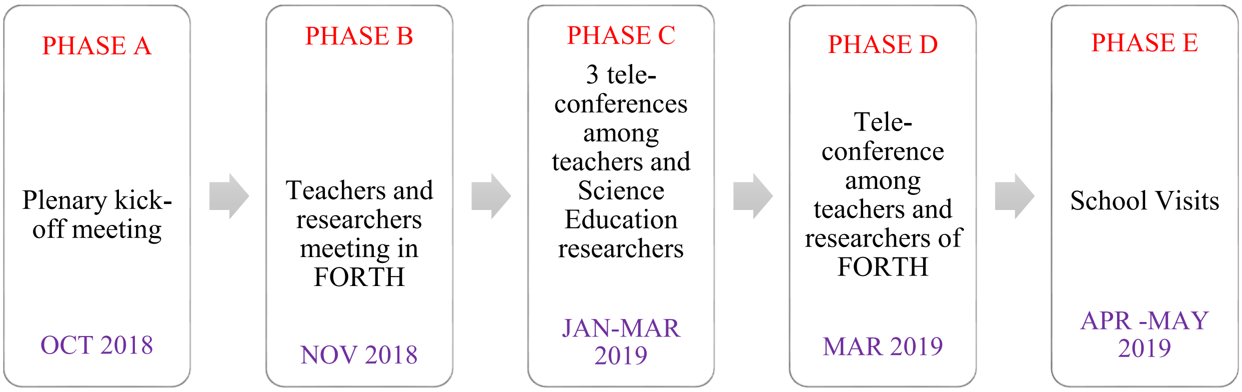

Figure 1. The timeline of the study.

Data collection is based on audio/video recordings of all meetings. So as to enrich our data, interviews were conducted with the teachers before and after the school visits at FORTH. Due to the exploratory nature of the study, qualitative methods of content analysis were used (Mayring 2015). All the recordings of the meetings were verbally transcribed and then categorized based on the Interconnected Model of Professional Growth (IMPG) by Clarke and Hollingsworth (2002), as shown in Figure 2.

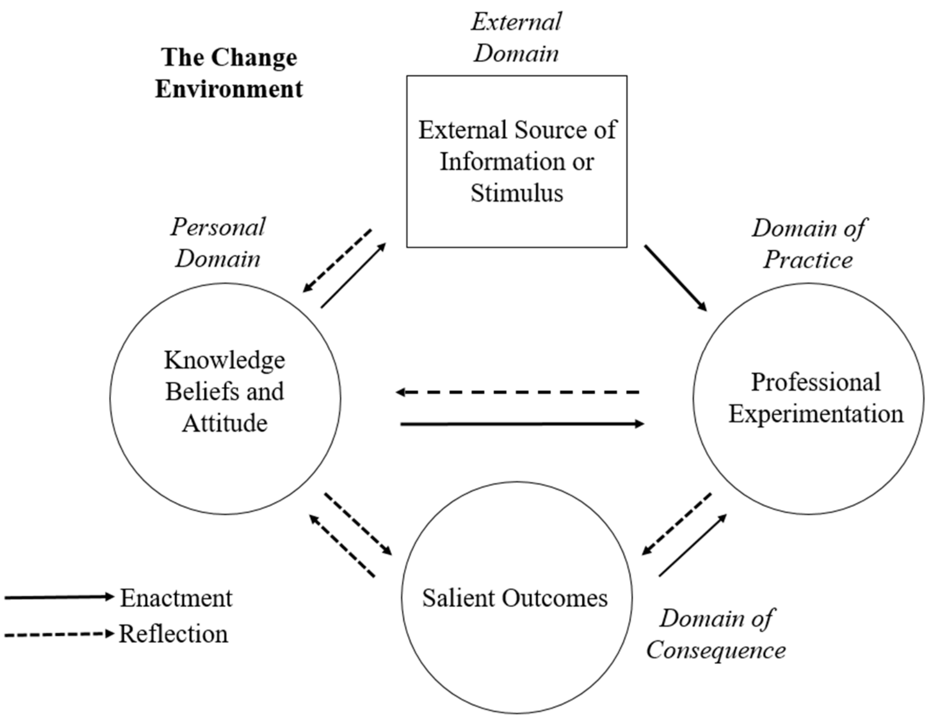

Figure 2. The Interconnected Model of Professional Growth (IMPG) by Clarke and Hollingsworth (2002).

According to the IMPG, there are four types of domains represented in the model. The external domain, which in our study are the members of each CoL, is distinguished from the other three domains. The personal domain refers to teacher's personal knowledge, beliefs and attitude. The domain of practice corresponds to teacher's professional actions, which in our case is the design of the school visit to the research canter. Finally, the domain of consequence refers to the inferred consequences of those actions, which in our study correspond to students' learning outcomes from the visit.

The IMPG is adapted and extended for the needs of the present study, as shown in Figure 3. On the left side of the figure is the teachers' world, whereas on the right side is the researchers' world and in the middle is their common Domain of Practice, as their common aim is to co-design the school visits at FORTH. Change in one domain is translated into change in another through the mediating processes of "reflection" and "enaction".

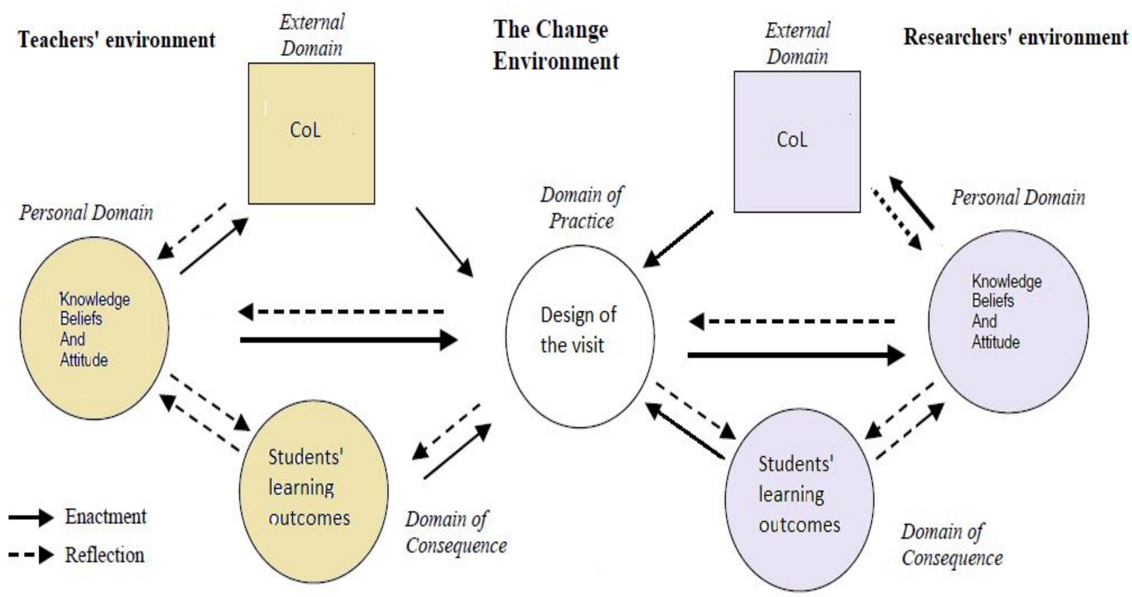

Figure 3. Adaptation and extension of Interconnected Model of Professional Growth.

In addition to the IMPG, the Contextual Model of Learning in out-of-school settings by Falk & Dierking (2000) was used (Figure 4). Considering that the research question in this study is to identify the factors that teachers and researchers take into consideration when planning the visit, we identified the content of each interaction based on the contexts of the model.

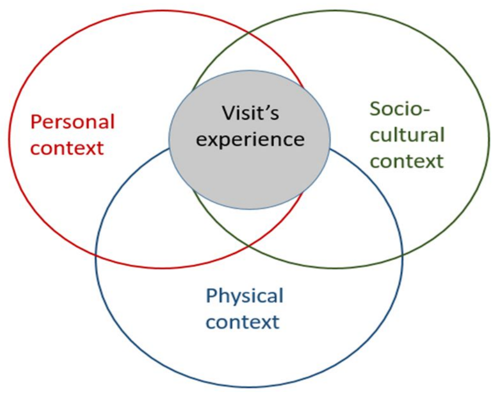

Figure 4. The Contextual Model of Learning by Falk and Dierking (2000).

The Personal context of the model includes: 1) visitor's motivation and expectations of the visit, 2) prior knowledge, 3) prior experience, 4) prior interests and 5) choice and control. The Socio-cultural context includes social interactions: 6) within the immediate social group and 7) by others outside the immediate social group. Finally, the Physical context includes: 8) the advance organizers, 9) orientation to the physical space, 10) architecture and large-scale environment, 11) design and exposure to programs and 12) subsequent reinforcing events.

RESULTS

The results presented here correspond to the collaboration between teachers and researchers in co-designing the structure of the school visits. Though the teachers' and researchers' interactions in the context of the CoL were counted in each phase of the study, the results presented in this paper correspond to phase D (see above Figure 1). During phase D, the IMPG takes the following form (Figure 5).

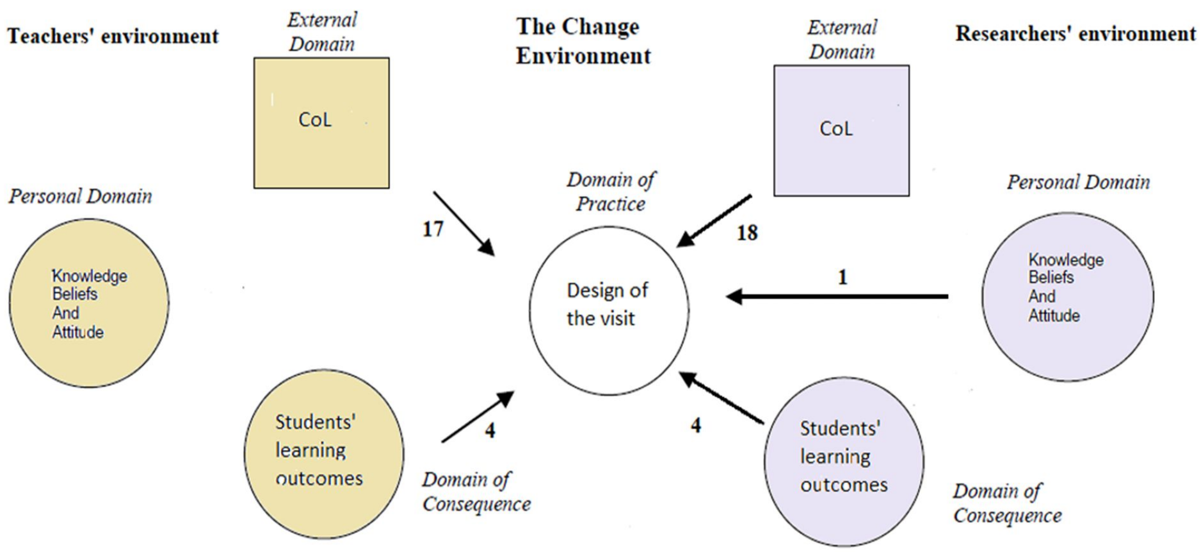

Figure 5. The IMPG during Phase D.

The number and the type of interactions between teachers and researchers in their attempt to co-design the final structure of the visit at FORTH are shown in Table 1.

Table 1. Number and type of interactions between teachers and researchers.

Context	*Sub-context*	*# Interactions (Teachers' change environment)*	*# Interactions (Researchers' change environment)*
Physical	Design of activities	13	17
	Teachers' expectations	3	-
	Advance organizers	2	1
	Architectural factors	1	1

	Subsequent reinforcing events in the classroom	-	1
Socio-cultural	Mediation by others outside the immediate social group	3	-
	Within group social mediation	-	1
Personal	Choice and control	-	1

Science teachers and FORTH researchers designed the school visit at the research center, taking mainly into account the physical and social contexts. More specifically, their main interest was to redesign the existing activities so as to encourage students' participation and engagement with hands-on activities. Though the safety of the students as well as the architecture of the labs were two limiting factors. On the other hand the fact that both teachers and researchers take into consideration the pre- and post-visit activities in the classroom shows that they do not conceive the visit as an isolated one-day occurrence. At the same time, the social interactions among students themselves and students and researchers were enhanced, by creating small groups of students during the school visits. The students could choose in which group and experiment would be engaged, giving them an extent of choice and control. Finally, as it can be seen from Table 1, neither the researchers nor the teachers did take into account to such an extent, or at least in an explicit way, the personal context of the students.

DISCUSSION AND CONCLUSIONS

As the research in informal settings progresses, it is essential to study the collaboration among the various stakeholders in this procedure. Of course, the heterogeneity of the informal settings does not allow us to define the optimal conditions for this collaboration but rather expand our knowledge and understanding of this collaboration in an innovative environment, such as research centers.

The collaboration between science teachers and researchers of FORTH is something that has not been studied before in the research of out-of-school settings. In the context of a CoL, both teachers and researchers exchanged views on how to design the school visits, taking into consideration a plethora of factors, such as safety, space restriction, students' engagement, social interactions, etc. In conclusion, teachers and researchers co-designed a visit that was consistent with the uniqueness of the setting, but also consistent with many recommendations of informal science teaching (Dewitt & Storksdieck 2008).

During the co-design of the school visit, the personal context of the students was not explicitly taken into account. This fact could be a field for future research. A way to enhance this dialogue between the three different overlapping contexts of the Contextual Model of Learning (Falk & Dierking 2000) could be to create Communities of Learners that are composed of not only researchers and teachers, but students as well.

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THE AUSTRIAN ECOLOG SCHOOLS NETWORK: RESULTS OF A QUANTITATIVE SURVEY

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ECOLOG is a programme and network for the greening of schools and education for sustainability in Austria. For 25 years, over 600 ECOLOG schools and 13 colleges of teacher education have been integrating an ecological approach into their everyday school life and school development. Throughout the ECOLOG-schools network's existence, a series of evaluations, inquiries, and studies have been produced (Rauch & Pfaffenwimmer, 2020). Based on these evaluations and to obtain current quantitative data on the implementation of ECOLOG at the participating schools, a questionnaire survey was sent to all ECOLOG school coordinators with 154 respondents (25% response rate) in the school year 2018/19, with the aim of deriving relevant measures to support ECOLOG schools. The results show that the coordinators implemented the ECOLOG principles in their everyday school life through environmentally conscious actions, while pupils learned how to deal with limited resources and were exposed to new ways of thinking and working. However, there is still room for improvement, for instance in shaping cooperation with out-of-school partners.

Keywords: Environment, Quantitative methods, Environmental Education, Educational networks

INTRODUTION

ECOLOG, a key action programme and network for the greening of schools and education for sustainability, was developed in 1996 by an Austrian team of teachers working on the international ENSI project (Affolder & Varga, 2018). ECOLOG is a national support system with the aim of promoting and integrating an ecological approach into the development of individual schools and attempts are being made to embed the programme in Austria's federal states through regional networks. To provide support, a network structure involving ECOLOG regional teams in the nine Austrian provinces has been developed; furthermore, a scientific advisory board has been established. Central support is provided by the Ministry of Education, Science and Research (BMBWF) and by the Institute of Instructional and School Development (IUS) at the University of Klagenfurt. Additional support measures are provided by the FORUM Environmental Education (an NGO), via seminars for heads and coordinators of ECOLOG network schools, the Education Support Fund for Education for Sustainable Development, as well as via the National Environmental Performance Award for schools and university colleges of teacher education (Rauch & Pfaffenwimmer, 2019).

ECOLOG is structured in three levels to support schools in the ECOLOG programme: (1) the coordination by the IUS in partnership with the BMBWF; (2) nine ECOLOG regional teams (one in each Austrian province) in collaboration with educational and environmental authorities, university colleges of teacher education and various organizations of environmental education; and (3) ECOLOG coordinators and teams in all ECOLOG schools.

Originally embedded in the OECD-Project "Environment and School Initiatives", the ecologization of schools project in Austria was conceptualized as a comprehensive school development concept following quality criteria, such as action-orientated and reflective forms of open learning or project instruction, where pupils learn actively (e.g., by generating local knowledge) and take over responsibility for creative processes and constructive relationships with the local community or neighbourhood (Rauch, 2000). ECOLOG is based upon an action research approach (Rauch, 2016). Schools analyse the ecological, technical, and social conditions of their environment and, resultingly, define objectives, targets, concrete activities, and quality criteria to be implemented and evaluated. Students and other stakeholders of a school should be involved in a participatory way, and collaboration with authorities, businesses, and other interested parties is encouraged. The measures concern, among others, areas like saving resources (energy, water, etc.), reduction of emissions (i.e., waste, traffic), spatial arrangement (from the classroom to the campus), the culture of learning (communication, organisational structure), health promotion, social learning, as well as the opening of the school to the community.

All in all, over 600 schools *(approx.10% of Austrian schools)* with about 15,000 teachers and approximately 110,000 students as well as 13 (out of 14) university colleges for teacher education are currently part of the network. Many others are reached through the website, teacher in-service-training seminars, and newsletters.

METHOD

Throughout the past 25 years of the ECOLOG-schools network's existence, a series of evaluations, inquiries, and studies have been produced (Rauch & Pfaffenwimmer, 2020). Based on these evaluations, a quantitative survey was carried out by the IUS at the participating ECOLOG schools in spring 2019. At the time of the survey, there were 572 schools in the ECOLOG network. The survey was sent to the coordinators of all ECOLOG schools.

The main goal of the survey is to gain a quantitative overview of ecological measures and activities at participating schools based on previously mainly qualitative, accompanying research studies (e.g., Rauch, Pfaffenwimmer & Dulle, 2016; Ziener 2017; Fleiß, 2018; Rauch & Pfaffenwimmer, 2019). Support systems and cooperation of the school with the outside world are examined to be able to further develop the support systems for future activities within the framework of ECOLOG. In addition, it was an urgent matter for the research team to find out how public relations are carried out at schools and what challenges, restrictions, and opportunities coordinators see at ECOLOG schools.

The following research questions were formulated:

1. Which motives are responsible for joining the network?
2. Which public relations strategies are reported at the participating ECOLOG schools?
3. How and where is the ECOLOG programme made visible to the school community?
4. What is the general attitude of the coordinators towards ECOLOG?
5. How are the coordinators supported? What hinders the work of the coordinators?
6. What are ECOLOG's effects on students?

7. How do ECOLOG schools network with their surroundings?

8. How do the coordinators rate ECOLOG?

A questionnaire was developed which contained self-formulated items as well as some adapted items from the Federal-State Commission Germany project "21" questionnaire (Rode, 2005). A team at the IUS developed the items for the research instrument. After a pilot study with 20 coordinators (carried out at the end of March 2019), some items were adapted.

All coordinators at ECOLOG schools were invited to participate in the online survey. The survey response rate was 25% of all coordinators (N = 146), 77% of whom are female Descriptive statistics (means, Cronbach-Alpha) as well as inductive statistics (regression analysis) describe a status-quo of ECOLOG schools in Austria. The SPSS programme was used for the statistical calculations.

RESULTS

In the following section the research questions formulated above will be addressed.

Responsible for joining the ECOLOG network are mainly the school management (61 %) followed by the current coordinators (33 %) and the former coordinators (30 %). The main motivations for schools to join the ECOLOG Network are the personal and professional interest in ecological issues of the initiator and a potential better public image of the school (research question 1). The data shows a broad spread of the subjects in which ECOLOG is implemented in the 2018/2019 school year. In elementary schools, the ECOLOG programme is implemented in all subjects. In vocational and general secondary schools, ECOLOG is mainly taught in the natural sciences (biology / ecology).

Regarding public relations at ECOLOG schools (research question 2), responses indicate that elementary schools increasingly address the local community directly by, for instance, inviting parents and the mayor to school projects. Secondary middle and secondary upper schools, on the other hand, prefer websites and media coverage. The public relations work in both print and online media, as well as the use of the ECOLOG-Logo, can and should be expanded in the future.

Closely related to the strategy for public relations is also the question of where and how ECOLOG is made visible to the school community (research question 3). Results show that the ECOLOG declaration is presented at a prominent place at the school. ECOLOG is part of the school programme in only 32% of the participating schools. On the other hand, it is encouraging that 61% of the coordinators state that ECOLOG can be found in the school's mission statement. The implementation of ECOLOG in the school programme, as well as in the school profile, and in the school development plan, is seen as essential for a successful implementation and the creation of a sustainable school culture.

In general, the participating coordinators rate ECOLOG positively. The attitude of the coordinators (research question 4) in the elementary schools is the most positive, followed by those who teach in the new middle schools.

Research question 5 focusses on the supporting and hindering factors. Previous studies (Fleiß, 2016; Fleiß, 2018; Lehner, 2016; Rauch & Dulle, 2011; Ziener 2017) made it clear that ECOLOG acts as a support system for teachers, and this survey confirms that the schools are well supported by the network. The information on the ECOLOG website (MW = 3.64, SD = 0.92) and ECOLOG network's materials and brochures (MW = 3.59, SD = 1.05) are especially considered beneficial. Teachers at ECOLOG schools are supported by the coordinators, particularly through their motivating teachers to carry out ECOLOG activities with their students (MW = 3.99, SD = 0.98). Furthermore, the experience exchange within the ECOLOG network (e.g., at network meetings) proves to be a valuable support for the coordinators.

One of the main challenges mentioned is the additional workload of teachers who have the role of coordinators. Another expressed challenge is that school heads infrequently provide additional resources (MW = 1.82, SD = 1.32). Furthermore, the lack of some colleagues' participation in in the ECOLOG programme, as well as legal regulations which make implementation difficult, are named as challenges.

Positive effects on pupils (research question 6) are shown in the careful use of resources and the enhancement of a solution-oriented way of thinking and working. Joining ECOLOG also has an impact on the installation of waste separation systems and their sustainable use (MW = 4.37, SD = 0.91). Additionally, health-related aspects such as healthy snacks, and exercise units were integrated into the everyday school life (MW = 4.17, SD = 1.08). The reduction of energy costs is not yet one of the major successes at ECOLOG schools (MW = 2.48, SD = 1.29), but ECOLOG makes a positive contribution to school development in general (MW = 3.96, SD = 1.04).

In research question 7, the coordinators were asked how the ECOLOG schools' network with their surroundings. The analysis of variance showed that elementary schools cooperate significantly more often with the parents' association or the municipality than vocational schools. Overall, however, the cooperation with the school environment could be expanded. It turns out that schools cooperate more often with the parents' association and with blue light organizations than with universities, companies, and industries.

The participating schools were also given the opportunity to assess ECOLOG with school grades (1 is best grade, and 5 is worst). The coordinators rate ECOLOG with 2.10 (MW) in average, which is a good result.

DISCUSSION AND CONCLUSIONS

Overall, the results show that the coordinators anchored the ECOLOG principles in their everyday school life through environmentally conscious actions involving the pupils in concrete activities and reflections. But there is still room for improvement, for instance with respect to cooperation with out-of-school partners. In subsequent studies, the teachers and students at ECOLOG schools should be included.

ECOLOG is the largest, steadily growing school network in Austria's environmental education field. Results of both qualitative (e.g., Ziener, 2017) and quantitative studies - such as this one - show successes and provide information on areas where further development is needed.

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THE EFFECT OF STUDENTS' BASIC NEED SATISFACTION ON THEIR FLOW EXPERIENCE DURING FIELD TRIPS

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Biology education provides students with various opportunities to experience nature, which is assumed to enhance their motivation. For instance, field trips to the forest can enrich biology lessons through authentic experiences and practical work, which may add to students' flow experience. The possibility of experiencing a state of flow during the learning process is intertwined with additional motivational factors. During a field trip, flow may be positively affected by the perception of autonomy, competence and relatedness. These interrelationships have already been studied to some extent. However, the existing research has not focused on out-of-school learning. To address this research gap, we investigated students' perceived autonomy, competence and relatedness as predictors of their flow experience during a field trip to the forest. Our sample consisted of 163 students (53% female) from fifth to seventh grade. Students' perceived need satisfaction and flow experience were assessed during the field trip. The results confirmed perceived autonomy and perceived competence as predictors of students' flow experience. However, perceived relatedness did not predict their flow experience.

Keywords: motivation, out-of-school learning, field trips

RATIONALE

Biology education provides various opportunities for out-of-school learning activities (Karpa, Lübbecke, & Adam, 2015). For example, students may visit a science museum, an outreach science lab or a natural area such as a forest. A field trip to a forest can enrich biology lessons by enabling students to carry out practical work (Larsen, Walsh, Almond, & Myers, 2016), that cannot be conducted in the classroom. Moreover, during field trips, students may encounter experiences with original objects, such as invertebrates and plants. Experiences of this kind can enhance positive qualities of student motivation (Basten, Meyer-Ahrens, Fries, & Wilde, 2014; Klingenberg, 2014; Polte & Wilde, 2018). These qualities, which include intrinsic motivation (Ryan & Deci, 2017) and flow experience (Engeser & Rheinberg, 2008), are facilitators of learning.

During a flow experience, students are completely focused on the task at hand. They forget everything around them and are absorbed in the given activity (Csikszentmihalyi, 2000; Csikszentmihalyi, Abuhamdeh & Nakamura, 2005). Based on Csikszentmihalyi (2000) and Rheinberg (2008), the flow experience comprises the following elements. First of all, the given activity should have no contradictory demands but clear and unmistakable feedback. It should be free of interpretation so that the actor knows at all times what is to be done. In addition, there should be a balance between the demands of the activity and the skills of the actor, so that the latter faces an optimal challenge. The prerequisite is that the activity requires a high degree of concentration so that the actor focuses their attention on the action. This creates a limited stimulus field and the person in the flow state ceases to self-reflect. Finally, the actor can have an altered perception of time. Hours may be perceived as just a few moments.

As a situational experience, flow is often experienced during intrinsically motivated activities (Kowal & Fortier, 1999, 2000). These activities are driven by an individual's interest and enjoyment, rather than by external incentives, such as rewards, or pressure (Deci & Ryan, 2002; Ryan & Deci, 2000, 2017). In self-determination theory (SDT), intrinsic motivation depends on the perceived satisfaction of the needs for autonomy, competence and relatedness (Ryan & Deci, 2017). Perceived autonomy refers to the perception of being the origin of a voluntarily chosen action; perceived competence describes the perception of self-effectiveness in an activity and in meeting its requirements; perceived relatedness is the feeling of being an active part of a social group (Reeve, 2015; Ryan & Deci, 2017). The interrelationships of flow experience, intrinsic motivation and perceived need satisfaction has been investigated in previous studies. For instance, Kowal and Fortier (1999, 2000) found a positive effect of intrinsic motivation on flow experience. They suggested intrinsic motivation as 'a salient predictor' of flow experience (Kowal & Fortier, 2000, p. 179). In addition, these studies have revealed a positive relationship between the experience of flow and the perceived need satisfaction of autonomy, competence and relatedness.

Based on the existing research, we assume that students' perceived need satisfaction will have a positive effect on their flow experience during a field trip to an out-of-school learning location. Although other studies (e.g., Kowal & Fortier, 1999, 2000) have analysed this relationship in the context of swimming courses, it has so far not been investigated in relation to field trips. Our study aims to address this research gap.

RESEARCH QUESTION

This study investigates the relationship between flow experience and the perceived satisfaction of the three basic psychological needs. The research question is:

Do students' perceived satisfaction of autonomy, competence and relatedness predict their flow experience during a field trip to the forest?

METHOD

Participants and Setting

The sample consisted of 163 students from fifth to seventh grade (age: $M = 12.1$ years, $SD = 0.85$ years, 53% female). The students attended a half-day field trip to the Gut Bustedt biology centre, which is located in a forest.

The content of the field trip was related to the topic of food chains and food webs in the secondary-school curriculum of North Rhine-Westphalia, Germany (MSB NRW, 2019). The field trip focused on the biological ecosystems of the forest, specifically, the decomposition of leaves by microorganisms living in the forest floor. During the field trip, the students had to search the forest floor for invertebrates such as insects, snails and worms. They captured a number of these organisms and later identified them in the course room of the biology centre. The students decided for themselves where they searched and which organisms they would like to investigate in the course room.

Study Design and Measures

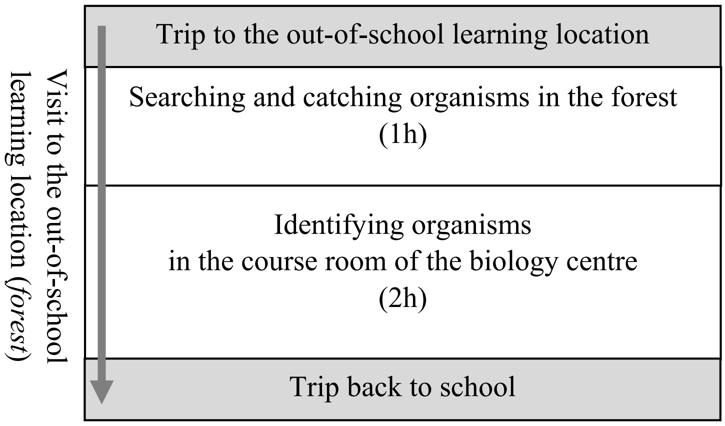

Figure 1. Study design.

Immediately after the students looked for and caught their chosen invertebrates, their flow experience was assessed using the *Flow Short Scale* developed by Rheinberg, Vollmeyer, and Engeser (2003). This scale consists of 13 items. The perceived need satisfaction was assessed directly after the students' arrival in the classroom so that the data collection was completed during the field trip. To assess the perceived need satisfaction, we used an adapted version of the *Work-related Basic Need Scale* developed by Van den Broeck, Vansteenkiste, de Witte, Soenens, and Lens (2010). The scale consists of the three subscales *autonomy*, *competence* and *relatedness* (Table 1). For all scales, we used a five-point rating scale (from 0 = 'not at all true' to 4 = 'completely true') and internal consistency was sufficient. To investigate students' perceived autonomy, competence and relatedness as predictors of their flow experience, we performed a multiple regression analysis.

Table 1. Test instruments, number of items, example items and Cronbach's α values.

Test instrument	Number of items	Example items	Cronbach's α
Flow Short Scale (Rheinberg et al., 2003)	13	'I am totally absorbed in catching the insects.'	.71
Work-related Basic Need Scale (Van den Broeck et al., 2010)			
Autonomy	7	'I felt free to catch the insects the way I think it could be best done.'	.65
Competence	6	'I felt competent when catching the insects.'	.66
Relatedness	15	'When catching the insects, I felt as a part of a group.'	.89

RESULTS

The preliminary analysis shows that all correlations are significant and have medium to high effects (table 2).

Table 2. Descriptive statistics (mean values, standard deviations) and bivariate correlation coefficients.

	M	*SE*	1	2	3	4
1 flow experience	2.68	0.55	-			
2 perceived autonomy	2.46	0.68	.45**	-		
3 perceived competence	2.68	0.67	.47**	.61**	-	
4 perceived relatedness	2.52	0.74	.26**	.54**	.49**	-

Note. N = 163; all variables range from 0 = 'not at all true' to 4 = 'completely true'; ** $p < .01$.

Afterwards, a multiple linear regression analysis was performed (Table 3). The regression model was able to identify predictors of students' flow experience ($R^2 = .52$, $F(3,159) = 19.31$, $p < .001$). Students' perceived autonomy and competence predicted their flow experience. By contrast, students' perceived relatedness did not predict their flow experience.

Table 3. Results of the multiple linear regression analysis.

	β	*SE*	*p*
Constant	1.50	0.17	<.001
Perceived autonomy	.23	0.07	.002
Perceived competence	.27	0.07	<.001
Perceived relatedness	-.04	0.06	.534

Note. N = 163; All variables range from 0 = 'not at all true' to 4 = 'completely true'.

DISCUSSION

Out-of-school learning is beneficial to students' learning (Gebhard, Lude, Möller, & Moormann, 2021). In line with the assumptions of self-determination theory (Ryan & Deci, 2017) a field trip can provide opportunities for the satisfaction of the three basic psychological needs, namely, autonomy, competence and relatedness. If these needs are satisfied, self-determined motivation can arise (Ryan & Deci, 2017). Our study focusses on a certain type of intrinsic motivation, the flow experience. Our results confirmed students' perceived autonomy and competence as predictors of their flow experience during the field trip to the forest. However, perceived relatedness was not confirmed as a predictor of their flow experience. These findings are in line with the results of Kowal and Fortier's (1999, 2000) studies on the flow experience in physical education.

Students' perceived autonomy might have been positively affected by the experience of nature (Wilde, 2021). Based on Reeve's (2015) theoretical framework, this impact may be related to the characteristics of forest visits. For instance, the visit in this study may have promoted a feeling of freedom and a perception of self-congruence among the students. Seeing oneself as the origin of action, acting out of one's own free will (volition), and being removed from immediate social constraints and rules of action (choice) can have a positive effect on the perception of autonomy (Reeve, 2015). In our study, the students had freedom of choice as they could decide for themselves where in the forest floor to look for insects and which they would catch and identify. Moreover, catching insects during the forest visit required a high degree of concentration from the students. This meant they had a limited stimulus field and needed to focus on the task at hand, thereby enabling flow (Csikszentmihalyi, 2000; Rheinberg, 2008).

In addition, our study shows that students' perceived competence positively predicted their flow experience. This finding is consistent with previous studies (Kowal & Fortier, 1999). The perception of competence refers to the balance between a person's skills and a given challenge (Ryan & Deci, 2017). When students in our study stated that they felt competent, their skills seemed to match the challenge of catching, handling and identifying the 'creepy crawlers' of the forest floor. This match between skill and challenge is a precondition of flow (Csikszentmihalyi et al., 2005). According to Wilde (2021), nature experiences such as a visit to the forest might have a positive impact on the perception of competence. During the activity of this study, the students might have tried to catch a fast-crawling insect or a slippery snail, which would have provided immediate feedback from the environment (see Csikszentmihalyi, 2005), whether or not the students caught the creatures successfully. Children consider such feedback to be informative (Hofferber, Basten, Großmann, & Wilde, 2016); in the case of failure, it allows for the adjustment of their behaviour. These characteristics of an activity can affect the perception of competence and, in turn, promote the flow experience (Reeve, 2015; Wilde, 2021).

Contrary to our assumptions, students' perceived relatedness did not predict their flow experience. This might be explained by the fact that the students mainly searched for the insects independently. Specific interactions during the field trip, however, may have been meaningful to them, such as sharing impressions and experiences (DeWitt & Storksdieck, 2008). In activities that require collaboration, the flow state can depend on perceived relatedness (Raphael, Bachen, & Hernández-Ramos, 2012). Future studies could evaluate students' relatedness in a more differentiated way, in order to explore meaningful collaboration in out-of-school learning. In these studies, the concept of social flow (Walker, 2021) might be considered.

Lastly, the limitations of this study need to be addressed. Our study focussed on students of a certain age and specific outdoor activities. Research involving older students and different activities might yield divergent results. For instance, an activity at an outreach science lab with expensive equipment might be more predetermined than a visit to the forest. It should also be noted that the study was performed during the winter months when the temperatures were quite low. These weather conditions might have distracted the students from their activity with the insects.

CONCLUSION

Since the flow experience is beneficial to learning, measures to support this experience are needed in educational settings. Our results indicate that fostering students' perceived autonomy and competence might be one way to promote flow. This approach could involve providing choices or using autonomy-supportive language. Such measures have already been investigated as regards to their impact on self-determined motivation and interest at school (e.g., Großmann & Wilde, 2018; Hofferber et al., 2016). However, these previous investigated measures need to be adapted to the respective out-of-school setting.

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PROMOTING ACTION COMPETENCE IN THE CONTEXT OF SUSTAINABLE DEVELOPMENT – A DESIGN BASED RESEARCH APPROACH

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In this paper the theoretical framing of a practical course for 10th graders with the aim to promote action competence (AC) in the context of Education for Sustainable Development (ESD) is reported. Action competence in educational contexts is seen as an essential competence for acting as responsible citizens. With the launching of AGENDA 2030 the concept of AC has recently been redefined. The aim of the study is to design, to test and to investigate a complex one-year-lasting teaching educational program to promote AC in the context of sustainable development (SD). Based on the principles of Design Based Research (DBR), research will be conducted in cycles of design-conduct-evaluate-redesign. At theoretical level the concept of AC shall be further developed. At school-practical level a program for an elective course of the final year of a secondary school in Germany will be developed and evaluated with qualitative methods. The course will focus on the ecological characteristics of cotton plant (Gossypium) and its role in production, trading and consumption of clothing at local and global level. First theoretical results of the initial cycle are theory-based Guiding Principles (GP), which form the basis for the development of the educational concept of the course. The GP refer to a) the teaching content, b) the didactical-methodical level and c) the interpersonal/ pedagogical level. In further steps, the development of the course is adapted to the framework conditions of the cooperating school. In the following, the methodological DBR-approach is described, the GP are shown and, in conclusion, an overview of the course concept is presented.

Keywords: Design Based Research, Context-based Learning, Qualitative methods

CONTEXT AND RESEARCH-FOCUS

"To create a more sustainable world and to engage with issues related to sustainability as described in the Sustainable Development Goals (SDGs), individuals must become sustainability change-makers." (UNESCO 2017, p. 63). To meet this requirement, education is a key ingredient: Individuals must be provided with the necessary knowledge and skills to recognize their societal responsibility and to express it in their actions (ibid.). To put this in practice in the German educational context the Curriculum Framework Education for Sustainable Development (ESD) was elaborated (KMK/BMZ/Engagement Global, 2016). It emphasizes the promotion of action competence (AC), particularly in the sense of participation in processes, which are in accordance with the SDGs. In addition, the need for changing designs of teaching is stated in various national publications (e.g., Geisz & Schmitt; 2016). Despite various approaches addressing issues of SD in schools and promoting corresponding competences, studies found that the concept of the SDGs is often unknown and receives little consideration (Müller-Christ et al., 2017; Engagement Global, 2020).

The Curriculum Framework for ESD emphasizes the responsibility of each school subject to promote these competences and to teach topics of global learning. Furthermore, in the general guidelines of the national educational standards of the subject of biology (KMK, 2005) the social mission of the subject towards society is demonstrated: "Since the human being itself is the subject of biology lessons, he contributes to the development of individual self-understanding and emancipatory action. This is the basis for […] environmentally compatible action in both individual and social responsibility." (p. 6). Nature is understood as a system, that humans are part of. For active participation, the promotion of communication and decision-making competences are outlined: "The basic biological understanding enables the assessment of biological interrelations, e.g., in the environmental field, taking into account nature conservation and sustainable development, [...] regarding economic, social or ethical aspects." (p.10) To be able to justify their own or another judgement, students must change perspectives and reflect on individual, as well as socially negotiable values.

Since topics of global learning are mainly addressed in the subject of geography, the related guidelines of the national educational standards (DGfG, 2020) are also taken into account. These standards focus especially on promoting systems competence to understand the interconnections of natural and human geographic factors and to examine their development and problems. In addition, the promotion of AC is highlighted: "Understanding the interaction of (...) environmental, economic, and social/political factors enables students to understand the need for sustainable development, from the local to the global level, and the ability and willingness to act accordingly to them" (p. 27). It is emphasized, that responsible action is possible only if action-relevant knowledge would also be imparted (e.g., about problems and possible solutions). Furthermore, students must develop corresponding motivation and interest.

Although the topics and goals of SD are explicitly addressed in the German ESD framework as well as in the standards of biology and geography, in the cooperating school of this study they are often addressed subordinately. They are not anchored either at the school organizational level nor in the school guidelines. However, students' timetables include elective courses. These are curriculum-free spaces, which provide the opportunity for the school to integrate courses fitting their principles or for teachers to focus on topics adapted to the students' needs.

Here is the starting point of this study, which is part of a doctoral project. It ties in with the demands and aims to develop, design, implement, evaluate and redesign a locally adapted elective school course that focuses on the promotion of action competence in the context of sustainable development (ACiSD). At the theory level, the purpose is to contribute to a locally applicable theory on promoting ACiSD by developing Design Principles (DP).

THEORETICAL FRAMEWORK

The concept of AC is based on different definitions: AC is understood as competence of individuals or groups, as well as educational approach (Sass et al. 2020). In the past, the educational approach has been considered as a key concept in research and curriculum development. The concept of AC was introduced in the 1990s in the field of environmental education. Demarcated from 'pro-environmental activity' or 'modification of behavior', it incorporates participatory action taking and changing perspectives. Directed towards problem solving, it can include both direct and indirect actions as well as actions on individual and collective level. This requires knowledge about causes and possible solutions and is guided by commitment, visions and experiences. (Jensen & Schnack, 1997; Jensen, 2004) However, the concept of AC represents an ideal, that is linked to a holistic understanding of education (related to the German notion of '*Bildung*'), which consists of concepts as democracy, equality or SD. From a philosophical point of view, the role of education is to form students to be active members of society. Based on this assumption, the achievement of a goal or specific level would not be possible since consequences of actions interact and are not predictable. (Mogensen & Schnack, 2010)

In a meta-study conducted by Sass et al. (2020), they take up the different perspectives on AC and offer a new definition against the background of SD. Viewed as the competence of individuals, AC can be described as „desired learner outcome of a subjectification model of education within a societal context that values active citizens." (Sass et al. 2020, p. 294). Based on this understanding, an individual, that is competent to act sustainably, is defined as „someone who is committed and passionate about solving a societal issue, has the relevant knowledge about the issue at stake as well as about the democratic processes involved, takes a critical but positive stance toward different ways for solving it, and has confidence in their own skills and capacities for changing the conditions for the better." (ibid., p. 303). Referring to these characteristics, Sass et al. designed a model that illustrates the following core features of ACiSD: knowledge, critical reflection skill, willingness, confidence in own skills and capacities for change. Used as indicators, they allow conclusions to be drawn about individual ACiSD. These features are adapted and shall be promoted within the project.

RESEARCH FRAMEWORK

In order to develop a course for the promotion of students' ACiSD and to generate theoretical and practical results, the DBR approach forms the methodological framework of the study. The school structure frames the duration of the course, which is why the two implementations each cover one school year. The data is collected at selected points during the course.

Research questions and aim of the study

The iterative approach of DBR (see figure 1) shall close the often-criticized gap between theory and practice in teaching-learning research. Teaching-learning arrangements including key Design Principles (DP) should equally result from the empirical research as well as from contributions to theory development (e.g., Bakker 2018; McKenney & Reeves, 2019). Hence, the goal of the study is to provide context-specific theory development of ACiSD and to develop a tested instructional design to promote its core features. Accordingly, the overarching research question is: *How should the course be designed and structured in terms of subject matter and didactics so that it can promote students ACiSD?* To answer this question, it is investigated, inter alia, to what extent the core features of ACiSD, based on the model of Sass et al. (2020), can be promoted within the elective course. The development of the first course-prototype is theory-based. Therefore, the central question of this initial phase is*: Which Guiding Principles (GP) can be derived from the theory to promote ACiSD?* Based on the GP a first course program is deduced and central DP are drafted.

Research method and design

For the initial development of the course design, GP are derived from the theory. Therefore, current theoretical and empirical studies on the definition of AC and ACiSD as well as their promotion in educational contexts were viewed. In addition, principles of the integration of the SDGs in German educational contexts and related requirements were included.

The cooperation with the research school leads to specific framework conditions for the course implementation, which are included in further steps of development: The elective course takes place once a week for two hours in two consecutive school years (2020-21 and 2021-22). The participating student-groups, aged 15-16 years, are in their final year of secondary school. In both courses, there is a high diversity in the students' learning performances. Consequently, this heterogeneity must be taken into account in the processes of designing and constructing the course. Also, the learners' perspectives on the topics must be included. (e.g., Boeve-de Pauw, 2015; Bakker, 2018)

While the DBR approach forms the methodological basis of the study, for data collection qualitative methods are chosen: individual and group interviews, document analysis and participatory observations are conducted. In addition to the researchers' external perspective, the internal perspective of the students, especially of their self-perceived ACiSD, can be investigated this way. The individual interviews are conducted in the first school year, outside of class time. The group interviews are conducted in the second school year, during class time.

Based on the results, the course will be further developed, and DP will be specified within the framework of DBR. While the GP are more general guidelines, the DP, based on the empirical results, will be more substantiate in a subject-specific manner (Bakker, 2018). The structure of this process of research and development is shown in figure 1.

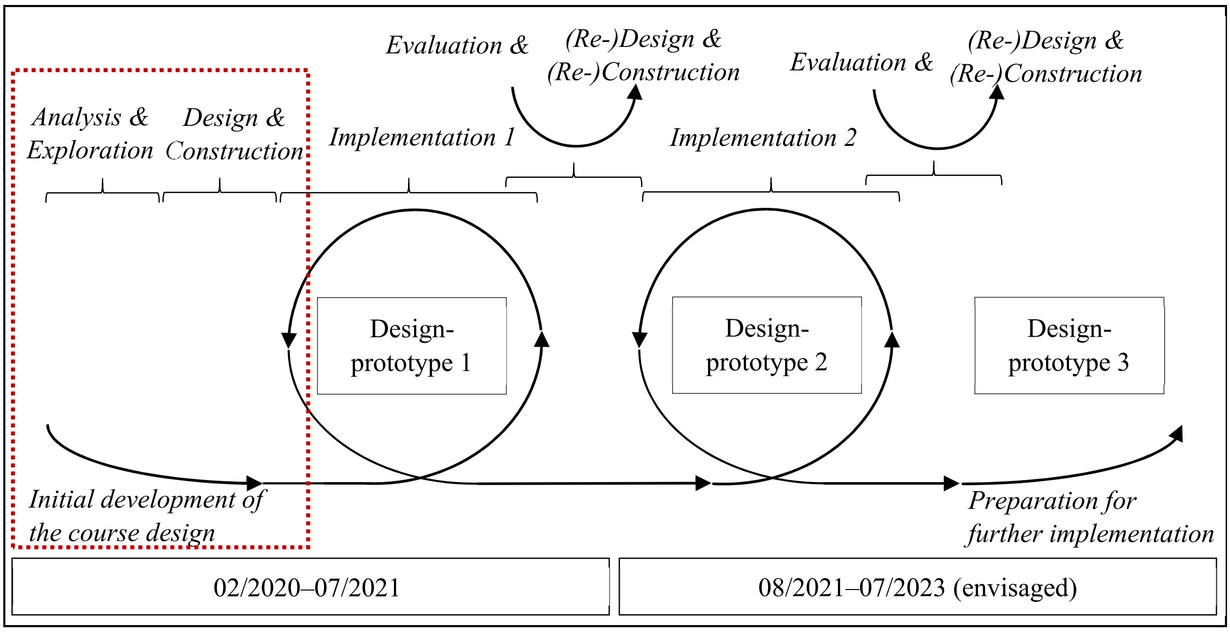

Figure 22. Structure of the DBR-design of the study. The subcycle presented in this paper is marked in red.

RESULTS

As shown in figure 1, results of the initial phase are GP and a first concept of the course. The GP are derived from theory and form the basis for this prototype and its associated DP. While the DP guide the further development and will be specified, the GP are general guidelines, included both explicitly and implicitly in the concept of the first design prototype.

Defining Guiding Principles (GP)

In an initial phase of the study, theory-based GP to promote ACiSD were drafted. As shown in table 1, the principles refer a) to the teaching content and focuses on the appropriate topic, b) to the didactical-methodical level and suitable approaches and c) to the interpersonal, pedagogical level. Since the teacher normally decides on the lessons structure, their content (based on the curricula) and didactical-methodical approaches, the levels are mostly influenced by his or her actions and decisions. The selection of the three levels is based on the definition of teaching-learning-processes by Reinmann and Mandl (2006).

Table 32. Guiding principles (GP) as derived from the theory. Levels and GP are not sorted by importance.

Level of teaching-learning process	Guiding Principles (GP)	Reference (e.g.)
teaching content	addressing the purposes of sustainability (AGENDA 2030/SDGs), on local and global level	Boeve-de Pauw, 2015; KMK/BMZ/Engagement Global, 2016; Müller-Christ et al., 2017
	topic areas of subject are interdisciplinary (concerning dimensions of sustainability: social, environmental, economic)	Jensen, 2004; Schreiber, 2016; DGfG, 2020
	topicality of the content / topic is relevant for students	Geisz & Schmitt, 2016
	including action-oriented knowledge: addressing dimensions of causes, effects, visions, strategies (direct, indirect actions)	Jensen, 2004; DGfG, 2020
	topic areas of subject are divers, from different perspectives („pluralistic approaches"), with conflicting interests/tensions	Mogensen & Schnack, 2010; Schreiber, 2016
didactical-methodical approaches	implementation of action-oriented activities	Mogensen & Schnack, 2010; Schreiber, 2016
	including phases of project designing (put plan into practice)	Eames et al., 2009; Schreiber, 2016
	creating possibility of gaining experiences	Jensen & Schnack, 1997; Eames et al., 2009
	tasks of targeted problem solving, solution directed	Jensen & Schnack, 1997; Jensen, 2004

	fostering collaboration/communication through group-work	Sass et al., 2020; Schreiber, 2016
	creating occasions for (critical) reflection and anticipation processes toward different as well as own perspectives	Jensen & Schnack, 1997; KMK, 2005; Boeve-de Pauw et al., 2015
interpersonal, pedagogical level	students involved in decisions (democratic decision-making)	Jensen & Schnack, 1997
	teacher as learning guide: developing teaching-learning arrangement, promoting self-organized learning	Eames et al., 2009; Schreiber, 2016
	encouraging to express opinions and visions: „welcoming different points of view"; appreciating the diversity of opinions	Jensen, 2004; Eames et al., 2009; Boeve-de Pauw et al., 2015; Sass et al., 2020
	positive manner of communication („language of possibility")	Mogensen & Schnack, 2010

The GP are drafted based on current theoretical and empirical studies on AC and ACiSD as well as their promotion in educational contexts. Since the first definition of AC was made by the Danish researchers Jensen & Schnack (e.g., 1997) in the context of environmental and health education, their work was considered as a starting point. Based on these results, further related theoretical and empirical research was analyzed. Of particular interest was research, that further developed the concept of AC in the context of SD and offered educational approaches.

Since the course concept of this study is developed within and for a school in Germany, principles of the integration of the SDGs in German educational contexts and related requirements were included. Here, the Curriculum Framework ESD provides specifications for Germany. On the one hand, general guidelines were observed, on the other hand, specific instructions concerning the promotion of AC were included.

Deducing the Course Prototype

Based on the GP, conclusions can be drawn for the prototypical design of the course and its concept. First, it must be noted, that not all existing approaches of ESD and promotion of ACiSD can be taken up into the design of the course. Rather, the GP should serve as a guide to select appropriate approaches, which should be integrated. Especially regarding the numerous methods, a suitable selection is crucial. In general, the course combines principles and approaches promoting ACiSD addressing the normative goals of SD. The further, detailed development of the course and its single lessons was done including specifics of the learning group and their perspectives on the topics as derived from the interviews. To meet individual student needs during the course, flexibility of the program has been maintained.

For the further development of the course, the following, central DP were derived from the GP: 1. content is subject-oriented (concerning the dimensions of sustainability), 2. problem-based learning is focused, 3. tasks are action-oriented, 4. settings are collaborative (mainly group work). These principles are respected during all cycles of the development of the course and will be further specified.

Consequently, the course is designed consisting of three parts: I. introduction of the goals of the AGENDA 2030 and the SDGs using different methods, II. an action-oriented approach (learning in “marked place” formation as main method) to impart knowledge about interdisciplinary contents of "Cotton and Clothing", including the diversity of perspectives and III. a group project development, implementation, and reflection, which refers to the contents of the first and second part. Table 2 shows an overview of the structure of the elective course. One double lesson has a duration of 90 min; due to the structure of the timetables in the cooperating school the course takes place once a week in double lessons.

The challenging tasks of the study will be not to indoctrinate the supposedly “right” actions, values, or opinions on a moralistic way, but to lead students to form their own responsible and reflected opinion, according to those principles they act on (Mogensen & Schnack 2010). At the end, in addition to the theoretical contributions, a tested and evaluated course design for the promotion of ACiSD should be a result of the DBR doctoral thesis.

Table 33. Overview of the structure of the elective course.

Part	Lessons (90 min each)	Comment/purpose of lessons
I: Future, development and sustainability	1–2: Introduction and organizational aspects; view of the (own) future, meaning of SD	Associations with topics; perceptions/attitudes are communicated
	3–6: Needs of people; development in the future; AGENDA 2030/SDGs	Understanding background and goals of sustainability/previous knowledge visible
II: Cotton and Clothing	7–18: Interdisciplinary, action-oriented knowledge acquisition on the topics (included problems) of production and consumption of cotton (and) clothing	Acquisition of interdisciplinary knowledge (reflection/evaluation)
	19–20: Using the syndrome approach, identifying non-sustainable developments, collecting action possibilities to change towards SD; Conducting a discussion in predefined roles (subsequent reflection outside of the roles)	Systems thinking, making connection of aspects visible, knowledge/ideas of action possibilities; Change of perspective, reflection of different points of view
III: Project development: SD in production and consumption of clothing	21–30: Planning, development, implementation and reflection of projects addressing the issues of part II (and I)	Application of knowledge in project development, problem solving, reflection of actions/options
	31–32: Final session: exchange about own ideas for the future development regarding sustainability/SD	Communication/reflection of own perceptions and attitudes; evaluation of course

CONCLUSIONS

In this study, an attempt was made to develop a complex course design to promote action competence in the context of ESD. Therefore, in the initial phase, a review of theory was made and general Guiding Principles (GP) were drafted. Based on these GP, a first concept of the course adapted to the conditions of the partner school was designed in discussion with science educators of the Institute of Science Education. The result is a complex, 32 hours lasting course program „Cotton and Clothing“. Furthermore, central DP were deduced from the GP.

Since the course shall locally be adapted to the school framework, in further steps, specific conditions of the learning group will be included. As an example, the heterogeneity of the learners must be addressed. Thus, on the one hand, there is the requirement to accommodate the guidelines for designing an educational concept to promote ACiSD. On the other hand, it must be possible for all students to work on the materials at their own levels. Therefore, methods are required that promote self-organized learning. If needed, support possibilities (such as additional instructions or hints) must be provided. Also, the schedule must be proven so that students of different levels have the possibility to successfully solve the tasks.

Other factors affecting the structure of the course were restrictions in school operations caused by the COVID-19 pandemic. In consequence, several changes in the concept and research plan had to be made. Furthermore, the observance of additional hygienic conditions requires extensive organization of both teaching and data collection. How far results are influenced by that must be discussed.

To sum up, the research design following the DBR has been proven successful to put the ACiSD course on a good track. The theoretical frame could be clarified, first DP identified, and a first course program deduced. Findings of the evaluation of the course will be presented later.

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SATOYAMA FOREST MANAGEMENT GAME: CAN ELEMENTARY SCHOOL STUDENTS LEARN THE DIFFERENCE IN MANAGEMENT METHODS?

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The United Nations adopted the Sustainable Development Goals (SDGs) in September 2015. Goal 15, 'Life on Land,' points to the importance of protecting and restoring terrestrial ecosystems, promoting their sustainable use, and addressing sustainable forest management (United Nations, 2018). Teaching content related to this goal is considered important internationally. In Japan, Satoyama is a region that can provide knowledge about biodiversity and environmental conservation. However, the changes that occur in Satoyama occur on a relatively long timescale and thus cannot be easily visualised. The characteristics of Satoyama vary depending on the vegetation of the region, and management must be adapted to the region. To address this issue, Shingai et al. (2020) developed a 'Satoyama Management Game' that allows users to select multiple versions of Satoyama as the target. Subjects become Satoyama custodians and learn about the region by experiencing simulated Satoyama management in the game, aiming to maintain 'good Satoyama' in terms of biodiversity for 300 years. In this paper, we report the learning effects of the multi-Satoyama version of the Satoyama Management Game. The subjects were 72 sixth-grade students from Noda City, Chiba Prefecture. The participants were first divided into two groups: 36 participants who played the Hyogo version and 36 participants who played the Miyazaki version. The subjects were given an in-game tutorial and played the game six times. After completing the game, the participants replied to a questionnaire. They were asked to respond to four items regarding the typical methods of Satoyama management.

Keywords: Biodiversity, Environmental Education, Serious Games

BACKGROUND

The United Nations adopted the Sustainable Development Goals (SDGs) in September 2015. Goal 15, 'Life on Land', points to the importance of protecting and restoring terrestrial ecosystems, promoting their sustainable use, and addressing sustainable forest management (United Nations, 2018). Teaching content related to this goal is considered important internationally. In Japan, Satoyama has been identified as a place where people can learn about biodiversity and environmental conservation. The Ministry of the Environment of Japan characterizes Satoyama as areas located between nature and cities consisting of villages and the surrounding forest, as well as farmlands, reservoirs, and grasslands. Satoyama has been formed and maintained through various human activities associated with agriculture and forestry. However, it is difficult to observe changes in Satoyama because they are renewed through logging and subsequent growth at relatively long intervals of 20–30 years.

To address the difficulty of learning about changes in Satoyama, simulation games have been developed to help learners effectively understand biodiversity and environmental conservation in these areas. In simulation games, learners can experience events on a larger time scale. Such games are thus effective tools for supporting learning (Calderón & Ruiz, 2014). Asahina et al. (2019) conducted an analysis using the 'Satoyama Management Game' developed by Kawaguchi et al. (2017). Their research reveals the effectiveness of the game.

Shingai et al. (2020) improved upon the Satoyama Management Game and developed it for multiple regions. There are four typical types of Satoyama in Japan with different vegetation types. In this paper, we report the results of an evaluation experiment for elementary school students on the learning effects of the 'Satoyama Management Game' for these two Satoyama models (Hyogo and Miyazaki).

PURPOSE

We conducted an experiment with elementary school students on a multi-regional version of the Satoyama Management Game. The purpose of this study was to conduct an exploratory evaluation to determine whether the participants, elementary school students, were able to understand Satoyama management techniques through their experience of playing the Hyogo or Miyazaki versions of the Satoyama Management Game.

SATOYAMA MANAGEMENT GAME

The Satoyama Management Game used in this study was developed by Shingai et al. (2020). Since the details of the game are described in Shingai et al. (2020), this section presents only an overview of the game.

Participants of the game become Satoyama custodians and learn about the region by experiencing simulated Satoyama management in the game, aiming to maintain 'good Satoyama' in terms of biodiversity for 300 years. Figure 1 shows the locations of Hyogo and Miyazaki prefectures and their respective play screens. There was a difference in vegetation between Hyogo and Miyazaki Satoyama. The game progresses as a participant selects one of the seven commands at the bottom of the screen (20 turns per game). These seven commands are common to both Hyogo and Miyazaki: 'Clear-cut logging', 'Tall tree cutting', 'Evergreen tree cutting', 'Afforestation', 'Pest control', 'Deer Removal', and 'Do nothing'. A detailed explanation of the game screen is shown in Figure 2.

Figure 1. Locations of Hyogo and Miyazaki prefectures and their respective play screens.

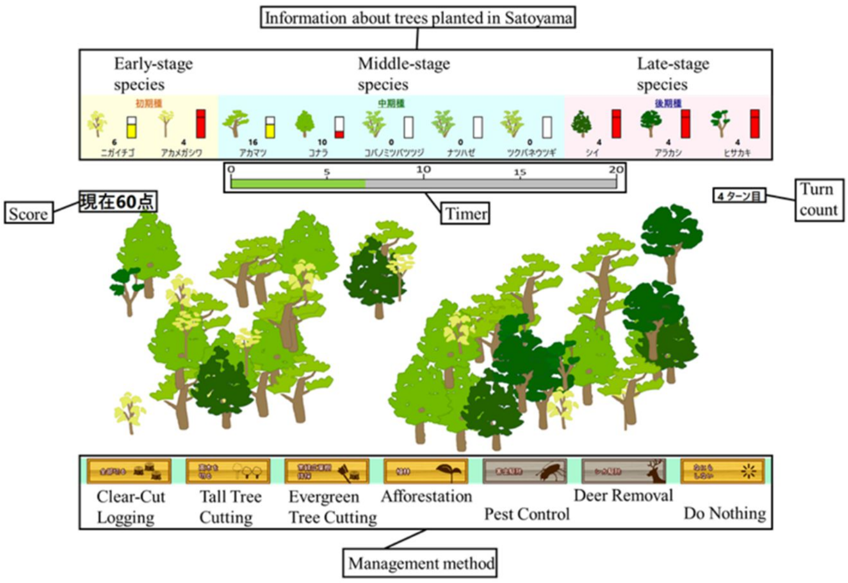

Figure 2. Details of the game screen.

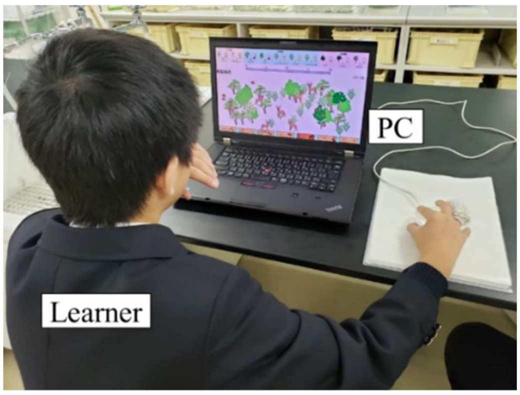

Figure 3. Playing the Satoyama Management Game.

Since the climates of Hyogo and Miyazaki are different, so is the vegetation and the effective management methods.

In Satoyama management in the game, a high score is achieved when there are many medium-term species in Satoyama. To maintain diversity, it is necessary to maintain the vegetation in the transitional mid-stage. In Hyogo's Satoyama, only late-successional species are evergreen trees, so reducing late-successional species by using 'Evergreen tree cutting' will lead to a higher score. On the other hand, in Miyazaki's Satoyama, most of the mid-season species are also evergreen trees, so using 'evergreen broad-leaved tree cutting' would result in the removal of most of the trees in Satoyama. Therefore, using 'Tall tree cutting' to reduce the number of late-stage species in Miyazaki will lead to higher scores.

METHODS

Outline

The participants were 72 sixth-grade students from Noda City, Chiba Prefecture. They were first divided into two groups: 36 participants who played the Hyogo version and 36 participants who played the Miyazaki version. The participants were given an in-game tutorial and played the game six times. After completing the game, the participants responded to a questionnaire. They were asked to reply to four items regarding the typical methods of Satoyama management, following which interviews were conducted.

Analysis method

Respondents were asked to answer four questions on a seven-point scale. Their responses were categorised into 'very much agree;' 'agree;' and 'slightly agree' as positive responses and 'neither agree nor disagree,' 'somewhat disagree,' 'disagree,' and 'completely disagree' as neutral or negative responses. The number of respondents per question was totalled and a 2 × 2 Fisher's exact probability test was performed. We also asked the students, 'What strategy did you use to get a higher score in Satoyama Management Game?'

RESULTS

Table 1 presents the questionnaire results. Regarding the bias of the responses between Hyogo and Miyazaki, significant differences were found in 'Tall tree cutting' and 'Evergreen tree cutting'. Significantly more participants answered that it was better to use 'Evergreen tree cutting' in Hyogo and 'Tall tree cutting' in Miyazaki. No significant difference was found in 'Clear-cut logging' and 'Afforestation', which had no differences in usage between Hyogo and Miyazaki.

Table 1. Results of the 'Satoyama Management Game' on Satoyama management.

	Questions		neutral or negative responses	positive responses	p
1	It is better to use "Clear-cut logging" in Satoyama management.	Hyogo	6	30	n.s.
		Miyazaki	4	32	
2	It is better to use "Tall tree cutting" in Satoyama management.	Hyogo	9	27	*
		Miyazaki	2	34	
3	It is better to use "Ever-green tree cutting" in Satoyama management.	Hyogo	3	33	**
		Miyazaki	19	17	
4	It is better to use "Afforestation" in Satoyama management.	Hyogo	1	35	n.s.
		Miyazaki	1	35	

N=72,**p<.01,*p<.05,n.s.:No significant difference.

Tables 2 and 3 present the results of the interviews. Excerpts from the responses of four people in each version to the question item, 'What strategy did you use to get a higher score in Satoyama Management Game?' In the Hyogo version, we obtained the answer of using 'Evergreen tree cutting'. In the Miyazaki version, we were able to obtain the response of using 'Tall tree cutting'.

Table 2. Results of the interviews (Hyogo version).

Answer to "What strategy did you use to get a higher score in the Satoyama Management Game?（Hyogo version）	
Answer1	I actively used "Evergreen tree cutting" and then "Afforestation".
Answer2	I will get a higher score if I first do "Evergreen tree cutting" and then "Afforestation".
Answer3	I've cut down a lot of evergreen trees.
Answer4	I repeated the process of "Afforestation" and "Evergreen tree cutting".

Table 3. Results of the interviews (Miyazaki version).

Answer to "What strategy did you use to get a higher score in the Satoyama Management Game?（Miyazaki version）	
Answer1	I repeated the process of "Afforestation" and "Tall tree cutting".
Answer2	I cut down the tall trees and did a lot of planting.
Answer3	Planting trees and cutting down tall trees increased my score.
Answer4	I aggressively cut the tall tree.

DISCUSSION

The results of the questionnaire suggest that elementary school students were able to understand Satoyama management methods by playing the Hyogo and Miyazaki versions of the Satoyama Management Game. The results of the interviews also suggest that the students were able to understand effective management methods in each area. It was found that participants who played the multi-regional version of the Satoyama Management Game acquired management techniques that corresponded to their region.

In future work, we will analyse the changes in the commands that participants chose during the game to clarify whether they were able to learn Satoyama management techniques.

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Part 10 / Strand 10

Science Curriculum and Educational Policy

Editors: *Eilish McLoughlin & Odilla Finlayson*

Part 10. Science Curriculum and Educational Policy

Curriculum development. Reform implementation, dissemination and evaluation. International comparison studies such as TIMSS and PISA. Evaluation of schools and institutions. Policy and Practice issues: local, regional, national, or international issues of policy related to science education.

Part 10: INTRODUCTION

Science Curriculum and Educational Policy

Editors: *Eilish McLoughlin & Odilla E. Finlayson*

Introduction

The 2015 OECD report on the *Future of Education and Skills Education 2030* challenged governments to future-proof national education systems by raising two key questions – what competencies and skills will be needed in the future? How will these competencies be implemented and assessed? Several studies have shown a disconnect between what educators consider competencies and skills and employers' expectations of 21st Century graduates. Two contributions in this section provide useful insights for framing education policy and developing science curricula against a growing international movement to design and implement STEM curricula in schools. A key challenge for educational systems is to design and use assessment strategies that measure students' competencies and skills. To this end, one of the contributions examines the use of high-stakes examinations, which are a common feature at the end of upper secondary education, in assessing student learning in science.

Tetsuo Isozaki and Takako Isozaki propose that exploring the historical and socio-cultural nature of science and technology education and the relationship between them will provide foundational data that can be used to organise effective collaboration or integration among STEM subjects to develop STEM literacy. Their study investigated the socio-historical nature of science and technology education and compared its origins in European and East Asian countries in the second half of the nineteenth century, with a particular focus on UK and Japan. They report on different approaches to the introduction of science in schools due to the state's education intervention: while British scientists argued the importance of teaching science from the perspectives of the utilitarian and cultural values of science to the intellectual culture of human development, there was a little obstacle to the introduction of science into Japanese schools by the centralised government from the perspective of the utilitarian value of science. They conclude that to facilitate student learning in STEM education, they need to interlink diverse knowledge to solve issues in a social context by learning how to fit what they have learned in each subject into a general STEM scenario.

Radu Bogdan Toma reports that the STEM movement is symbolic of a recurring story about how policymakers promote educational trends that lack scientific support or are grounded on theoretical principles whose soundness is yet to be established. His study reflects on the educational and research practices that are being proposed under the STEM umbrella. He argues that the STEM movement conceals a strong neoliberal ideology aimed at fuelling nations' competitiveness by growing a workforce in these fields. He concludes that "STEM" is widely used in the educational landscape as a slogan to attract funding and economically exploit educational books and materials now rebranded as STEM and marketed as educational innovations. He summarises that the value of the STEM movement is equivocal at best and raises concerns about the tendency to lump different approaches under the same popular acronym.

Damienne Letmon, Odilla E. Finlayson and Eilish McLoughlin present their examination of high-stakes physics and chemistry examinations using Bloom's revised taxonomy. They report that a common feature of many educational systems is high-stakes examinations, marking the end of upper secondary education. The challenge for these examinations is to pose questions that not only assess students' content knowledge but also assess students' learning across cognitive domains. Their study compared the cognitive domains of the high stake-written physics and chemistry 2016 examinations of six countries (England, Ireland, the Netherlands, New South Wales, South Africa and Scotland) using a defined list of action-verbs associated with Bloom's revised taxonomy. They concluded that the cognitive demand "remember" was assessed to varying extents in all but one of the examination papers. In general, across all Physics and Chemistry examinations, there was a strong emphasis on assessing the cognitive demands of "understand" and "apply" and less emphasis on the domains of "analyse" and "evaluate". None of the examinations had questions coded for the cognitive skill 'create'.

These contributions demonstrate the commitment within ESERA to researching curriculum and policy using a range of methodologies and including international and comparative studies. We hope you will enjoy reading the papers and that they provide models for related studies in other European policy areas across Europe and beyond.

THE RELATIONSHIP BETWEEN SCIENCE AND TECHNOLOGY EDUCATION IN THE NINETEENTH CENTURY: A COMPARATIVE HISTORY BETWEEN THE UK AND JAPAN

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While there is abundant literature on science and technology education, few studies have explored their relationship from historical perspectives. Exploring this relationship and the historical nature of each subject will provide information on how to organise science, technology, engineering, and mathematics (STEM) education in contemporary schools. As a case study, we investigated the socio-historical nature of scientific and technical education, comparing its origins in the European countries and East Asian countries in the second half of the nineteenth century, focusing on the UK and Japan, respectively. We found different attitudes towards scientific and technical education in the UK and Japan due to varying socio-historical contexts. In the historical context, we concluded that science educators need to deeply consider the following question from the state's contexts and cultural perspectives: What is STEM literacy for?

Keywords: science and technology education, STEM literacy, culture and education

BACKGROUND AND PURPOSE OF RESEARCH

Extant literature involving government documents on secondary school science and technology (or scientific and technical) education suggests that the two departments should work together for improving science, technology, engineering, and mathematics (STEM) education. However, few studies have explored the historic relationship between science and technology under STEM education, and how such collaboration has worked in the historical context. Exploring the historical and socio-cultural nature of each subject and the relationship between them will provide foundational data that can be used to organise effective collaboration or integration among STEM subjects to develop STEM literacy (Bybee, 2010).

As described in *Nature* (1904), Japan acquired 'European knowledge' (p. 97) at the beginning of its modernisation period in the mid-nineteenth century, and the newly organised government encouraged the introduction of 'scientific technology' (Watanabe, 1976, p. 127) or science and technology without deeply reflecting the historical context of Western culture and religion. Although Japan generally adopted Western ideas, it took a different approach to scientific and technical education. Consequently, there are striking differences in scientific literacy between East Asia (primarily Japan) and the West (*Nature*, 2010) even today.

Although Jenkins (2019) argued that 'reflection on the past is necessarily limited as a guide of the future' (p. 170), comparing different countries' approaches to science and technology education can help to understand the socio-historical contexts and the nature of science and technology to reflect on the effective relationship between the subjects. Therefore, this research aims to recognise the nature of STEM subjects by exploring the historical and socio-cultural relationship among them, primarily between science and technology, to establish a foundation on which STEM literacy can be subsequently developed. As opposed to previous research, this comparison can provide a model for a more precise examination of similar historical and socio-cultural issues in other countries.

RESEARCH METHOD

A professor at Tokyo Higher Normal School, Takahashi (1908) showed that there were three cultural and religious factors of influence to Japanese culture in the period of modernisation, just before 1872, when the modernised school system was established: China, Buddhism, and the West. He argued that China and Buddhism did not contribute much to the development of scientific ideas. However, the influence of the West was very marked. Therefore, the authors employed a comparative historical approach (Briggs, 1972) between the UK (primarily England) and Japan in the second half of the nineteenth century. As British and Japanese historians and economists (e.g., Green,1997, Hobsbawm, 1975, Morishima, 1982) argued, Japan took a different approach to development of education comparing the UK. Isozaki and Pan (2016) described the UK as the 'science export country,' while Japan was the 'non-Axial civilization' and the 'science import country.' British Royal Commissions, such as the Devonshire Commission (1875) in the nineteenth century revealed that British education, especially scientific, technical, and engineering education lagged behind state-supported education in comparison to continental countries, such as France and Germany. The state-intervention in education led to varying ways of approaching science and technology teaching.

LITERATURE REVIEW

Extensive literature exists on the history of scientific and technical education in the UK; for example, Turner (1927), Cardwell (1972), Layton (1973), and Jenkins (2019) wrote about science education; and Argles (1964) and McCulloch, Jenkins, and Layton (1985) on scientific and technical education. Sociologists of education, such as Green (1997) and Young (1986), also discussed the historical evolution of scientific and technical education. Some researchers have compared the UK's approach with that of other European countries, such as France and Germany, but there have been few similar comparisons with Japan. There is considerable literature on the history of science education in Japan (*rika* in Japanese: Ogawa, 2015). With a few exceptions, such as Isozaki (2014, 2017), almost all literature is in Japanese, without any reference to the relation between scientific and technical education. However, the existing research can provide several analysis points for our current research, such as the relation between the nation state/country and approach to education.

THE BACKGROUND IN THE NINETEENTH CENTURY

Although the UK was still enjoying the first success of the Industrial Revolution and its economic supremacy, Hobsbawm (1975) highlighted that one significant consequence of a science-based industry was that the educational system, especially primary/elementary and higher education, became increasingly crucial for industrial development. The continental countries recognised that scientific and technical education was regarded as an essential vehicle of economic growth, and industrialisation occurred under the initiative and tutelage of the state. For example, France had the *École Polytechnique* and *grandes écoles* and Germany had organised *Technische Hochschule* at that time.

However, in the case of the UK, some economists (e.g., Hobsbawm, 1975) and historians (e.g. Ashby, 1963; Green, 1997; Winer, 1981) argued that despite the economic advantages of the early success of the Industrial Revolution, the British backwardness in scientific and technical education in the nineteenth century was explained as the so-called 'cultural critique' (Green, 1997, p. 56) which focused on the anti-industrial and anti-utilitarian culture, and the doctrine of *laissez-faire*. As Ashby (1963) and Green (1997) stated, public and grammar schools remained classical culture, and until the last quarter of the nineteenth century, universities did not contribute towards scientific and technical needs.

Japan had the foresight to address the urgent issue of modernisation to avoid being a victim of the Western capitalism comparing such as other Asian countries, and was able to exercise nation state power without fierce resistance from public opinion. Thus, Japan's leaders were convinced that 'the only way to catch up with the economic superpower Britain was through education' (Stephens, 1991, p. 26); other fields, such as finance, foreign affair, and military, were urgently and strongly centralised. Consequently, as Hobsbawm (1975) stated, Japan was the only country of all the non-European countries that succeeded in meeting and beating the West and never applied *laissez-faire*. Economist Morishima (1982) argued that the newly organised Japanese government successfully achieved 'take-off' in the Japanese economy, which was a different spirit from English capitalism: 'economy combining Japanese soul and Western technology' (p. 87). As a way to establish the modernised society in Japan, the government had employed *oyatoi-gaikokujin*, who were foreign advisors and teachers of various fields such as education, science, and engineering with high salaries. For example, based on the advice of British engineer Edmund Morel to facilitate industrial development, the Japanese government established the Ministry of Public Works in 1870 and the Institution of Engineering in 1871 (later changed to the Imperial College of Engineering in 1877, and then Faculty of Engineering, the Imperial University, in 1886). Relatively more British scientists and engineers who were teachers of the Imperial College of Engineering, such as Henry Dyer, William E. Ayrton, and John Milne, were recruited as *oyatoi-gaikokujin* than in any other western country. Consequently, Watanabe (1976) argued that Japan introduced 'scientific technology' (p. 123) or science and technology, not only pure science.

THE CONDITION OF SCIENTIFIC AND TECHNICAL EDUCATION OF SECONDARY SCHOOLS IN THE UK AND JAPAN

Green (1997) argued that throughout the nineteenth century, British scientific and technical education was notably backward in comparison to that of other countries in Europe. In the UK, several Royal Commissions were organised in the second half of this period, such as the Public Schools Commission (Clarendon commission: 1861–1864), the Scientific Instruction and the Advancement of Science (Devonshire commission: 1871–1875), the Royal Commission on

Technical Instruction (Samuelson commission: 1882–1884), and the Royal Commission on Secondary Schools (Bryce commission: 1895). These Royal Commissions revealed that inadequate scientific education was taking place in the public and grammar schools. They recommended the importance of teaching scientific and technical education. The Devonshire Commission (1875, p. 4) highlighted the chief reasons for such schools to omit teaching science (1) absence of funds; (2) uncertainty about the educational value of science; and (3) difficulty of finding time for a new subject in an already overcrowded curriculum. Particularly, the second reason was crucial for the introduction of science teaching in schools. Therefore, Victorian scientists, such as Thomas H. Huxley (1895), witnesses of the Devonshire commission (1875), and members of the British Association for the Advancement of Science (BAAS) (1868), noted the importance of teaching science as an essential part of 'Liberal Education of a great branch of Intellectual Culture' (Devonshire commission, 1875, p. 10) from utilitarian and cultural values of science. This meant that advocates of science education took care to distinguish it from technical education. Curtis (1965) indicated that even if the Clarendon Commission had recommended that science should be placed into public schools' curricula, the essential idea of the commissioners who were impressed by the German Gymnasium was that studies of the classics should remain as the core of the curriculum in public schools. Despite these efforts, and political and public opinion to support science (*Nature*, 1885), its 'progress was slow' (Cotgrove, 1958, p. 29; Jenkins, 2019, p. 75). To be worth adding to the school curriculum of the public and grammar schools, science had to be 'pure and academic' (e.g., McCulloch, Jenkins, & Layton, 1985; Jenkins, 2019). Although the Bryce Commission (1895) recognised technical education as part of the newly defined 'secondary education', it was of 'perennially low status, conservatively rooted in workshop practice and hostile to theoretical knowledge' (Green, 1997, p. 72).

In contrast to the UK, there was little struggle to organise science education (*rika*) in Japan, as science had been established as an essential component of Japanese secondary school curricula since its institutionalisation in the second half of the nineteenth century. The Japanese had introduced Western science due to its utilitarian value in schools through textbooks as 'teachable science' (Knight, 1992). For example, Roscoe's *Science primers: Chemistry* (1872), which aimed to understand science principles through a series of chemical experiments, and 'by bringing it into immediate contact with Nature herself' (Roscoe, 1872, preface), was quickly and completely translated into Japanese in 1874 to be used as an elementary school textbook; however, in many cases, it was used for 'reading' due to a lack of suitable teachers with sufficient knowledge of Western science at that time. Secondary school's conditions were similar to the case of elementary school. Although the curriculum tended to favour pure and academic science, as in the UK, it sometimes referred to science in the context and relevance to daily life in Japan. Since the modernisation in the mid-nineteenth century, Japanese science educators have constantly observed and been influenced by the trends of science education in the West. However, technical education in Japan, as a part of secondary vocational education, had been institutionalised since the 1880s. While vocational secondary school curricula essentially depended on the school's policies and enhanced workshops, physics and chemistry were included in the basic study for vocational education. Therefore, unlike in the UK, science and technology education were separated, and there was no debate about the definition of technical education as a part of vocational education or its distinction from science education in secondary education. When Dairoku Kikuchi, who graduated from the University of Cambridge, translated Russell's book (1869) *Systematic technical education for the English people* into Japanese (Kikuchi, 1884), he used the term '*shokugyou kyouiku*' in Japanese which means 'vocational education' as the translated term 'technical education.' This means that in Japan, technical education was placed as an essential part of vocational education, not general education that intended to go to higher education level.

SCIENTIFIC AND TECHNICAL EDUCATION AND ENGINEERING IN THE UK AND JAPAN

Russell (1869), Arnold (1892), Huxley (1895), and the Royal Commissions showed that compared to continental countries, such as France and Germany, the UK (especially England) was notably backward in most areas of scientific and technical education throughout the nineteenth century. However, as Cotgrove (1957) stated that distinguishing between science and technical education in the nineteenth century in the UK was difficult, Huxley (1895) used two terms 'technical' and 'scientific' education without a clear definition in his lectures. The UK, especially England, lacked the connection between science theories and their application to industry. Ayrton (Samuelson Commission, 1884), who was a distinguished teacher at the Imperial College of Engineering in Tokyo, as a witness to the Samuelson Commission noted that there are two kinds of technical education: of a master of works and of a workman (Samuelson Commission, 1884, p. 115); he explained about the Imperial Colleges as all the branches of technical education were brought under 'engineering'. Referring to William Thomson's (Lord Kelvin) instruction at the University of Glasgow and his experience at the Imperial College, Ayrton pointed out that '[t]echnical education is the application of science to industry' (Samuelson Commission, 1884, p. 118). This definition primarily targeted the higher education level which is similar to 'engineering education.' For him, engineering education included scientific theories and their application to industry; whereas, the technical education of a workman meant the workshop training that gave 'accuracy of eye and dexterity of hand' (Samuelson Commission, 1884, p. 118) without scientific theories. The pride of anti-industrialism in education created an ignorance of manual work, applied science and trade instruction (Vlaeminke, 1990, p. 73).

In Japan, the Ministry of Public Works invited Dyer as the principal from Glasgow to stablish the Imperial College of Engineering in Tokyo. Many of the staff involving a principal at the college were British, such as Ayrton and Perry, who were later professors at the Finsbury Technical College in London. Dyer (1904) attempted to adopt the unified system that combined two systems for educating engineers in the continental countries, such as France and Germany, with the British system in the college. Therefore, the programme provided 'a highly scientific training, combined with actual practical experience in engineering workshops' to students (*Nature*, 1877, p. 44), and the course of the college included three courses: (1) general and scientific, (2) technical, and (3) practical (Dyer, 1904, p. 5). The method of combining theory and practice in the training of engineers was called the 'sandwich' (Dyer, 1904, p. 427) system. Additionally, Dyer (1879) recognised the importance of foreign language and Japanese literature as well as scientific studies as a part of liberal education in college and engineering studies. It is noteworthy to state the following: (1) Ayrton's Japanese laboratory was highly praised, and his colleague Perry reported that 'Maxwell jestingly said that the electrical centre of gravity had shifted toward Japan (from Glasgow, London, and Berlin [the authors added])' (*Nature*, 1908, p. 74), and (2) Dyer (1904) titled one of his books: *Japan as the Britain of the East*, and stated that 'the chief lesson to be learned from Japan is the need for a truly national spirit for the accomplishment of great ends' (p. 427). Brock (1980) concluded that the shared experience of teaching science and engineering of Ayrton and Perry at the Imperial College of Engineering in Japan was a necessary factor in the success of the Finsbury Technical College in London, and highlighted that this is a typical case of 'the experience of reverse transculturation' (p. 239). Ironically, under the leadership of British scientists and engineers, engineering in higher education was organised earlier in Japan than in the UK, specifically England.

Based on the suggestion by the German *oyatoi-gaikokujin*, Gottfried Wagener, and Japanese politicians, the Japanese Ministry of Education established the Tokyo Vocational School. The school provided technical and industrial science education for becoming vocational school teachers and senior management engineers in 1881 (Tokyo Institute of Technology, 1940). In 1899, the vocational school order for secondary school education was promulgated, and vocational schools were categorised into five types: technical schools, agricultural schools, commercial schools, merchant marine schools, and vocational supplement schools. Every old Imperial University established before WWII in Japan had a Faculty of Engineering (or Faculty of Science and Engineering). Dyer's engineering education became the origin of engineering education in Japan. Due to the timely organisation of engineering education in higher and technical education during secondary education, Japan succeeded in becoming industrially developed similar to the Western countries. However, the connection between engineering education and technical education in the nineteenth century in Japan was feeble.

THE APPROACHES TO SCIENTIFIC AND TECHNICAL EDUCATION OF SECONDARY SCHOOLS IN THE UK AND JAPAN

Why did the approach to the organisation of scientific and technical education vary between the UK and Japan in the second half of the nineteenth century? Extant literature notes that educational intervention in the UK was limited due to the doctrine of *laissez-faire* (e.g., Layton, 1973; Green, 1997; Isozaki & Pan, 2016). There were other reasons such as a lack of suitable teachers (e.g., Turner, 1927; Jenkins, 2019), anti-science and anti-technology counterculture (Young, 1986), and an anti-industrial and anti-utilitarian culture (Vlaeminke, 1990, Green, 1997). These 'cultural critique(s)' (Green, 1997, p. 56) can be attributed to the 'English gentleman' (Jenkins, 2019, p. 61) effects. Additionally, Green (1997) indicated the failure 'in the response of new industrial and bourgeois classes' (p. 58). Under these circumstances, Victorian scientists, Royal Commissions, and BAAS advocated the importance of utilitarian and cultural values of science to intellectual culture. They argued that human development should require the inherent value of science in addition to the value of classics. Thus, the purpose of science education, in other words, the significance and value of learning science was firmly debated. As a result of Victorian scientists' and politicians' efforts, science education was gradually placed in the public and grammar schools. However, science education intended to be pure and academic, such as mathematics education, rather than technical education, and lost its relevance to everyday life and industry at the secondary education level.

In contrast, when Japan's modernised society was newly established in the second half of the nineteenth century, Japan's state intervention in education was much stronger than that of the UK (Isozaki, 2014; Isozaki, & Pan, 2016). Compared with the UK, Japanese leaders had fewer anti-cultural feelings towards science and technology, and the impact of the scientific technology of Western civilisation characterised as 'steam and electricity' (Watanabe, 1976, p. 123) was extremely significant for both the leaders and the people. Therefore, the utilitarian value of science was enhanced by its introduction in school. Although Japan did not have well-educated teachers in Western science and technology at the beginning of the modernisation period, the government invited foreign advisors and teachers from Western countries and sent students to study science and other academic fields in the West. In addition, Western science books were quickly translated into Japanese for school use. Consequently, with few obstacles, the Japanese politicians and educators successfully recontextualised Western science for teaching in Japan (Isozaki, 2014). The school subject science (later *rika*) was firmly placed in school curricula from elementary throughout higher education levels from the beginning of modernisation in the mid-nineteenth century. In contrast to the UK, however, even though teachers were keen to know how to teach science, there was little opportunity to deeply debate the purpose of science education. Technical education at the secondary school level was placed as a part of vocational education and was distinct from science. The purposes of engineering at higher education and technical education during secondary school education were naturally different, and there was no connection between them.

We can observe the different approaches to the introduction of science in schools due to the state's education intervention: while British scientists argued the importance of teaching science from the perspectives of the utilitarian and cultural values of science to the intellectual culture of human development, there was little obstacle to the introduction of science into Japanese schools by the centralised government from the perspective of the utilitarian value of science. Therefore, Japanese science teachers were keen to understand how to teach science introduced by the West in the classroom.

DISCUSSION AND CONCLUSION

The attitudes toward scientific and technical education were different in the UK and Japan due to socio-historical contexts in the nineteenth century. While British scientists and educators struggled to establish science in schools, they engaged in reflective thinking about the purpose and methods of science education, considering the following questions: *What is science for?*

Moreover*, why and how should science be taught in schools?* Additionally, *what contents of science should be taught?* For example, BAAS (1868) sought to acquire scientific information and promote scientific training; further, the Devonshire Commission (1875) argued that science could contribute to 'the training of [one's] intellectual power' and supply one with 'valuable information' (p. 6). Huxley (1895) proposed the scope and sequence of teaching contents of science and wrote many science books, such as *Introductory* (1880), which was a series of science primers edited by Huxley, Roscoe, and Balfour Stewart, and *Physiography* (1887) focused on observation and object lessons. Henry E. Armstrong (1903), a colleague of Ayrton and Perry at the Finsbury Technical College, criticised Huxley's book (1887)*: Physiography* as 'the book to be avoided' (Armstrong, 1903, p. 86), and proposed the heuristic method in laboratory in science teaching. Consequently, the Victorian scientists argued the importance of teaching science from perspectives of utilitarian and cultural values of science, and then proposed the teaching contents with scope and sequence, and methods of science teaching.

In contrast, leaders of the new Japanese government introduced Western science into schools based on the utilitarian values of science. They encouraged the integration of Western scientific technology and Japanese soul or spirits as Dyer (1904) and Morishima (1982) argued. Japan imported the established Western framework of science education without its background, such as philosophy. Therefore, when a new scientific subject known as '*rika*' was established in the elementary school curriculum in 1886 by the government, there was a surprise about '*rika*' and there was a discussion about 'what *rika* is' among teachers (Takahashi, 1908). The central government always stated the purpose of science education (*rika*) through orders. This circumstance led Japanese science educators to miss the opportunity to deeply discuss the following questions: *What is science for?* Moreover*, why should science be taught in schools?* They did not deeply consider the nature of Western science and technology and their educational and social functions at that time. Consequently, while British science educators focused on reflecting on the abovementioned questions when they argued the values of science in education and proposed scientific methods, Japanese science educators focused on considering *how* science (*rika*) should be taught in classrooms, because Japanese science educators took for granted that the purpose of science education (*rika*) was given through every revision of the orders issued by the central government. Although 'science' in schools was introduced by textbooks as teachable, there was a lack of suitable teachers to teach and be familiar with Western science at that time. Consequently, they introduced the methods of science teaching proposed and practiced in the West, such as object lessons (Huxley, 1887), and the development-principle education theory by James Johonnot (1896), primarily in elementary education. Some progressive science teachers gradually allowed secondary school students to conduct experiments around the twentieth century, just before and after introducing the heuristic method into Japan from the UK (Kametaka, 1904).

Scientific and technical education were difficult to distinguish, and the relation between technical and engineering education was also unclear in the UK in the nineteenth century. Contrastingly, technical education was firmly placed as a part of vocational education in secondary education, and there was a clear distinction between science education (*rika*) and technical education in Japan. Although science education (*rika*) included content relevant to daily life, it was never technical education. In Japan, engineering education was organised at the higher education level by strong initiatives of government under the leadership of British scientists and engineers, as opposed to the case of the UK.

These facts in the case of the second half of the nineteenth century in the UK and Japan exemplify that every school subject in each country has its own historical and socio-cultural background, which features the nature of the subject that is unique from the other subjects in contemporary schools. The historical and socio-cultural relationship between mathematics and the other three subjects has not been discussed, because this relationship was not as problematic as the relationship between scientific and technical education both in the UK and Japan in the nineteenth century. Investigating this relationship is a separate issue that remains to be studied; the present case study will be adapted within the continental countries, such as the UK and France, or Germany, and other Asian countries.

In STEM education, students may need to inter-link diverse knowledge to solve issues in a social context by learning how to fit what they have learned in each subject into a general STEM scenario. When we consider the following question: '*What is STEM literacy for?*' in the historical context, we must recognise the nature of each STEM subject and examine the question from the state's contexts and socio-cultural perspectives. Therefore, as Wong and Dillon (2019) state, from historical perspectives, a 'collaboration' rather than an 'integration' represents the nature of the relationship between the subjects of STEM education in Japan. Consequently, we consider how to collaborate between STEM subjects based on considering the nature of each STEM subject for effectively developing STEM literacy.

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STEM; OR THE MODERN PROMETHEUS OF SCIENCE EDUCATION

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There is a sense of déjà vu in the STEM movement, reminiscent of the story about how didactic approaches based on theoretical ideas whose soundness has yet to be demonstrated are strongly advocated. Despite the acronym's popularity, many aspects of the STEM discourse demand scrutiny. In this proposal, I reflect on the educational and research practices that are being proposed under the STEM umbrella. After contextualizing the STEM acronym in its historical contexts, I argue that the STEM movement conceals a strong neoliberal ideology aimed at fuelling nations' competitiveness by growing a workforce in these fields. As a result, I question the novelty of many STEM-related proposals especially insofar as they resemble long-standing science education efforts. This leads me to the conclusion that "STEM" is widely used in the educational landscape as a slogan to attract funding and economically exploit educational books and materials now rebranded as STEM and marketed as educational innovations. As a result, the value of the STEM movement is equivocal at best and raises concerns about the tendency to lump different approaches under the same popular acronym.

Keywords: integrated curricula, STEM education, science and mathematics

INTRODUCTION

The STEM movement is symbolic of a recurring story about how policymakers promote educational trends that lack scientific support or are grounded on theoretical principles whose soundness is yet to be established. In this sense, STEM has evolved into a major slogan that has gradually monopolized the international discourse on science education improvement. Despite the acronym's popularity, many aspects of the STEM debate require close examination. Against this background, I reflect on (i) its origins and the ideology that underpins such a movement; (ii) how it is conceptualized in the science education literature; (iii) and how it is used in the educational landscape.

ORIGINS OF THE STEM ACRONYM

The acronym STEM was coined in the 1990s by the National Science Foundation (NSF) as a "strategic decision made by scientists, technologists, engineers, and mathematicians to combine forces and create a stronger political voice" (STEM Task Force Report, 2014, p. 9). This acronym drew the attention of the educational community following the publication of the *Rising Above the Gathering Storm* reports (NAS et al., 2007, 2010), which argued that the United States (U.S.) advantages in terms of innovation and technological progress have begun to diminish in the last decade. The second edition of such a report painted "(…) a daunting outlook for America if it were to continue on the perilous path it has been following in recent decades concerning sustained competitiveness" (NAS et al., 2010, p. 2).

In short, while other nations made significant progress in the STEM disciplines, the U.S. ability to compete effectively deteriorated, which calls for greater emphasis on the development of educational programs aimed at the promotion and retention of talent in Science, Technology, Engineering, and Mathematics disciplines (Bybee, 2018). As a result, STEM has quickly become a policy slogan aimed at boosting international competitiveness and is being used to refer to initiatives that are in tandem with growing a workforce in these disciplines (Toma & García-Carmona, 2021; Weinstein et al., 2016).

Consequently, behind this acronym hides a 'Trojan horse' that projects false prosperity, welfare, and status but, in essence, hides a pronounced capitalist ideology (Bencze et al., 2018) and represents a deficient educational model that does not advance in the resolution of the problems faced by contemporary science education (Zeidler, 2016). Hence, STEM is an ideological positioning of science education (Carter, 2017) that seeks to align school science curricula in a direction “that reinforces and legitimizes a neoliberal hegemony of global competition and capitalist expansionism” (Weinstein et al., 2016, p. 201).

In this sense, STEM is used to proclaim the need for another Sputnik moment to address the decline of U.S. competitiveness (Bybee, 2013). The STEM movement looks to be the modern-day Sputnik, aimed at recharging US competitiveness against China in the same way as the 1957 satellite launch triggered the implementation of scientific education reforms to reclaim technological advancements lost to the Soviet rival. Thus, what appears to be an essential condition for U.S. development materializes in an ideological positioning of science education, which, framed under the STEM umbrella, stands as a vehicle to serve the goals of neoliberal political agendas (Carter, 2017).

CONCEPTUALIZATIONS OF STEM

To access financial grants devoted to projects promoting such a discourse, the STEM acronym became widely present in the educational landscape worldwide and rapidly acquired a wide spectrum of meanings and conceptualizations. Indeed, while the acronym started as a political discourse for national and state policies, it quickly began to be coined by educators and researchers as an educational movement with the ambitious goal of increasing the number of students pursuing STEM-related careers (Tanenbaum, 2016).

As a result, STEM is being conceptualized from an educational standpoint through a broad continuum of diverse and sometimes contradictory educational initiatives. Existing definitions range from a greater emphasis on STEM coursework to calls for the adoption of integrated curricula (Toma & García-Carmona, 2021). This notion of STEM, often known as integrated STEM, attempts to closely resemble how STEM knowledge is generated and applied in real life. It is suggested that "STEM content should not be taught in isolation, but rather in a way that reflects how STEM knowledge is used outside of school; this knowledge is further contextualized or driven by some problem or issue” (Dare et al., 2018, p. 4).

However, most definitions of integrative STEM relate to the integration of two or more disciplines, eerily similar to previous attempts in the 1980s and 1990s that focused on the integration of science and mathematics (for a review, see Toma & García-Carmona, 2021). For example, Sanders (2009) defined it as a teaching approach that explores the connections among any two or more of the STEM subject areas, and/or between a STEM subject and any other school subjects. Similarly, Moore et al. (2014) referred to STEM education as "(…) an effort to combine *some* or all of the four disciplines of science, technology, engineering, and mathematics into one class, unit or lesson that is based on connections between the subjects and real-world problems" (p. 38, emphasis added). Kelley and Knowles (2016) defined integrated STEM as "(…) the approach to teaching the STEM content of *two or more* STEM domains, bound by STEM practices within an authentic context for the purpose of connecting these subjects to enhance student learning" (p. 3, emphasis added).

There are significant educational antecedents for such curricular integration, including initiatives championed by the Science and Mathematics integration (S&M) and the Science-Technology-Society (STS) movements (Aikenhead, 2002; Pang & Good, 2000). Hence, one wonders whether STEM, following such a definition, should be considered a new approach at all and if it adds any value to science education. Likewise, the lack of a theoretical and pedagogical framework guiding the didactic transposition of such integration into classroom practice has led to using this acronym in empirical studies addressing solely one discipline in isolation, thus being inconsistent with the promoted discourse of curricula integration (for reviews, see Martín-Páez et al., 2019; Toma & García-Carmona, 2021).

HOW IS THE STEM ACRONYM USED

Given the ambiguity inherent in STEM, it is unsurprising that many experts are coining new acronyms such as STEAM (STEM + ARTS), iSTEM (imagination and STEM), or STREAM, which refers to STEAM + robotics or STEAM + reading (for a full discussion, see Toma & Garca-Carmona, 2021). This *STEMification* of the science education scene is therefore not surprising, given the substantial investments in research and educational projects framed around this acronym (Anderson, 2020). When assessing educational materials, the use of STEM as a convenient buzzword becomes even more obvious (Figure 1). A growing number of educational materials are being promoted using the STEM acronym. An inspection of these products reveals that they are remarkably similar to products that have been promoted for decades but are now rebranded as innovative STEM resources.

On the other hand, there is a plethora of research articles conveniently including the STEM acronym in their titles (Figure 2). Yet, much of such research addresses only one discipline (Martín-Páez et al., 2019). Amidst this situation, several critical voices complain that STEM is being promoted at the expense of an operational definition. In an attempt to disentangle the meaning of STEM, Akerson et al. (2018) concluded that STEM is a "(…) socially constructed label that is in response to economic and global pressure" (p. 5) and that the advent of the STEM movement is reducing attention to other important aspects of science education, such as the teaching of nature of science.

CONCLUDING REMARKS

In this proposal, I discuss key features of the STEM movement. In this sense, I situated STEM as a political slogan that conceives science education as a tool for achieving capitalist goals.

Next, I highlighted that existing definition contradicts the STEM discourse calling for the integration of four disciplines, and that such conceptualizations resemble integrated curricula approaches that have been promoted for over four decades. Finally, I draw attention to the commercial usage of this acronym in marketing products, accessing funding, or bringing attention to scientific publications.

Figure 1. Example of material marketed under the acronym STEM or STEAM.

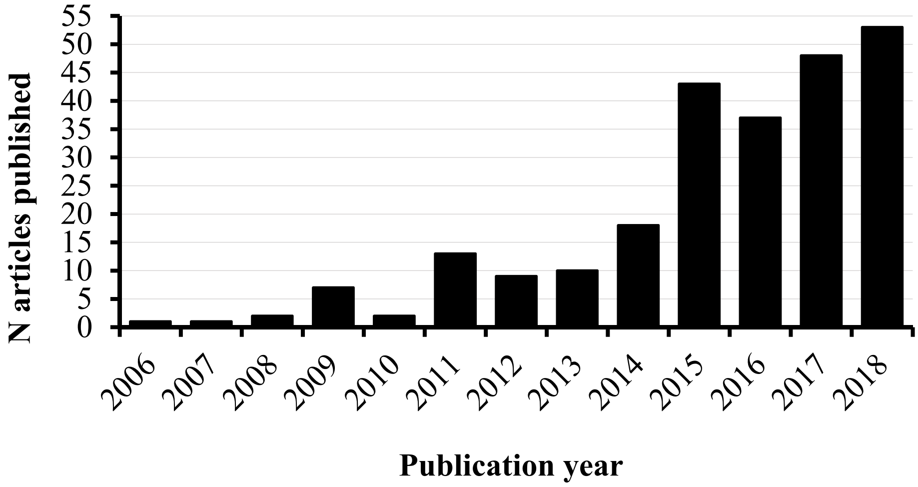

Figure 2. Articles indexed in the Web of Science database that use the term "STEM education" in their titles.

STEM education is therefore inevitably evocative of Frankenstein's monster, in that it is devised from an accumulation of outdated strategies reimagined in such a manner as to represent a new creature that is presented to the educational community as an innovative approach. Thus, the STEM acronym (or perhaps, better referred to as *FrankenSTEM*) is a political movement that translates into an educational model of questionable innovation that lacks research-based support. Likewise, its disproportionate use raises critical concerns about the tendency to lump educational efforts under a popular heading to attract funding, as well as for the commercial exploitation of books and educational materials now promoted as STEM.

In this context, I wonder if educators will recall Mary Shelley's words in *Frankenstein, or The Modern Prometheus*, as they reflect on STEM in the coming years: "How to describe my emotions at this catastrophe, or how to delineate the wretch whom with such infinite pains and care I had endeavored to form?"

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EXAMINING HIGH STAKES PHYSICS AND CHEMISTY EXAMINATIONS USING BLOOM'S REVISED TAXONOMY

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A common feature of many educational systems are high stakes examinations which mark the end of upper secondary education. The challenge for these examinations is to pose questions which not only assess students' content knowledge but also assess student's cognitive skills. This study compares the cognitive skill levels of the high stake written physics and chemistry examinations of six countries (England, Ireland, the Netherlands, New South Wales, South Africa and Scotland) using a defined list of action-verbs associated with Bloom's revised taxonomy. The examination year of 2016 was selected as the syllabi and examination system of these six countries had not changed in the two previous years with similar topics being examined. The analysis of higher order cognitive levels showed that across the physics examinations there was a greater focus on assessing the cognitive skill of 'apply' from 70% (Netherlands) to 23% (New South Wales) with a smaller percentage of questions assessing 'analyse' and 'evaluate'. Across the chemistry examinations between 83% and 99% of the marks were for questions assessing 'remember', 'understand' and 'apply' with very few questions assessing 'evaluate'. The 'evaluate' skill level was less than 16% in physics and less than 7% in chemistry. None of the examinations had questions which coded for the cognitive skill 'create'.

Keywords: Cognitive skills, Physics and Chemistry Examination, Blooms Revised Taxonomy

INTRODUCTION

The high-stakes public examinations which mark the end of upper secondary education have been a common feature of most education systems. These high-stake assessments, irrespective of the form of such assessments, are based on a specifically drawn-up programme or syllabi mandated or approved by the relevant educational bodies. Dufaux (2012) described such high-stakes examinations as 'assessments for qualification and certification' as they provided access to third level education, be it academic or vocational as well as direct entry to the workforce (Dufaux, 2012; Kellaghan, 1996).

In 2002, Bloom's revised taxonomy was presented as a two-dimentional one comprising of a knowledge component and a cognitive component. At the core of this revised taxonomy was the use of action-verbs associated with each cognitive level. The original first category of knowledge was renamed ***remember.*** The other five categories were renamed with action-verb equivalents of ***understand, apply, analyse, evaluate*** and ***create*** (Anderson, 2005; Krathwohl, 2002; Krathwohl & Anderson, 2010)**.** For the past 20 years this revised taxonomy has been used to assess the cognitive content of high-stakes examinations as well as alignment of these examinations with the curriculum. ((Edwards, 2010; Liu et al., 2009; Motlhabane, 2017; Nurlailiyah et al., 2019; Prashant Thote & Gowri S, 2020; Tikkanen & Aksela, 2012; Tsaparlis

& Zoller, 2003). These studies prompted the two research questions addressed in this paper i.e.

- *How do the cognitive skill levels of high-stakes written physics examinations compare across countries?*
- *How do the cognitive skill levels of high-stakes written chemistry examinations compare across countries?*

To address these questions a cross-national comparison of the examination quesions was carried out using the cognitive dimensions of Bloom's revised taxonomy with the associated action-verbs as the analytic tool of choice (Lee et al., 2017).

METHODOLOGY

Selection of countries for the study

Physics and Chemistry high-stake examinations were selected based on the following criteria:

- Separate examinations for physics and chemistry.
- Comparable topics and question-styles on examination papers.
- Written state-wide standardised examination based on the programme as drawn up by the relevant education authorities.
- Similar adminstration conditions for students sitting the examinations.
- Relevant programme was implemented for at least the previous two years (to ensure syllabi was embedded in the education system).

Using the above criteria, the following public examinations for 2016 from six countries were selected for analysis (Table 1).

Table 1. Countries and relevant examinations selected.

England	A-levels
Ireland	Leaving Certificate Examination
The Netherlands	HAVO (***H****oger* ***A****lgemeen* ***V****oortgezet* ***O****nderwijs)*
New South Wales	Higher School Certificate
Scotland	Highers
South Africa	National Senior Certificate

Coding of the examination papers using revised Bloom's taxonomy

Prior to coding the examination papers, a list of action-verbs was compiled from two independent studies, namely Newton et al (2020) and Stanny (2016). This list comprised of 30 action-verbs per cognitive level. Using such a predefined list reduced the subjective bias in coding the questions. However this subjectivity was tested when action-verbs are registered in more than one cognitive level (Pugh & Gates, 2021). Having identified these action-verbs, a search of the frequency of their occurance in the examination papers was carried out which indicated just eight such verbs (Table 2). Using Krathwohl's definition of each of the levels a supplementry list was drawn up of these action-verbs to include further meaning of the verbs.

Table 2. Supplementry list of eight action-verbs common to cognitive levels (Krathwohl, 2002).

Remember	Understand	Apply	Analyse	Evaluate	Create
		Calculate (mathematical calculations)	Calculate (organising)		
Describe (recalling)	Describe (explaining)			Describe (judgment using criteria)	
	Explain (meaning of terms)	Explain (a procedure)		Explain (judgments using criteria)	Explain (generating original view)
	Identify(denoting)	Identify (procedure)			
	Illustrate (meaning)	Illustrate (a procedure)			
	Predict (infer)	Predict (results of procedure)			
	Show (meaning)	Show (procedure)			
		Write (procedure /formulae)			Write (generating original views)

Determining the cognitive skill levels across the questions

The following coding process was adopted. Action verbs in each question part were idenified and high-lighted. Using the Stanney-Newton compiled list of action verbs each quesiton part was coded to one of the six coginitve levels of Bloom's revised taxonomy. An example of this process is shown in Figure 1.

9. Describe an experiment to show that sound is a wave motion. (15)

Explain the physical principles underlaying each of the following:

(i) Sounds can be heard more clearly on a cold night than on a warm day. (12)

(ii) A glass can be shattered by a singer singing a high note. (12)

When the source of a note moves past a stationary observer the pitch of the note seems to change. What is the name given to this phenomenon? (6)

A whistle which is emitting a note of 1kHz is whirled in a horizontal circle on the end of string 1.2m long at a constant angular speed of 50 rad s^{-1}. What is the highest and lowest frequencies heard by a person standing some distance away? (21)

(Speed of sound in air = 340 m s^{-1})

Cognitive levels applied to highlighted cues in example above

Question	Question Cues-	Marks	Level of Bloom's taxonomy
9	Describe	15	Remember
9(i)	Explain	12	Understand
9(ii)	Explain	12	Understand
	What is the name given...	6	Remember
	What is the highest....	21	Analyse

Figure 1. Example of coding process adopted.

For example, the action verb 'describe' is coded as the cognitive level *remember* (Figure 1) and is the mostly commonly used action verb that required students to recall knowledge. Similarly, the action verb 'explain' was widely used to probe student *understanding* (Table 2).

The inset table in Figure 1 depicts the allocation of marks for the coded question parts. In this example question, which a total of 66 marks available, 21 marks were coded for *remember*, 24 marks for *understand* and 21 for *analyse*. This process was applied across all question parts for each of the six examination papers in physics and in chemistry. The overall proportion of questions parts, which were coded at each of the six cognitive levels, was calculated as a percentage of the total marks available in the examination paper.

FINDINGS

The analysis of these examinations using action verbs associated with Bloom's Revised Taxonomy highlighted the differences in the cognitive skill levels of high-stakes physics and chemistry examinations across these six countries. All six physics and chemistry examinations had questions based on combinations of single-answer questions, short answer questions, context-based questions to include sketch/graph/diagram, computational questions and short essay style questions. Apart from Ireland, students in the other countries had to answer all the questions. Irish students could choose any eight questions of the eleven available on the examination papers to answer.

Table 3 sets out the percentage distribution of each cognitive level for the six physics examinations. Except for Ireland and New South Wales, there was less emphasis on marks being assigned to the lower cognitive skills of *remember* and *understand* with percentage distributions for *remember* ranging between 0% (the Netherlands) and 18% (South Africa)) and for *understand* between 8% (the Netherlands) and 26% (England). In Ireland, 37% of the question parts coded as *remember*, while in New South Wales, 37% of the questions marks coded as *understand.* The majority of question-parts which coded for the cognitive skill *apply* used the action-verb 'calculate' with a percentage distritution between 23% (New South Wales) and 70% (the Netherlands). The percentage distribution of questions coding for *analyse* ranged from 1% (Scotland) to 18% (New South Wales). Scotland allocated 15% of the marks to question-parts coding for *evaluate.* None of the countries had questions coding for *create* cognitive skill.

Table 3. Percentage distribution of marks per cognitive skill levels across the physics examinations.

Exam in	*Remember*	*Understand*	*Apply*	*Analyse*	*Evaluate*	*Create*
England	9%	26%	42%	16%	7%	0%
Ireland	**37**%	23%	36%	2%	1%	0%
the Netherlands	0%	8%	**70**%	9%	14%	0%
New South Wales	13%	**37**%	23%	**18**%	11%	0%
Scotland	8%	15%	60%	1%	**15**%	0%
South Africa	18%	10%	**65%**	7%	0%	0%

The percentage distribution for each cognitive level for the six examinations in chemistry is set out in Table 4. Across the six examinations, the percentage distribution of marks assigned to the cognitive levels of *remember* ranged from 10% (New South Wales) to 38% (Ireland). The percentage distribution of marks being assigned for question-parts coding for *understand* ranged from 19% (South Africa) to 36% (Ireland).

Apart from South Africa, the other countries assigned between 24% and 49% of the marks to question-parts coding for *apply.* South Africa assigned 65% of the marks to this same cognitive skill. As with physics the majority of question-parts coding to *apply* the action verb was 'to calculate'.

The percentage distribution of marks for question-parts coding to analyse was between 1% (South Africa) and 15% (New South Wales) while a much smaller percentage of question-parts (1%-6%) coded to *evaluate*. Similar to finding for physics, where were no question-parts which coded to *create.*

Table 4. Percentage distribution of marks per cognitive skill levels across the six chemistry examinations.

Exam in	*Remember*	*Understand*	*Apply*	*Analyse*	*Evaluate*	*Create*
England	13%	23%	49%	9%	**6%**	0%
Ireland	**38%**	**36%**	24%	2%	1%	0%
the Netherlands	25%	31%	27%	14%	3%	0%
New South Wales	10%	34%	40%	**15%**	3%	0%
Scotland	31%	26%	35%	4%	4%	0%
South Africa	15%	19%	**65%**	1%	0%	0%

A combination of the percentage distribution of marks for the two lower cognitive skills of *remember* and *understand* showed that the physics examinations had between 8% (the Netherlands) and 60% (Ireland) of question-parts coding to these skills. In comparison, between 34% (South Africa) and 74% (Ireland) of questions-parts on the chemistry examinations coded to these. Across all the physics examinations there was more question-parts assessing the cognitive skill of *apply* from 70% (Netherlands) to 23% (New South Wales) with a comparable range in chemistry of 65% (South Africa) to 24% (Ireland). The percentage of question-parts coding for the higher cognitive skills of *analyse, evaluate* and *create* was between 0% and 15%. Neither subject examination had any question-parts coding for *create.*

DISCUSSION AND CONCLUSIONS

The focus of this desk-based comparative study was solely on the content of the publicly available 2016 examination documents issued by the education authorites of each of the countries as in Table 1. The cognitive skills, as presented, were based on the written word of the examination whether it was the intended outcome of the assessors/setters of the examinations (Matters & Masters, 2007). Using the compiled Stanny-Newton list of action-verbs as well as the supplementary list in Table 2 when coding for each of the six cognitive levels ensure the same assessment standard was applied to all the examinations.

Examining the data from the physics papers indicate that, with some exceptions, there was less emphasis on marks being assigned to cognitive skills of '*remember*' and '*understand*' type of questions. Three of the examinations, the Netherlands, Scotland and South Africa assigned a high percentage of the respective total marks to the cognitive skill *apply* that is 70%, 60% and 65% respectively. A similar analysis carried out by Motlhabane on South African physics examinations of 2014 and 2015 showed that 64% of the questions assessed the cognitive skill *apply* (Motlhabane, 2017). However, most of the question-parts which coded for this skill used the same computational action -verb as these the examples shown

Calculate the heating power of the element. (the Netherlands, physics 2016 Q. 5)

Calculate the effective resistance of the parallel branch. (South Africa, physics 2016, Q.8.1.5)

The Netherland's physics syllabus referenced prior knowledge that students should know and so would not be a feature of the examination – hence the absence of any question-parts coding to *remember* and a low percentage of marks, 8%, being assigned to questions assessing *understand*. Consequently, more question-parts focused on assessing cognitive skills of *apply*, *analyse* and *evaluate.*

The data from the chemistry analysis paints a very different picture. Across all the examinations the emphasis was on the *remember* and *understand* type of questions with the percentage of marks assigned to each of the cognitive levels of *remember* and *understand* ranging from 10% to 38% (*remember*) and from 19% to 36% (*understand*). This emphasis on the lower cognitive skills is in keeping with similar studies (Burns et al., 2018; Edwards, 2010; Letmon et al., 2021; Madaus & Macnamara, 1970; Tsaparlis & Zoller, 2003). As mentioned earlier, there were no mandatory questions on the Irish physics and chemistry examinations thus allowing students to choose eight questions from eleven. This choice element of the examinations meant that each of the eleven questions had to assess approximately the same cognitive skills in order to maintain comparability between all the questions (Bramley & Crisp, 2019). In comparison, the mandatory nature of the question-parts on the other examination papers should have enabled more question-parts to focus on assessing the higher skills of *analyse* and *evaluate*. Yet the data did not bear this out.

IMPLICATIONS AND FURTHER STUDIES

The 2015 OECD report on the *Future of Education and Skills Education 2030* challenged governments to future-proof national education systems by raising two key questions – 'what competencies and skills will be needed in the future? how will these competencies be implemented and assessed?' (OECD, 2015). Studies have shown a disconnect between what educators consider skills and employers' expectations with employers considering the skills most lacking were *problem-solving*, *analytical* and *critical thinking skills* (Cunningham & Villasenor, 2016; Hanushek & Woessmann, 2008) which could identify to Bloom's cognitve skills of *apply, analyse* and *evaluate.* The data as presented in this study highlighted the paucity of question-parts assessing *analyse* and *evaluate* skills while the majority of question-parts coding to *apply* were solely computational ones. However, using the action-verb list as the sole determining tool to identify and compare the cognitive skills across national examinations presented a limited or dimensionless analysis of them. The gathered data was based on a single year's examination raising the questions –

(a) How reflective was the data of the national curiculum objectives of the relevant countries?

(b) What role did the examiners' reports have in evaluating the examinations with respect both to the national curriculum objectives and to the students' written responses to the examionation questions?

One of the criteria for selection was the comparability of topics being examined. However, this study focused on the examination questions without reference to the topics which prompts a third question

(c) What might the comparison of cognitive skills as reflected across comparble topics reveal?

A further study addressing these three questions is ongoing. In addition, further work is needed to develop and promote the use of questions which assess the cognitive skills of evaluate and create in these high-stakes examinations at the end of upper second level education.

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Part 11 / Strand 11

Evaluation and Assessment of Student Learning and Development

Editors: *Lukas Rokos & Mathias Ropohl*

Part 11. Evaluation and Assessment of Student Learning and Development

Development, validation and use of standardized tests, achievement tests, high stakes tests, and instruments for measuring attitudes, interests, beliefs, self-efficacy, science process skills, conceptual understandings, etc.; authentic assessment, formative assessment, summative assessment; approaches to assessment. Monitoring student learning and implications for teaching.

Part 11: Evaluation and Assessment in Science Education

Editors: *Lukas Rokos & Mathias Ropohl*

Introduction

Evaluation and assessment are still hot topics for researchers (not only) in the field of science education. Evaluation and assessment are important in all contributions presented in Strand 11. In total, there are five contributions from different educational backgrounds in this chapter, namely, Czech Republic, Greece, Portugal, and Singapore. Individual papers present very different perspectives on the issue of evaluation and assessment within various educational systems, and different educational levels (primary, secondary, tertiary), but they also differ in the methodology used (quantitative, qualitative, and mixed methods). Whether we focus on biology, physics, chemistry or mathematics, standardised tests, assessing students' motivation to study science subjects or ways of providing feedback on student performance, you will read interesting insights of the presented research projects that are useful for the entire ESERA community.

We hope that the following contributions will inspire you:

1) National exams and standardised tests

Quality assessment of the Portuguese secondary education biology and geology national exams is a paper focusing on external evaluation at the secondary level, specifically on students' results in biology and geology. It demonstrates the lack of validity and reliability of these exams, as well as cognitively demanding tasks that could be factors for the high number of failures.

Data sensemaking demands of stimulus-based questions in standardized physics assessments presents preliminary findings from the analysis of stimulus-based questions in Singapore. The coding scheme introduced in the paper has the potential to be generally used in stimulus-based questions related to biology and chemistry.

2) Assessment of abstraction skills

Assessing abstraction skills in early primary school amid environmental study describes the development and assessment of computational thinking skills and the use of a respective assessment tool developed by the authors. The statistical analysis of first and second-grade primary school students' abstraction skills provides a background for studies that will attribute ecological essence to computational thinking activities. By the analysis, the correlation between computational thinking and environmental consciousness could be validated.

3) Motivation

The impact of undergraduate students' academic experience on their motivation to learn chemistry and physics uses cluster sampling for students from three different academic majors to investigate motivation in higher education. The authors found that recent academic experience has stronger effects on students' motivation to learn chemistry and physics than more distant experiences.

4) Feedback as a key aspect of assessment

Analysis of teacher written feedback in biology inquiry task with stress on affective connotations introduces findings from distance teaching in the Czech Republic and efforts of in-service teachers to provide formative feedback to students, including an explanation of the assessment criteria and work with their mistakes. Although affective connotations may have a strong motivational effect, they are still rather rare in the feedback provided by teachers.

QUALITY ASSESSMENT OF THE PORTUGUESE SECONDARY EDUCATION BIOLOGY AND GEOLOGY NATIONAL EXAMS

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In Portugal, the external evaluation of students in secondary education takes place through national exams, which grades have a significant impact on their academic future. The students' results in Biology and Geology national exams have revealed a prevalent and persistent scenario of failure, with very low average scores and excessively high failure rates. In the teachers' opinion, among the main causes of this failure is the complexity of the exam. Thus, this study aimed to analyze the validity and technical quality of these tests in order to understand whether these assessment instruments are contributing negatively to the students' failure. To achieve this, a qualitative investigation was carried out, using documentary analysis through content analysis. Two Biology and Geology exams were analyzed, being the selection criterion the extremes of the students' results (the test with the best results and the test with the worst results), with the following objectives: (1) to analyze the validity and the technical quality of Biology and Geology exams; (2) to determine whether these exams assess the purposes of the subject syllabus; (3) to determine whether these exams assess the achievement of the educational objectives proposed by Bloom's Taxonomy.
It is concluded that the exams are cognitively demanding, since most questions assess higher categories of the cognitive process (application and analysis) of conceptual knowledge.
This investigation demonstrates the lack of validity and reliability of Biology and Geology exams, as well as technical quality problems.

Keywords: Science Education; Evaluation; Secondary School

INTRODUCTION

In Portugal, the conclusion and the certification of Secondary Education and the access to Higher Education depend on an evaluation system in which external assessment, in the form of national examinations, has a significant impact.

The students' results in Biology and Geology exam have revealed a serious situation of failure over the years, with very low average scores and excessively high failure rates (Lopes & Precioso, 2018). With regard to the average scores, the maximum score was 10.02 points (in 20) achieved in 2014 and 2016 exams, and the minimum score was 8.21 points, obtained by all students who took the exam in 2013 (Lopes & Precioso, 2018). As for the failure rates, they have been situated between 1/3 and 2/3 of the students who took the exam. The worst record occurred in 2013, in which the failure rate reached 64.4%, which means that 49235 exams revealed a score below 9.5 points, in a total of 76501 exams (Lopes & Precioso, 2018). This numbers show the real dimension of the problem.

In teachers' opinion, the main causes of the students' failure in Biology and Geology external assessment are: the exam's high degree of complexity, the stress and the anxiety caused in the students by the exam; students' difficulties related to reading, interpretation and communication skills; the very penalizing exam's correction and classification criteria; the high degree of complexity of the document analysis; the gap between what is required in the exam and what is required by the subject syllabus; the inadequacy of the exam to the students' maturity and the extensive subject syllabus (Lopes & Precioso, 2019).

In addition, several studies carried out in Portugal (Rosário, 2007; Raposo & Freire, 2008; Madureira, 2011; Sousa, 2011; Lopes, 2013; Marques et al., 2015) show the influence of national exams on pedagogical practices and teachers' evaluations. Teachers guide their practices to "train" students for what is required in the exam, using practices that they do not believe that are of the highest quality for learning; they make their evaluation tests with a similar structure of the exams and with the same classification criteria, even not agreeing with them and considering them penalizing for the students; and show great concern in approaching the entire subject's syllabus, even knowing that the pace they impose for teaching does not provide quality learning (Lopes, 2013).

In this way, exams, due to their existence, induce an inadequate learning model, which, for Black (1998), implies concluding their lack of validity. This is what has been described by research regarding exams in Portugal, which induce teaching to the test, which calls into question the validity of national tests.

Thus, it is important to analyze the validity and the technical quality of these exams to assess whether these assessment instruments are contributing negatively to the students' failure.

OBJECTIVES

Previous studies carried out by us (Lopes & Precioso, 2018) show a prevalent and persistent situation of severe school failure in the Biology and Geology exam, as male and female students have been getting worryingly low average ratings (between 8 and 11 points) and very high failure rates (between 45% and 65%). Therefor it is important to analyze the quality of these exams, in order to ascertain whether the assessment instrument may be contributing to this failure.

The objectives of this study are: (1) to analyze the validity and the technical quality of Biology and Geology exams; (2) to determine whether Biology and Geology exams assess the purposes of the subject syllabus; (3) to determine whether Biology and Geology exams assess the achievement of the educational objectives proposed by Bloom's Taxonomy.

METHOD

This study's population consists of ten Biology and Geology national exams, 1st and 2nd phases, which were carried out in the academic years between 2012/2013, the last year in which changes were applied in the national tests, and 2017/2018, the last year with full data provided by the Júri Nacional de Exames. A non-probabilistic convenience sample was selected, being the criterion the extremes of the students' results, both in terms of average ratings and in terms of test failure rates: Biology and Geology Exam 2014, 1st phase, in which the students achieved the best results; and Biology and Geology Exam 2014, 2nd phase, in which the students achieved the worst results. We opted for a qualitative investigation using document analysis and content analysis. Data collection instruments were constructed, which consisted of analysis grids to analyze the exam questions in order to obtain data on the following dimensions: Science Teaching Dimensions; Bloom's Taxonomy Cognitive Process Dimension. The analysis grids were subjected to prior validation by specialists in Education and Science Education.

In the data treatment, each one of the questions in each one of the exams was analyzed qualitatively, making the respective categorization for each of the dimensions analyzed (presence/absence of the category and points). Finally, it was made a quantitative approach. The results were recorded in a comparative table of the two tests.

RESULTS

The Biology and Geology exams consist of 4 groups of questions, 2 of Biology and 2 of Geology. 4 problems are presented to students and problem-solving questions are asked about them.

Regarding the dimensions of Science Teaching, the main Science Teaching purpose assessed is Learning science, as shown in Table 1. There is consistency from one test to the other, since both tests have 26 questions (175 points) included in the category "Learning science" and 4 questions (25 points) inserted in the category " Learning to do science”. The categories “Learning about science” and “Learning through science” are not represented, although they are presented, in the normative documents of the subject, as important purposes. It is understandable that the exam focuses more on “Learning Science”, that is, on the contents, however, if the syllabus’ subject program considers the other categories as important purposes, it is not understandable that two of them are not even represented, since that the exam, as a subject evaluation instrument, must evaluate the achievement of its purposes.

Table 1. Compared analysis of 2014, 1st phase and 2014, 2nd phase exams.

Quality evaluation of Biology and Geology exams		Exam: 2014 1st phase		Exam: 2014 2nd phase	
		n	Points (in 200)	n	Points (in 200)
Science Teaching Dimensions	Learning science	26	175	26	175
	Doing science	4	25	4	25
	Learning about science	0	0	0	0
	Learning through science	0	0	0	0
Bloom's Taxonomy: Cognitive Process Dimension	Remember	0	0	0	0
	Understand	5	25	3	15
	Apply	14	75	15	80
	Analyze	10	90	11	90
	Evaluate	1	10	1	15
	Create	0	0	0	0

Regarding the dimension of the Cognitive Process of Bloom's Taxonomy, there are some differences that may explain the differences in the students' classifications in the two exams. Although the two exams focus on the application and analysis categories, there are some differences. In the case of the 1st phase, the test in which the students had better results, there are 5 questions in the comprehension category, corresponding to 25 points, while in the 2nd phase, the test in which the students had the worst results, there are only 3 comprehension questions, corresponding to just 15 points. In the "Apply" category, in the 1st phase, there are 14 questions, corresponding to 75 points, while in the 2nd phase, there are 15 questions, corresponding to 80 points. In the "Analysis" category, in the 1st phase there are 10 questions and in the 2nd phase there are 11 questions, but corresponding equally to 90 points. In the "Evaluate" category, the highest category present in the tests, there is only one question in each test, but in the 1st phase, it corresponds to 10 points and, in the 2nd phase, it corresponds to 15 points. In none of the tests there are items that configure the categories of "Remember", the least demanding category, and "Create", the most demanding. But it is important to remember that, within the same category, the questions can have different degrees of difficulty, either because of the content they cover, in terms of quantity and quality, or because of the level and quantity of relationships and inferences that the student has to make to answer the questions.

The exams often assess specific contents and concepts with a higher degree of depth and/or difficulty than what the subject syllabus recommends. Answering to the questions requires the reading and elaborated analysis of documents (9 in the 2014, 1st phase and 8 in the 2014, 2nd phase) which can be texts, images, graphs, maps or tables. In general, these sources of information present new situations which are complex to read and analyze, using elaborate scientific language. There is a clear privilege of multiple-choice questions, although the exams' structure is maintained, with regard to the number and types of questions. It should be noted that, sometimes, the degree of difficulty arises with artificialities and less correct formulations of the questions that cause doubts and insecurities for students (Lopes, 2020).

CONCLUSIONS AND IMPLICATIONS

It is concluded that the exams are cognitively demanding tests, in which most questions assess higher categories of the cognitive process, such as Apply and Analyze, of conceptual knowledge.

It is concluded that the exams require high-level cognitive skills, which is in line with the results of other studies carried out in the same context in our country. Preto (2008) analyzed the degree of difficulty of items related to experimental activities of the 1st and 2nd phases of the 2006 exam and concluded that the questions require a high level of conceptual demand as they require the association of different contents, mainly requesting skills in the domain of reasoning.

The time for doing the exam (2 hours, with 30 minutes of tolerance) is not compatible with the interpretation of so much information in such a short period of time, because answering the questions demands the integration of content that requires complex reasoning.

The privilege that is given to multiple choice questions decreases the validity of the test, because this type of items makes the assessment of the student's ability to develop a reasoning difficult (Black, 1998). The student may be doing at least partially correct reasoning and making the question wrong, or he may be doing the wrong reasoning and getting the question right. It may not let students' problem-solving skills emerge. And therefore, the student is not being given an opportunity to show what he really knows in this domain. This option for multiple choice questions is related to the attempt to increase the reliability of the test, but it decreases its validity. This fact shows the conflict between these two concepts, denounced by Black (1998).

Regarding the science teaching purposes, the exam focuses on the dimension Learning Science; neglecting other purposes, such as Learning to do Science; Learning about the Science; and Learning through Science, which deprives it of validity, because it does not assess what the subject syllabus demands.

It is imperative to produce assessment instruments with better technical quality.

The exam prepared in 2020, due to the changes that the COVID pandemic has imposed during the academic year, may give some guidelines for its reformulation. It consisted of 33 items, of which only 10 were mandatory. 15 items of the remaining 23, contributed to the exam's final grade. Regarding the type of questions, short answer questions and selection completion questions (with multiple choice) were introduced. These changes gave students a greater opportunity to show what they know and what they are able to do and, therefore, we must consider if they should be introduced permanently in exams of the coming years.

A punctual test cannot be considered a rigorous and indisputable instrument that defines what a student knows and is capable of doing and, therefore, cannot so decisively determine the students' academic path and their future. The exam cannot be seen as an unquestionable and infallible assessment tool, but rather it must be rethought and continually improved.

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DATA SENSEMAKING DEMANDS OF STIMULUS-BASED QUESTIONS IN STANDARDISED PHYSICS ASSESSMENTS

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Stimulus-based questions in science assessments typically require students to make sense of data presented as informational text, picture, table, or graph in order to answer the questions. However, there is a lack of a tool for analysing data sensemaking demands of stimulus-based questions based on the type and number of data representations, as well as the data reasoning process involved. To meet this need, this study proposed a data sensemaking demands coding scheme for analysing stimulus-based questions. Preliminary findings from analysing stimulus-based questions in Singapore's national physics examinations for tenth-graders as well as think-aloud interviews with two preservice physics teachers suggest researchers' expected data sensemaking demands (based on coding scheme) agreed fairly well with preservice teachers' enacted data sensemaking when answering a stimulus-based question. Also, moderate agreement was achieved on the coding scheme between two raters. Thus, proposed coding scheme has demonstrated reasonable response process validity and reliability. With further evaluation and revision, proposed data interpretation coding scheme has the capacity for analysing biology and chemistry stimulus-based questions, in addition to physics questions.

Keywords: Assessment, Physics, Representation

INTRODUCTION

Stimulus-based questions in high-stake science assessments are intended to evaluate higher order thinking skills associated with critical thinking. One such example is data-based questions (DbQs) in the biology, chemistry, and physics Singapore-Cambridge GCE Ordinary level (O-level) national examinations taken by secondary four (grade 10) students in Singapore. These questions (eight to 12 marks each) require students to interpret, evaluate, or solve short structured or open-ended items using given information (Singapore Ministry of Education, 2016). That is, students have to make sense of presented data in order to answer the questions. However, there is a lack of a useful tool with ease of use for analysing the data sensemaking demands associated with stimulus-based questions. While various knowledge taxonomies and frameworks for analysing general cognitive demands, (e.g. Biggs SOLO taxonomy, Webb's Depth of Knowledge, and Bloom's revised taxonomy) are widely used by researchers and educators, these taxonomies and frameworks do not adequately reflect demands of making sense of data presented in various representations (e.g. tables, graphs, diagrams). Hence, this study seeks to determine preliminary reliability and validity measures of a proposed data sensemaking demands coding scheme by answering the following research questions (RQs): 1. How reliable is the coding scheme in terms of inter-rater reliability measure? and 2. To what extent is response process validity achieved i.e. agreement between researchers' expected data sensemaking (based on assigned codes) and preservice physics teachers' enacted data sensemaking when answering a stimulus-based question?

DEMANDS OF DATA SENSEMAKING

Learning with multiple external representations is complex and involves considerations of design parameters of the multi-representational system, functions of these representations, and cognitive tasks undertaken by learners when interacting with representations (Ainsworth, 2006). Thus, cognitive demands of working with data are multidimensional. While it is beyond the scope of this study to design a comprehensive analytic framework for data reasoning demands, two aspects—visual representations of data (LaDue et al., 2015) and processes involved in working with presented data (Morris et al., 2015)—provide productive starting points.

Analysis of visual representations in high school New York State Regents (June 2012) examinations in the sciences by LaDue et al. (2015) identified four representation categories in the physics examination paper (in decreasing frequencies): diagrams, graphs, tables, and a network (i.e., chart depicting relationships among components). These visual representations, excluding network, informed data representation types codes in our data sensemaking demands coding scheme. LaDue and colleagues did not consider whether multiple representations were required to answer each item. However, based on challenges associated with learning using multiple external representations (Ainsworth, 2006), it is likely the number of representations and representation type(s) presented would affect item cognitive demand.

Morris et al. (2015) analysed opportunities for working with data in 20 American middle school science textbooks based on four scientific inquiry processes associated with working with data: data recording (recording/displaying/organising data), data analysis (analysing data using mathematical procedure; estimating outcomes), data interpretation (explaining phenomenon; reporting fastest, most, etc.; suggesting alternatives to explanations), and making predictions from data. Aside from data recording, which is not relevant for our analysed questions, other processes informed the data reasoning codes in our coding scheme.

METHODS

Selection of stimulus-based questions and think-aloud interviews

To answer RQ1, 15 stimulus-based items in physics O-Level examination papers between 2009 to 2018 were selected for coding. All question parts were treated as individual items. A total of 145 items were coded by both authors. To answer RQ2, two physics preservice teachers (PST) were interviewed individually by the first author using a think-aloud protocol (van Someren et al., 1994). Participants were recruited from students enrolled in a teacher preparation course at the time of the study. Only two PSTs, Ken and Leo (pseudonyms), volunteered. Both PSTs had physics as a second teaching subject. During interview, PSTs articulated how they answered a seven-part 2015 DbQ (presented in a handout) as they worked through each part. Due to copyright, the actual question is not shown. Parts of the question relevant for discussion of the PSTs' responses are described (with modifications) in Figure 1. Interviews were audio-recorded and transcribed (11 and 18 minutes each). Transcripts and participants' written responses were analysed. Interview transcripts were coded collaboratively by both authors in discussion to reach consensus codes.

Data analysis

The data sensemaking demands coding scheme comprises two dimensions: data representation (type and number) and data reasoning. Answering a DbQ part may require coordination between several data representations. Thus, multiple data representation type codes were allowed per question part (e.g., presented picture and graph may both be required to answer a part). Data representation types (Table 1) include: *information* (I) i.e., text, including equations; *picture* (Pic) i.e. diagram/figure describing aspects of physical object(s) or process(es); *table* (T) where values of two or more quantities are presented in tabulated format; *graph* (G), including line graph, scatter plot, or bar chart, or *no data* (NA). Since multiple data representation type codes were allowed, simple agreement of codes (i.e., all identified data representation types for a part are in agreement) was used to determine inter-rater reliability for this code. Initial iteration of data reasoning codes considered data analysing, interpreting, and predicting/explaining described in Morris et al. (2015). However, difficulties in distinguishing between the three processes during coding practise prompted us to redefine the processes as two codes. Final data reasoning codes (Table 2) considered whether *data was used as information* (DIn) i.e., identify relevant data as answer or selecting relevant data for mathematical manipulation to arrive at answer or whether *data interpretation* (DPr) was involved i.e. determining similarities/differences/ relationships within/between datasets, predicting relationship/outcomes, or relating data to scientific concepts. Question part without data representation is coded as *no data* (NA). Cohen's kappa was used to determine inter-rater reliability for data reasoning codes. Written responses and other inscriptions on interview handouts were considered when deliberating the codes.

Table 1. Data type codes.

Data Type	Description
Information (I)	Information (e.g., values of physical quantities) or chunks of text provided at the start of a question part.
Table (T)	Data i.e. values for two or more variables is presented in table format.
Graph (G)	Line graph, scatter plot, bar chart, etc.
Picture (Pic)	Diagram or figure depicting some aspect(s) of real object(s) or scenes.
No data (NA)	No data or information is provided/required to answer question.

Table 2. Data reasoning codes.

Reasoning Process	Description
Data as information (DIn)	Data is used as information to answer the question. This includes: Identifying relevant data as answer to question without further math operations or reasoning, OR Selecting relevant data for manipulation through math operations (e.g., substitution as a variable into an expression) to arrive at the answer
Data interpretation (DPr)	Data needs to be made sense of in order to answer the question. This includes: Transforming data from one representation to a different representation e.g., plotting a graph based on tabulated data or transformed between different scales, or describing pattern/relationship in words based on given graph. May involve math operations; Determining similarities, differences, or relationships within or between data sets. May involve math operations, OR Predicting relationship beyond given data range or with different conditions. Includes plotting/filling in data point in graph/table beyond given range, suggesting relationship based on partial data sets, and predicting outcomes.
Not applicable (NA)	Answer does not require any given data. Should only apply to item already coded as "NA" for Data Type.

FINDINGS AND DISCUSSION

On coding scheme reliability (RQ1), data reasoning codes achieved Cohen's kappa of 0.57 ($p<.001$), indicating moderate agreement (Landis & Koch, 1977), while data representation type codes achieved simple agreement of 60.0%. On response process validity (RQ2), expected and enacted codes concurred on all but one item i.e., b(i) for both PSTs (Figure 1). For brevity, only two parts of the question are shown in Figure 1: a(i) provides the context to interpret b(i) which is discussed below. Note that Ken did not provide reasoning for b(ii); Leo did not answer c(ii).

For b(i), the authors opined interpreting (DPr) information (I) about the repeated experiment ("wind blowing over the wires") as well as tables (T) for the repeated experiment and original experiment were necessary to answer the item. However, both PSTs only considered one data representation type in their written responses. Ken's utterance "wind, what is the point of this? Oh, reduce overheating"—indicates he connected the information about blowing wind to the concept of heating/cooling (I; DPr), but his written response did not reference the wind. Instead, he said, "the resistance got smaller, for all the wires" and wrote a similar response. This suggests Ken interpreted the table for the repeated experiment (T; DPr) to answer b(i). Leo, however, initially interpreted the table for the repeated experiment, noting "the p.d. drops by 0.01" (T; DPr) compared to the original experiment. He then uttered "wind, could have cooled down the heat generated by the current" (I; DPr). Only the latter idea was included in Leo's written response.

Part	Question Part Description	Data Interpretation		
		Expected	Enacted ( ) = enacted reasoning not reflected in written response. Discrepant codes are underlined.	
			Ken	Leo
a(i)	[Question stem shows picture of a piece of fuse wire clipped at both ends by metal clips. Length of wires X and Y are stated] Using data [table of current, p.d.s across wire X and wire Y]…describe the relationship between current in X and p.d. across X…for (1) low currents; (2) high currents.	T; DPr	(Pic; DIn) T; DPr G; DPr	(I; DPr) T; DPr G; DPr
b(i)	The experiment is repeated with a wind blowing over the wires. Table shows new readings at low currents [for 0.5A and 1.0A]. Suggest a reason why the values of p.d. at the same current are now lower than previously.	I, T; DPr	(I; DPr) T; DPr	(T; DPr) I; DPr

Figure 1. Expected and enacted codes for parts of 2015 DbQ.

CONCLUSION AND FUTURE WORK

Findings suggest proposed data sensemaking demands coding scheme demonstrated reasonable inter-rater reliability and response process validity when coding scheme was tested with a set of stimulus-based items in standardised physics assessments. To extend coding scheme's usability, it will be used to analyse stimulus-based items in biology and chemistry assessments. Findings will be shared at the conference. This work will be of interest to science education researchers and practitioners seeking a tool to analyse data sensemaking demands of assessment items, in order to help students, meet such assessment demands.

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ASSESSING ABSTRACTION SKILLS IN EARLY PRIMARY SCHOOL AMID ENVIRONMENTAL STUDY

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This paper introduces part of a multifarious project on the development and the assessment of essential computational thinking skills, such as algorithmic thinking and abstraction, in early childhood education. More precisely, the part of the project that is presented refers to an assessment tool constructed by the authors, which focuses on evaluating the abstraction skills of first and second-grade primary school students. It employs data collection instruments and analysis techniques of mixed-method research and it is proposed to be applied in the classroom within the context of Environmental Study. Relevant research conducted in Greece with a sample of 435 students, from February to June 2019, is also discussed. The part of the research study we discuss focuses on evaluating students' abstraction skills and testing the relationship between abstraction skills and the levels of the content understanding of the Environmental Study course. The statistical analysis validated the correlation under investigation, supporting the innovative idea of the synergistic cultivation of computational thinking and environmental consciousness, and providing a robust background for relevant studies that will aim for attributing ecological essence to computational thinking activities.

Keywords: Computational thinking, science education, early childhood education

INTRODUCTION

Computational thinking (CT) is seen as a set of important competencies that are required in the modern digital era and, thus, several countries have already adopted priorities for its development from kindergarten to secondary education (Kanaki & Kalogiannakis, 2018; Relkin et al., 2021; Sung et al., 2017). At the same time, the demand for empowering environmental awareness emerges from the need for tackling or preventing contemporary environmental problems, such as pollution (Manisalidis et al., 2020), climate change (Celik, 2020; Lickley et al., 2020), ocean acidification (Doney et al., 2020), loss of biodiversity (Chawla, 2020), and ozone layer depletion (Lickley et al., 2020), to mention but a few. Within this context, we investigate the innovative idea of the synergistic development of environmental consciousness and CT skills during the early primary school years (Ardoin & Bowers, 2020; Kanaki & Kalogiannakis, 2019) providing a sturdy background for forthcoming research studies that will focus on proposing CT activities with ecological reflection.

Our study follows the principles of mixed methods research and focuses on first and second-grade primary school students. Its essence is to provide the educational community with novel means for cultivating CT competencies in the aforementioned age groups, together with a relevant assessment tool. As far as the proposed assessment tool is concerned, the parameters examined were (a) the validity and the reliability of the results obtained when applying the assessment tool, (b) the levels of fundamental CT skills of first and second-grade primary school students, and (c) the correlation of the levels of fundamental CT skills with the content comprehension of the Environmental Study course of first and second-grade primary school students. We also examined the correlation of fundamental CT skills with gender and the class of the students. In this paper, we discuss the part of our research that deals with the evaluation of abstraction, as one of the major CT skills, and its association with the educational achievements in the Environmental Study course. Thus, the research questions that drive this paper are (a) "Which are the levels of students' abstraction skills during the early years of primary school?" and (b) "Is there an association between abstraction skills of first and second-grade primary school students and their performance in Environmental Study course?"

THEORETICAL FRAMEWORK

To support young students to cultivate in-depth basic CT skills, the construction of relevant assessment tools is necessary (Grover, 2017; Román-González et al., 2019). Regarding the fundamental aspects of CT, although there is a variety of opinions (Tang et al., 2020) convergence is observed that abstraction is one of its essential elements (Barr et al., 2011; Shute et al., 2017; Wing, 2006).

Wing, who introduced the term of CT in 2006 (Wing, 2006), claimed that abstraction is the most noteworthy and advanced thought process among CT aspects (Wing, 2006, 2011). It is exercised for determining important properties of objects that are parts of a group and for hiding irrelevant distinctions among them, achieving the goal of an object to stand for many (Wing, 2011). Thus, the two faces of abstraction are (a) the act of not considering exceptional properties of an object in order to become representative for others of its kind, and (b) the process of generalizing by bringing out common properties of instances of an object (Kramer, 2007). For example, let's take the case of the hippopotamus which is a herbivorous mammal. In literature, there are few cases recorded that hippopotami consumed meat, indulged in cannibalism, or exercised predation (Dudley, 1998) although the anatomy of the hippopotamus' stomach does not justify eating meat, which is deviant behaviour and may occur in eating disorders (Eltringham, 1999). These few exceptions do not cause loss of generality. On the contrary, in the context of abstraction, the hippopotamus is characterized as herbivorous. Based on the above, we could say that the ability of an individual to identify exceptions that can be ignored without loss of generality can be a criterion for assessing their abstraction skills.

An important issue that arises is when the individual's abstract ability begins to develop. Due to Piaget's classical theory of children's cognitive development, abstraction begins to develop in the third stage i.e., the concrete operational, from about seven to 12 years old (Piaget, 1928). However, in his more recent work, these allegations seem to be overturned, as he presented in detail tests of the abstract ability of 18-month-old infants (Piaget, 2001).

METHOD

In order to answer the research questions, we conducted a research study adopting a coherent ethics framework, in the school year 2018 – 2019, on the island of Crete, in Heraklion city, employing a research sample of 435 primary school students of first and second grade. The sample was grade balanced – 218 first graders (50.11%) and 217 second graders (49.89%) – and gender balanced – 210 girls (48.28%) and 225 boys (51.72%).

As already mentioned, we employ mixed methodology for collecting data. For quantitative data, we suggest triangulation. In both of the methods proposed, the students have to assign the values of a specific attribute to a group of living organisms or inanimate objects.

The pillar of the first method is the digital platform PhysGramming, which we implemented for the needs of our research study. PhysGramming deploys a hybrid schema of text-based and visual programming techniques, with emphasis on object orientation and provides children the opportunity to create their own digital games (Kanaki & Kalogiannakis, 2018).

The second method is based on filling in worksheets. In both methods, the living organisms/ inanimate objects are depicted on the tool via pictures selected from a pool of pictures provided by the teacher. It is worth mentioning that the teacher who applies the assessment tool chooses its content, based on various criteria, such as the current course's unit, students' place of residence, etc. In other words, the teacher reconfigures the tool based on criteria that deem meaningful to apply.

At a qualitative level, personal semi-structured interviews are conducted, the content of which is relevant to the content of the current unit. The combined results of both quantitative and qualitative data place students into one of the four levels of abstraction: Excellent, Satisfactory, Medium and Basic. We came to these four levels based on the statistical analysis applied to the data of a relevant pilot study we conducted.

To understand the proposed evaluation method, let's see how it was applied in our research. Since the research was conducted in a region of Greece, we examined students' perceptions regarding the fauna of that region. We must mention that, during the presentation of the unit's content, the fauna of the region was not discussed. Thus, the results provided by the assessment tool were not related to the understanding of the unit's content.

We paid extra attention to the case of the crocodile since it has not been long since a crocodile was spotted in a lake of Crete. In addition, a popular family tavern in the region where the research took place hosted a crocodile until recently and for several years. Students should use their abstraction ability and not claim that the crocodile belongs to the region's fauna. If the tool is applied in another region of Greece or abroad, it does not make sense to check the students' abstraction skills by examining their perceptions regarding the fauna of the region where our research was conducted. Instead, the teacher should properly adjust the content of the assessment tool.

To estimate the levels of abstraction skills in quantitative terms, we analyse the data resulting from the indexing of the worksheets, as well as the log files provided by the digital platform that keep track of the students' achievements (Kanaki & Kalogiannakis, 2018). The fewer mistakes students make, the higher their level of abstract ability is. At a qualitative level, we analyse the data that emerge from the interviews.

As far as the assessment of the content understanding is concerned, students are assessed via relevant worksheets. In our research study, we examined students' perceptions about animals' eating habits. According to their performance, they were placed into one of the four levels of content understanding: Excellent, Very Good, Good and Almost Good. We came to these four levels based on the statistical analysis applied to the data of a relevant pilot study we conducted.

RESULTS

For processing, analysing and presenting the data derived from the application of the assessment tool, we employ several methods of statistical analysis. More precisely, we present frequency distributions that provide an introductory essence of the research's results. We construct contingency tables, implement chi-square tests and calculate p-values, in order to bring out possible correlations between independent and dependent variables. In the cases that we detect correlations, we calculate the odds ratio, in order to determine the probability of occurrence of the values of the dependent variable, regarding the independent variable. We finally employ machine learning (Nafea, 2018), as a supplementary method for statistical analysis, that provides clearly interpretable insights and reliable predictions regarding the possibility of new data being placed at each one of the levels of the variables under investigation (Rosé et al., 2019).

Frequency distribution

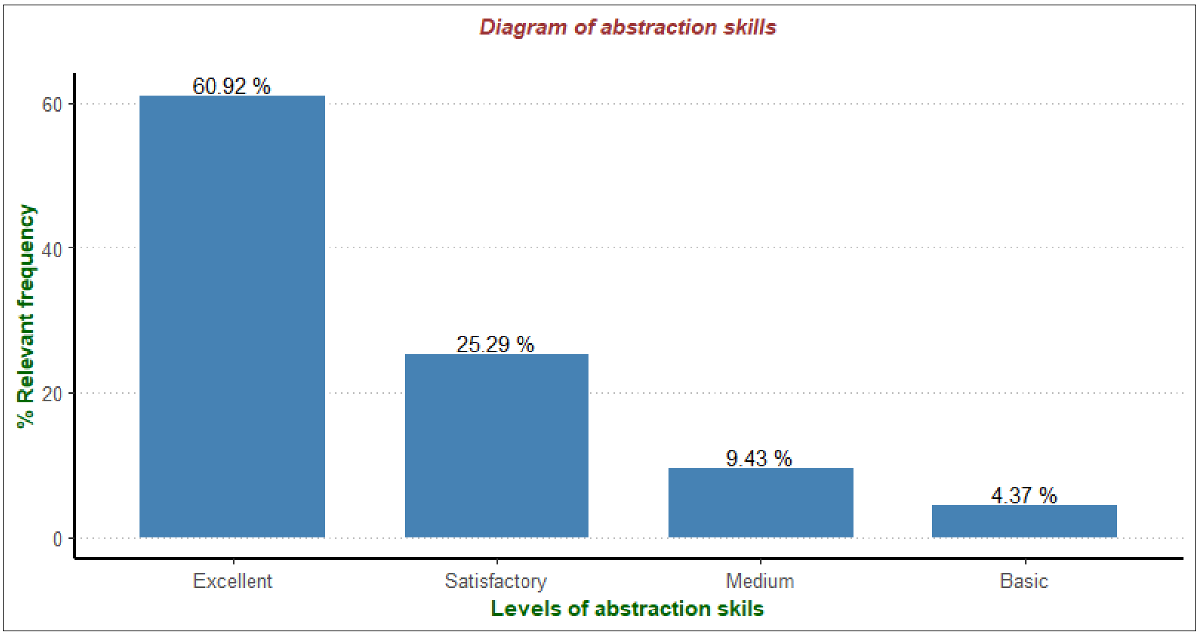

Figure 23. Frequency distribution

Figure 1 depicts the frequency distribution of the levels of abstraction skills detected in the research sample. We observe that 86.21% of the students demonstrated excellent or satisfactory abstraction skills.

Testing the correlation between abstraction skills and content understanding of the Environmental Study course

We set up the hypothesis that abstraction skills are not associated with the content understanding of the Environmental Study course. We test out the hypothesis set at a 5% level of significance and, thus, with the predetermined alpha level of significance to be 0.05. Based on the relevant contingency tables (Table 1, Table 2) chi-square is calculated to be 20.23, degrees of freedom are nine (df = 9) and the p-value is 0.01654. Since $p < 0.05$, we reject the hypothesis set and accept its alternative. Thus, we accept that there is an association between abstraction skills and content understanding.

Table 34. Contingency table of observed frequencies of the association between abstraction skills and content understanding

Content understanding / Abstraction skills	Excellent	Very good	Good	Almost good	Sum
Excellent	77	83	58	47	265
Satisfactory	21	34	29	26	110
Medium	5	12	9	15	41
Basic	4	11	3	11	19
Sum	107	130	99	99	435

Table 35. Contingency table of expected frequencies of the association between abstraction skills and content understanding

Content understanding / Abstraction skills	Excellent	Very good	Good	Almost good	Sum
Excellent	63.7191	83.3708	58.9551	58.9551	265
Satisfactory	26.4494	34.6067	24.4719	24.4719	110
Medium	9.8584	12.8989	9.1213	9.1213	41
Basic	6.9730	9.1236	6.4517	6.4517	19
Sum	107	130	99	99	435

Next, we examine the association of each one of the levels of abstraction skills with each one of the content understanding levels (Table 3). We calculate the odds ratio for every sub-table 2x2 (Table 4). In cases that the value of odds ratio is greater than one, the relevant levels of content understanding and abstraction skills are more likely to occur together than not. Results indicate that abstraction skills increase in relation to content understanding.

Table 36. Association of each one of the abstraction levels with the content understanding levels

			Abstraction skills							
			Excellent		Satisfactory		Medium		Basic	
			Yes	No	Yes	No	Yes	No	Yes	No
Content understanding	Excellent	Yes	77	30	21	86	5	102	4	103
		No	188	140	89	239	36	292	15	313
	Very good	Yes	83	47	34	96	12	118	1	129
		No	182	123	76	229	29	276	18	287
	Good	Yes	58	41	29	70	9	90	3	96
		No	207	129	81	255	32	304	16	320
	Almost good	Yes	47	52	26	73	15	84	11	88
		No	218	118	84	252	26	310	8	328

Table 37. Odds ratio for abstraction levels in relation to content understanding levels

			Abstraction skills							
			Excellent		Satisfactory		Medium		Basic	
			Yes	No	Yes	No	Yes	No	Yes	No
Content understanding	Excellent	Yes / No	1.92		0.65		0.42		0.8	
	Very good	Yes / No	1.20		1.06		0.91		0.17	
	Good	Yes / No	0.88		1.28		0.91		0.60	
	Almost good	Yes / No	0.49		1.09		2.25		5	

We also apply the machine learning method, seeking to predict the possibility of new data being placed at each one of the levels of abstraction skills, in dependence on the content understanding. Thus, the dependent variable is the level of students' abstraction skills, while the independent variable is the understanding of the course content. 80% of the survey data was used to construct the prediction equations and the remaining 20% for testing. The results obtained (Figure 2) verify the relation between the levels of abstraction skills and content understanding.

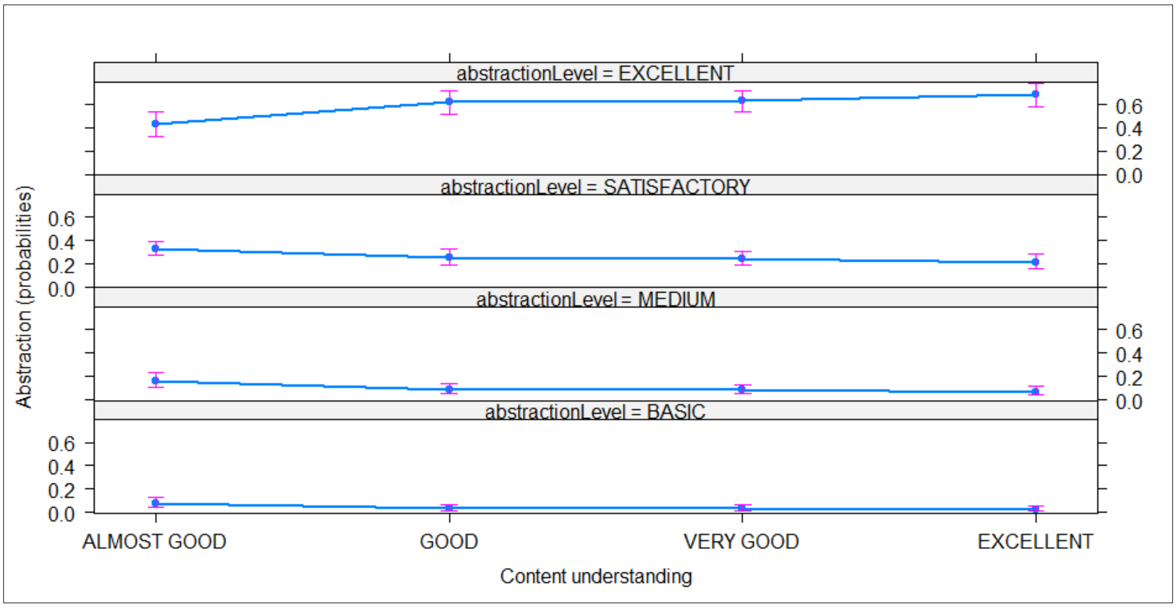

Figure 24. Predicting the probability of new data being placed at each one of the levels of abstraction skills, in dependence on the understanding of the course content

DISCUSSION AND PERSPECTIVES

Assessment is an important element of learning and pedagogy. It is necessary for evaluating students, teachers and educational policies. Our work focuses on evaluating skills related to the core aspects of CT in early primary school amid Environmental Study. We propose a relevant assessment tool, aiming to support the evaluation of CT competencies and, thus, to add to the field of CT development. The proposed tool not only detects the levels of CT skills of young students, but can also be used to facilitate the assessment of the effectiveness of related teaching interventions. It also contributes to the design of targeted teaching interventions for the cultivation of CT.

Furthermore, our study of investigating the potential correlation between fundamental CT skills, such as abstraction, and the content understanding of the Environmental Study course supports the contemporary social and educational demand of cultivating 21st century skills in compulsory education, even from the early years (Ardoin & Bowers, 2020; Kanaki & Kalogiannakis, 2019). Verifying this synergy facilitates the design of pertinent educational policies and the construction of pertinent educational activities, reinforces the concurrent development of the above-mentioned skills and provides a sturdy base for forthcoming studies that will stimulate the design of CT activities with ecological orientation. The innovative nature of our research study stems from the fact that there is no recorded study to investigate the correlation between fundamental CT competencies of first graders, such as abstraction skills, with their performance in the Environmental Study course. Moreover, the majority of pertinent surveys focus on older children (Alsancak, 2020; Kanaki et al., 2020), resulting in the under-exploration of the sensitive first school years.

It is worth mentioning that, trying to ameliorate the impact of the proposed assessment tool on students and teachers, we implemented PhysGramming to run not only on personal computers, but also on smart mobile devices (Kanaki, & Kalogiannakis, 2018). Although we have already tested the proposed assessment tool employing mobile technologies (Kanaki et al., 2022), we plan to further investigate the potential upgraded acceptance of the assessment tool when smart mobile devices take the place of personal computers.

CONCLUSIONS

In conclusion, in this paper, we reemphasize that a basic requirement for the effective cultivation of 21st century skills in K-12 is the construction of assessment tools that are developmentally appropriate for the target groups. Answering the research questions that drive this paper is of great importance to the field of developing CT as a set of skills, practices and concepts, which are relevant not only in studying computer science, but also in tackling multifarious problems computationally (Grizioti & Kynigos, 2021). Since it is of global interest to gear the upcoming generations up for the multifaceted active world problems (United Nations, 2018), it is vital to investigate how students may cultivate and utilize effectively CT competencies to grasp the concepts of contemporary social issues, argue about them and respond to their attendant challenges (Grizioti & Kynigos, 2021).

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THE IMPACT OF UNDERGRADUATE STUDENTS' ACADEMIC EXPERIENCE ON THEIR MOTIVATION TO LEARN CHEMISTRY AND PHYSICS

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This study aimed at investigating the impact of students' academic experience on their motivation to learn chemistry and physics in combination with the influencing factor related to students' academic major. A clustered sampling was used to select 281 participants who were undergraduate students attending three different academic majors (Environmental Technology, Conservation of Cultural Heritage, Food Technology) at a Greek tertiary education institution. Statistical analyses showed that students' motivation to learn chemistry and physics depends strongly on their academic major. Mediation analysis provided strong evidence that the influence of the academic major on motivation is mediated by the students' experience from the attendance of physics and chemistry courses both at secondary and tertiary education. The most recent academic experience was shown to exert a significantly more intense effect in shaping students' motivation to learn chemistry and physics relative to the one from the more distant past.

Keywords: Motivation, Higher Education, Quantitative methods

INTRODUCTION

The role of motivation in science learning is considered crucial by science educators (Koballa & Glynn, 2007) and the influence of several factors on students' motivation to learn various science disciplines (e.g., age, gender, school factors, parental support) is a field of active investigation (e.g., Britner & Pajares, 2006; Pintrich, 2003; Salta & Koulougliotis, 2015, 2020; Vedder-Weiss & Fortus, 2013). In an earlier study (Salta & Koulougliotis, 2020), undergraduate students' motivation to learn chemistry and physics were found to strongly depend on their academic major. Considering the role of several school factors, which establish a unique experience for each student, in influencing students' motivation, this study is an investigation of possible relations of students' motivation with their perceptions about academic experience. More specifically, the aim of this study is the statistical testing of the hypothesis that students' perceptions about their academic experience in both high-school and university science (physics and chemistry) courses could mediate the effect of academic major on students' motivation to learn chemistry or physics.

THEORETICAL BACKGROUND

The theoretical background of our studies is the social-cognitive theory developed by Bandura (2001) and extended by others (e.g., Pintrich, 2003). Within this theoretical perspective, motivation is defined as "an internal state that arouses, directs, and sustains science-learning behavior" (Glynn et al., 2011, p. 1160), and is conceptualized as a multidimensional construct.

Several motivational constructs associated with science learning, such as self-efficacy, self-determination, intrinsic motivation, career motivation and grade motivation, have been identified, thoroughly studied, and reviewed (Bryan et al., 2011; Glynn et al., 2011; Koballa & Glynn, 2007; Pintrich, 2003). Self-efficacy (SE) refers to students' beliefs with regard to their ability to do well in science tasks; self-determination (SD) is students' beliefs with regard to the control they have over their learning science; intrinsic motivation (IM) refers to the inherent satisfaction derived from learning science; and extrinsic motivation, which may be delineated to career motivation (CM) which refers to students' expectations for a science related career and grade motivation (GM) which is related to students' goals for high academic performance (Glynn et al., 2011; Koballa & Glynn, 2007; Pintrich, 2003).

Social cognitive perspectives also propose that students form their motivational beliefs by interpreting experience from their school environment, which includes, among others, the influence of the teacher, the school's specific goals, purposes and values, and students' perceptions of them (e.g., Britner & Pajares, 2006; Vedder-Weiss & Fortus, 2013). In this respect, there is a need for a deeper understanding of the role of students' academic experience on their motivation to learn various science-related subjects (Ardura et al., 2021; Pintrich, 2003).

METHOD

Participants

The participants in the current study were 281 full-time undergraduate students drawn from three different academic departments of a small-sized regional tertiary education institution (TEI) located in Western Greece, offering Bachelors' degrees in the following academic majors: Environmental Technology (ET, N=95), Conservation of Cultural Heritage (CCH, N=93) and Food Technology (FT, N=93).

Measures

Motivation to learn physics and chemistry: Students' motivation to learn physics and chemistry was measured by the Greek version (Salta & Koulougliotis, 2015) of the discipline-specific original instrument known as SMQ II (Glynn et al., 2011). The reliabilities (internal consistencies) of all scales, assessed by Cronbach's α, have values larger than 0.81, indicating a good overall reliability according to DeVellis (2003).

Experience from the attendance of physics and chemistry courses: Students reported their experiences from i) the textbook, ii) the teacher, iii) the laboratory and iv) the course in total, with 4 items referring to high school and 4 referring to TEI experience for each discipline course (physics or chemistry), using a Likert-type scale ranging from 1 (very negative) to 4 (very positive). Therefore, a total of sixteen experience items was made up.

A principal components exploratory factor analysis was independently conducted on each set of 8 items (one for the physics and one for the chemistry course) with varimax rotation in order to examine the number of dimensions existing among the items-variables related to each discipline course. Each analysis resulted in two factors with eigenvalues over Kaiser's criterion of 1 for each discipline course. These two factors, in combination, explained 66.23% and 68.19% of the variance for the chemistry and physics course, respectively. (Table 1) The items that cluster on the same factor suggest that factor 1 represents experience from high school courses while factor 2 represents experience from TEI course. The experiences from TEI physics, high school physics, TEI chemistry and high school chemistry courses all had high reliabilities; all Cronbach's α have values larger than 0.81, indicating a good overall reliability according to DeVellis (2003).

TABLE 1: Exploratory factor analysis for students' experiences

Items	**Rotated factor loadings**	
How would you characterize your experience …	Experience from TEI physics courses	Experience from high school physics courses
… from the TEI physics labs?	**.826**	.116
… from TEI physics courses overall?	**.819**	.178
… from the teachers who taught you physics at TEI?	**.792**	.190
… with TEI physics textbooks?	**.791**	.211
… high school physics courses overall?	.206	**.835**
… from the teachers who taught you physics at high school?	.053	**.834**
… with high school physics textbooks?	.256	**.780**
… from the high school physics labs?	.201	**.756**
Eigenvalues (Variance)	3.854 (48.179)	1.601 (20.006)
Cronbach's α	.845	.838
How would you characterize your experience …	Experience from high school chemistry courses	Experience from T.E.I. chemistry courses
… from high school chemistry courses overall?	**.856**	.178
… from the teachers who taught you chemistry at high school?	**.805**	.041
… with high school chemistry textbooks?	**.799**	.175
… from the high school chemistry labs?	**.780**	.099
… from the teachers who taught you chemistry at TEI?	.017	**.834**
… from TEI chemistry courses overall?	.237	**.827**
… from the TEI chemistry labs?	.103	**.775**
… with TEI chemistry textbooks?	.135	**.729**
Eigenvalues (Variance)	3.443 (43.039)	1.855 (23.186)
Cronbach's α	.836	.813

Note: Factor loadings over .40 appear in bold

RESULTS

Paired-samples t-tests showed that the mean score for students' experience from high school was lower than their experience from TEI for both physics and chemistry courses. Moreover, students reported more positive experience from the attendance of chemistry relative to physics courses in either high school or TEI. The earlier study conducted on the same sample (Salta & Koulougliotis, 2020) had showed that students majoring in CCH are differentiated from those in the other two majors by possessing lower motivational scores in all five measured motivational scales which were related to physics learning (namely IM. SE, SD, CM and GM) and three scales (namely IM, SE and GM) related to chemistry learning. That study had also showed that students majoring in FT are differentiated from those of the other two majors by exhibiting higher motivation in the scales of CM and SD related to chemistry learning. Our hypothesis that students' experience could be mediating the effect of the academic major on their motivation to learn either chemistry or physics was tested via the use of the PROCESS variable path analysis modeling tool of SPSS (Hayes, 2013). In this analysis, the antecedent variable X (academic major) is modeled as influencing the consequent variable Y (motivation to learn chemistry or physics) directly as well as indirectly through the following two mediators: students' experience from high school physics or chemistry courses (mediator M_1) and students' experience from TEI physics or chemistry courses (mediator M_2). The conceptual diagram of this model is shown in Figure 1. Statistical inference for estimating the difference of the evaluated statistical coefficients from a zero value is conducted via examination of *p*-values (for the coefficient c' of the direct effect) and via bootstrap confidence intervals (for coefficients a_1b_1, a_2b_2 and $a_1b_1+a_2b_2$ of the specific and total indirect effects) at the 95% confidence level.

The analysis showed a statistically significant direct effect of the academic major on eight (out of 10 in total) motivational components concerning chemistry and physics learning (all five related with chemistry and three related with physics namely IM, SE and GM). In addition, the total indirect effect of the academic major on motivation (combination of M_1 and M_2), is statistically significant for all 10 motivational components. An examination of the specific indirect effects shows that the one concerning the experience from high school courses (mediator M_1) is statistically significant for six (out of 10 in total) motivational components (physics and chemistry IM, SE and GM), while the one concerning the experience from TEI courses (mediator M_2) is statistically significant for all 10 motivational components. It is thus deduced that experience from high school and TEI courses collectively mediate the effect of the academic major on students' intrinsic motivation, self-efficacy, and grade motivation to learn physics and chemistry. On the other hand, the effect of the academic major on students' self-determination and career motivation (for both physics and chemistry) is mediated solely by the experience from TEI courses.

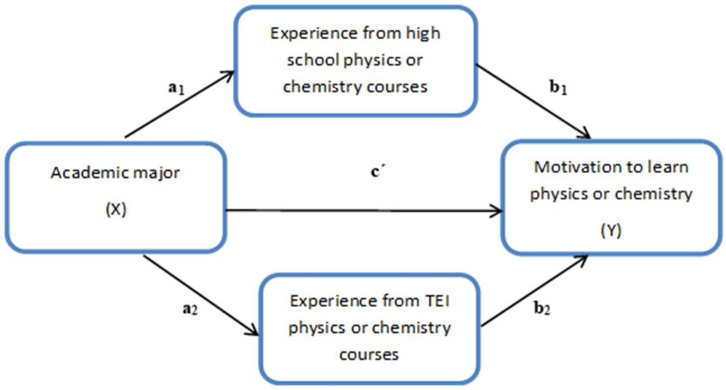

Figure 1. The conceptual diagram of the parallel multiple mediator model with two mediators.

CONCLUSIONS

The current study provided strong evidence that the previously documented domain specificity of motivation – exhibited via an increased motivation for chemistry vs physics learning (Salta & Koulougliotis, 2020) – was accompanied by a similar domain specificity of students' experiences as well. Thus, the undergraduate students report more positive experiences from the attendance of chemistry-related (vs physics-related) courses both in secondary as well as in tertiary education. This trend was stronger in the more recent (i.e., from TEI) relative to the more distant (i.e. from high school) experiences. The domain specificity of motivation depends not only on the specific motivational construct but on the academic major of the students as well (Salta & Koulougliotis, 2020). In fact, pursuing studies in an academic major is related to a distinct set of academic characteristics related with the curriculum content and often with the corresponding student. More specifically, the curricula of all three majors include courses which are related with both physics and chemistry but to a different extent. Thus, the majors CCH and FT contain more courses related to chemistry relative to physics with the ratio of chemistry-related vs physics-related ECTS units being ca. 2.4 and 3.8 for CCH and FT, respectively. In contrast, the curriculum of the ET major is almost equilibrated between chemistry and physics-related courses with the latter being slightly more by ca. 15%. In addition, similarly to the motivation measurements, the domain specificity of students' experiences was shown to be differentiated among the three academic majors as well, with it being more intense among the students of the CCH majors. Thus, CCH majors report more positive experiences in chemistry (vs physics) courses both in TEI and in high school, while the FT and ET majors report statistically similar high school experiences between the two courses and more positive TEI experiences in chemistry relative to physics.

Our hypothesis that the relationship between students' academic major and their motivation to learn either chemistry or physics is mediated by their experiences was confirmed. Taking into account that school influence on students' motivation is multidimensional and involves, among others, social and instructional dimensions (Wigfield et al., 2015), the tested factor has been the experiences of the students from the attendance of chemistry and physics-related courses either in high school or during their studies at TEI. This finding provides evidence that that the measured students' motivations for chemistry and physics learning are not simply a result of the differential student composition in each major. In addition, the documented more intense mediation effect of the most recent experience (TEI vs high school courses), supports the notion that, irrespective of the students' background, the provision of higher quality academic experiences in the present time could enhance their motivation for chemistry and physics learning.

The main limitation of the present study is related to the fact that the inference of the results is based solely on quantitative self-report data. However, its findings may provide the basis for continuing research in the field of motivation to learn science. The observed difference between undergraduate students' motivation to learn chemistry and physics and its connection with students' experiences from the attendance of the respective courses could be tested among students in different age groups starting from lower secondary school preferably in a study that follows a longitudinal research design. Examination of the temporal evolution of the domain specificity of motivation and its influencing factors would provide new knowledge useful to researchers, education practitioners and educational policy makers.

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ANALYSIS OF TEACHER'S WRITTEN FEEDBACK IN BIOLOGY INQUIRY TASK WITH STRESS ON AFFECTIVE CONNOTATIONS

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This article focuses on the analysis of written feedback provided by teachers on the student's solution to a human biology inquiry task during distance teaching in Covid-19 lockdown. The analysis monitored whether the written feedback was formative, contained affective connotations, and an explanation of the evaluation criteria. In total, four classes of students (N = 60) and four teachers from three selected schools participated in this study. Teachers' feedback was analyzed using the coding tool developed and verified within the ASSIST-ME project. The analysis showed that the teachers tried to make their comments formative, explained the evaluation criteria repeatedly to the students, and justified why the student's solution is incorrect. The affective connotations were rather exceptional in the feedback provided. Teachers stated that it was difficult to write a comment that was easy to understand for the students and that they would prefer to provide oral feedback where they could clarify everything with the students immediately. Teachers who provided feedback that contained affective connotations also added that they would like to motivate students with these positive comments.

Keywords: formative assessment, emotion, feedback

THEORETICAL BACKGROUND

Assessment and Formative Feedback

Assessment is a key competency of a teacher, and the importance of formative assessment has increased step by step since the end of the twentieth century (Black & Wiliam, 1998). Especially in light of the situation associated with distance teaching, it is often necessary to use continuous assessment of student performance and provide them with adequate feedback. The level and processing of the feedback provided are a key aspect for the further development of the student's learning. Teachers are encouraged to provide formative feedback to students, but the question is whether this feedback really carries aspects of formative assessment. It means that it gives students guidance on how to continue their learning in order to achieve the set goals and eliminate the identified imperfections. Appropriate formative feedback allows students to focus on learning difficulties and thus facilitate their future correction (Wiliam & Leahy, 2015).

Feedback is not in itself a formative assessment, and for which it is often mistaken for confusion. The aim of feedback as a basis for formative assessment is to overcome the gap between the current level of student knowledge or skills and the level that the teacher has set as a desirable goal (Hattie & Timperley, 2007). Feedback provides teachers with information that helps guide their further teaching. Students receive information on how their previous learning is progressing (Nicol & Mcfarlane-Dick, 2006).

The effectiveness of feedback is influenced by a number of factors, such as the student's learning style, the teacher's person, the classroom climate, the teaching methods and forms used, as well as the student's language level and knowledge and skills (Evans et al., 2016). In order to be able to use formative assessment effectively in teaching, the teacher must have a clear idea of why he / she uses this assessment and what its main purpose is. The teacher's actions in a given situation depend not only on his pedagogical and professional knowledge (Magnusson, Krajcik, & Borko, 1999) but also on the specific situation that occurred during teaching (Cross & Lepareur, 2015).

Emotions and Affective Connotations

The role of emotions in assessment and feedback is less explored than the cognitive and motivational components, although affective connotations could be a crucial part of feedback because they can affect the way students use this feedback (Rowe, 2017). If students feel negative emotions from the feedback of the assessor, there could be a higher rejection rate of the offered help (Ryan & Henderson, 2018). In contrast, the feeling of positive emotions leads to a sense of success and can also lead to greater student effort in other tasks.

Research has identified several emotions that can affect the learning process, such as joy, hope, pride, anger, anxiety, shame, hopelessness, boredom, or interest (Rowe, Fitness & Wood, 2015; White, 2013). Furthermore, positive emotions have been shown to generally improve learning and achievement, especially in the areas of metacognition, focus on performance, or motivation (Pekrun & Stephens, 2010). Negative emotions, while in many cases impairing motivation and performance, can also be beneficial (Pekrun & Stephens, 2010). Psychological research shows that different words can trigger specific emotional responses (Abbasi et al., 2015) and that emotions and language expressions are strongly linked (Lindquist et al., 2015). When communicating, nonverbal channels can be used to emphasize emotions, facial expressions, postures, or body language (Niedenthal et al., 2003), which can be used to provide oral feedback. However, in written feedback, care must be taken with abstract words that tend to have more emotional characteristics than specific words (Meteyard et al., 2012). Talmi (2013) presents the connection between remembering a given moment and its emotional aspect. Huntsinger (2013) adds that attention can be increased by positive emotions, such as happiness, but reduced by a feeling of anxiety.

METHODOLOGY

The presented study is part of larger project (reg. No. TL02000368) aimed at promoting the use of formative assessment in inquiry-based teaching of science and mathematics. This research was carried out during the first wave of covid-19 lockdown in the Czech Republic (in spring 2020), when the way of teaching had changed from face-to-face teaching to distance teaching and the evaluation of student results was shifted to the level of written feedback mainly.

The study focuses on the following research questions:

1) To what extent does the feedback provided contain formative aspects?

2) To what extent do teachers use subjective sentences and emotional expressions in the feedback provided?

3) How does the feedback from an individual teacher differ?

Data Collection and Sample

Students solved the human biology inquiry task and carried out their own experiment. In total, 4 eighth grader classes from 3 selected schools (N = 60) and 4 teachers participated in this study (they will be more characterized in the results). As mentioned, the study took place during distance learning in spring 2020, and students completed a protocol related to the inquiry task, teachers provided them with structured written feedback on their performance.

The study also included semi-structured interviews with the four teachers, in which they reviewed the assessment process and discussed the quality of the student's protocols, provided feedback, but also described how the students received their feedback and subsequently used it to resubmit their protocols. The duration of the interview ranged from 30 to 50 minutes and was preceded by obtaining oral consent to record their responses to the recorder and their use in the research study.

Data Analysis

Teacher feedback was analyzed with a coding tool that was developed and validated within the ASSIST-ME project (Tab. I; Constantinou & Papadouris, 2016). The tool evaluated the following dimensions of feedback: emotional side, completeness and weight of comments from the teacher, dependence on the specified criteria, justification of the given comments, and level of guidance for the next steps in the learning process of the students.

Table 1. Illustrative examples from the coding tool (Constantinou & Papadouris, 2016).

<table>
<tr><td colspan="5">To what extent does the feedback carry connotations related to affective aspects? Specify the frequency of statements (e.g., sentences or segments of sentences) within the feedback comments that carry affective connotations.</td></tr>
<tr><td colspan="5">a) instances that were likely to serve as encouraging feedback but were restricted to vague phrases (e.g., excellent/bravo, etc.).</td></tr>
<tr><td colspan="5">b) instances that were likely to serve as encouraging feedback by explicitly identifying (and providing credit for) what the student has achieved</td></tr>
<tr><td colspan="5">c) instances that were likely to serve as discouraging feedback and were formulated in a vague manner (e.g., you have not put much effort, this is substandard, this was not a good response, etc.).</td></tr>
<tr><td colspan="5">d) instances that were likely to serve as discouraging feedback and were formulated in a specific manner that identifies what the student has failed to do.</td></tr>
<tr><td colspan="5">Overall, what is the likely affective impact of the feedback comments on the student taking into consideration other data sources, e.g., post-instructional interviews, observations? Select the level of the Likert scale that you deem more appropriate.</td></tr>
<tr><td>1
It is likely to have a very negative impact</td><td>2
It is likely to have a rather negative impact</td><td>3
Neutral
(any affective impact)</td><td>4
It is likely to have a rather positive impact</td><td>5
It is likely to have a very positive impact</td></tr>
</table>

The audio recordings taken from the interviews were transcribed into a text editor. Two researchers then independently identified interesting and important statements in the interviews (one of the coders was not involved in the research, so his view could not be affected). Their selections were compared, and after the discussion, the most important messages were included in the analysis.

RESULTS

The results will be presented in relation to individual research questions.

RQ1: To what extent does the provided feedback contain formative aspects?

Teachers in depth (84.6 %) or carefully (10.4%) related their assessment to set criteria for evaluation of student work. They mostly mentioned that students should correct or add more information to their protocols to better achieve the goal. In 64.4 % of the cases, the items contained such advice, in 25.4 % of the remaining items the protocol was correct, and therefore there was no need to provide the advice. However, it was very interesting how the teacher gave this advice. In some cases, the teacher directly wrote what should be corrected or added, so it can be said that this feedback was not very formative because the student only followed the instructions from the teacher and wrote the information in his / her protocol. In other cases, the teacher tried to guide the students to the new solution through instructional questions or statements that lead the students to a new solution. This way could be seen as the formative one.

At the same time, it was investigated on which other aspects teachers focused their assessment. Most often (63.4 %) they mentioned the level of the detail of information in the student's protocols (the need to expand, supplement, etc.). Furthermore, they focused their comments on the correct description of the procedure or the use of the correct terms (23.8 %). They were less focused on the text quality in terms of grammar (8.7 %) and product-related aspects, e.g., graph size, text structure, and way of recording data (4.4 %).

RQ2: To what extent do teachers use subjective sentences and emotional expressions in the feedback provided?

In total, 82 subjective statements appeared in all feedbacks analyzed (N = 480). Affective connotations were found in 77 cases. 42.1 % of these statements represented the feedback which supported and accurately described and highlighted what the students had already achieved. 26.3 % of the statements were vague phrases such as 'excellent', 'bravo', etc. Affective connotations with negative meaning were found in 25 cases (5.2 %). 13 of them were again vague phrases (e.g., 'you slacked it off', 'this is not correct', etc.) and 12 gave information where the students made a mistake only.

The impact of teacher's comments on students was neutral in most cases (68.8%), 13.3% of the comments were rather positive and 8.8 % were very positive. There were only four comments with a very negative estimated impact and 8.3% of the comments with a rather negative impact.

RQ3: How does the feedback from an individual teacher differ?

Teacher A has 13 years of experience and is also familiar with formative assessment. She participated in several projects that focused on the use of formative assessment, namely, the use of written feedback and peer assessment. She tries to use formative assessment in her teaching often, most often in oral form. She creates various materials and plans when and in what contexts she will use formative assessment, e.g., self-assessment or peer-assessment. However, she adds that she most often performs on-the-fly assessments. She most often used subjective sentences (46.7 %) and 25.8 % of all comments included affective connotations. Therefore, the feedback was very personal, and it also contains emotional charges.

Teacher B has 1.5 years of experience and is therefore a beginning teacher. She does not have much experience with formative assessment, she knows all the information from her training at the university. She states that she is trying to incorporate formative assessment, but for the beginner, it is relatively difficult for now because she has to focus on many other aspects related to teaching. She finds it easier to use the on-the-fly assessment, so she tries to incorporate it into her teaching. She also adds that the information gained from the students helps her better plan the next lessons. Teacher B used subjective sentences in 21.9 % of cases and in almost a third of all comments, this teacher wrote affective connotations (31.3 %).

Teacher C has 21 years of experience; we can call her an experienced teacher. She encountered formative assessment in the context of professional development courses, but personally this approach did not interest her much. She states that she is used to providing support in her style, which she is not going to change. She believes that she simply provides the necessary information to the students in her comments. Teacher C used subjective sentences very rarely (2.7 %), but there were emotional-themed statements in 15.2 % of the comments, which, unlike previous teachers, were mostly negative.

Teacher D has 4 years of experience and can also be described as a beginning teacher. She met with a formative assessment while studying at the university. Her bachelor and diploma theses dealt with this issue. Even as a beginning teacher, she tries to use as much formative assessment as possible, creates various materials, and searches for other resources. Teacher D barely used even subjective sentences (1.3 %) or affective connotations (0.7 %).

The character of the statements provided by the individual teachers is summarized in Figure 1.

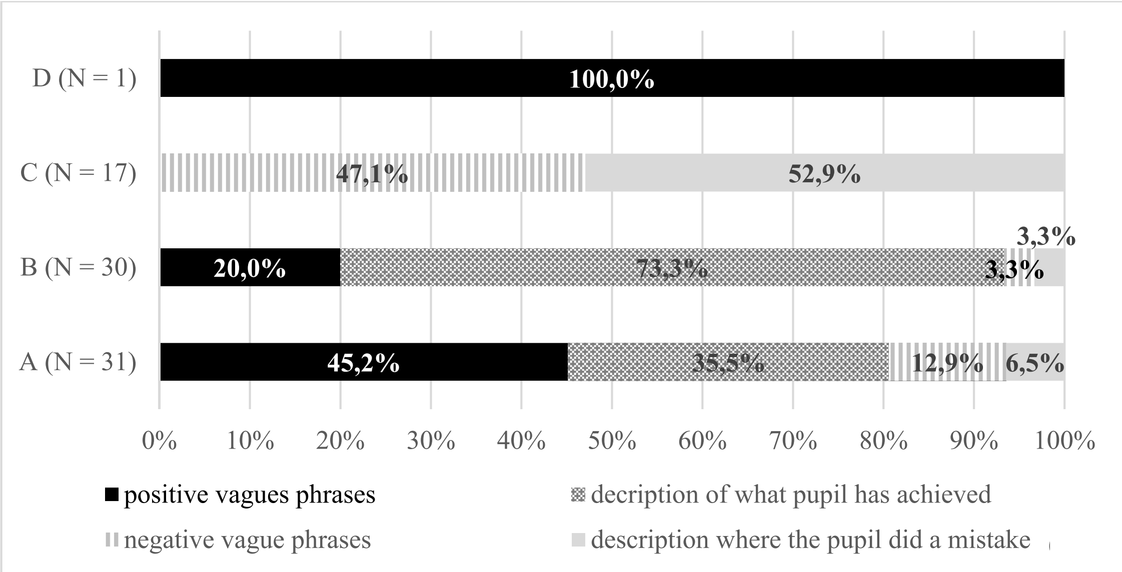

Figure 1. The character of affective connotations of the individual teacher.

The aspects on which the teachers focused their feedback were also identified. As can be seen in Figure 2, the teachers focused mainly on the level of detail provided. Teacher A also very often evaluated the visual aspect in a positive way. She praised the students for how they presented the results of the experiment, how they recorded the data, etc. Teacher C also focused on the visual aspect, but she looked for errors. She criticized the arrangement of the protocol. Teacher C also focused on the quality of the text, blaming students for grammatical errors or missing commas in sentences in the procedure description. In two cases, teacher D warned the student to read the text and correct some of the grammatical errors, but without the intention of harming them. Teacher B focused explicitly on content related to the field of human biology and did not care about grammar or visual aspects of the protocol.

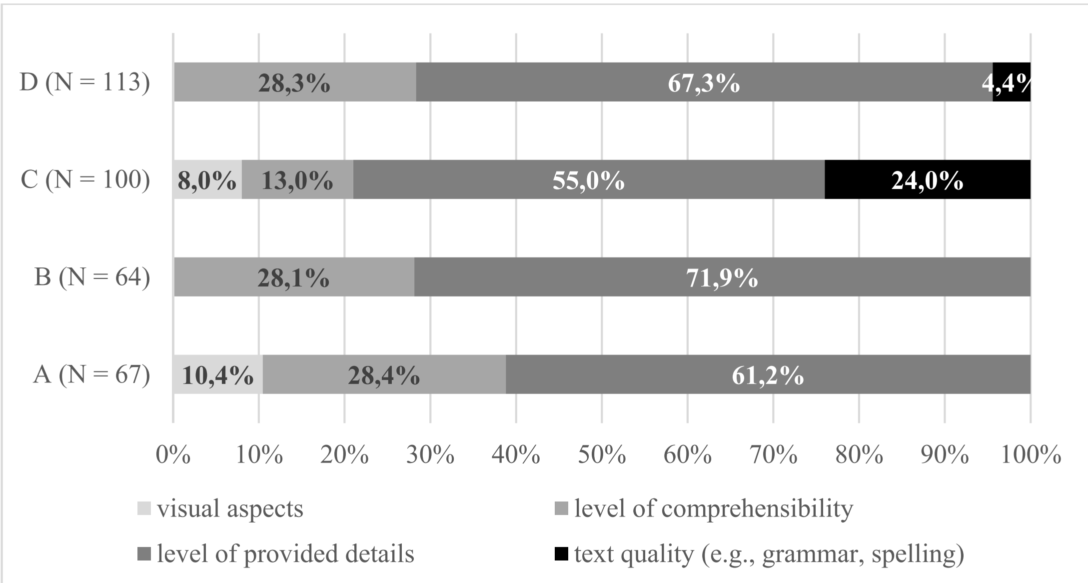

Figure 2. Aspects mentioned in teachers' feedback.

For individual comments, the presumable emotional impact of the feedback provided on the student was also estimated (Fig. 3). Of course, in this sense, these are rather illustrative conclusions which, however, were discussed with teachers in the interviews.

Most of the comments were written in such a way as to have a neutral impact on the students. As teachers A and B subsequently explained in the interviews, they tried to motivate the students with positive feedback, which could have an encouraging effect (e.g., *I like that you specifically describe the process of breathing and specify how breathing should take place).* The analysis showed that they tried not only to praise the students who had the protocol in order, but also the students who had shortcomings in it (e.g., *You did a piece of work in the protocol, but I recommend to proceed step by step according to the assignment*.). Some comments from Teacher C would have a rather negative impact on the student (e.g., *You have terrible nonsense in that protocol.*; *Is this how you write the results?*). Teacher C added that she always assesses students this way and warns them about mistakes. She sees no reason why she should praise someone for having the protocol in order. According to her, the student will receive a good grade for this. Teacher D mainly tried to use neutral commentary.

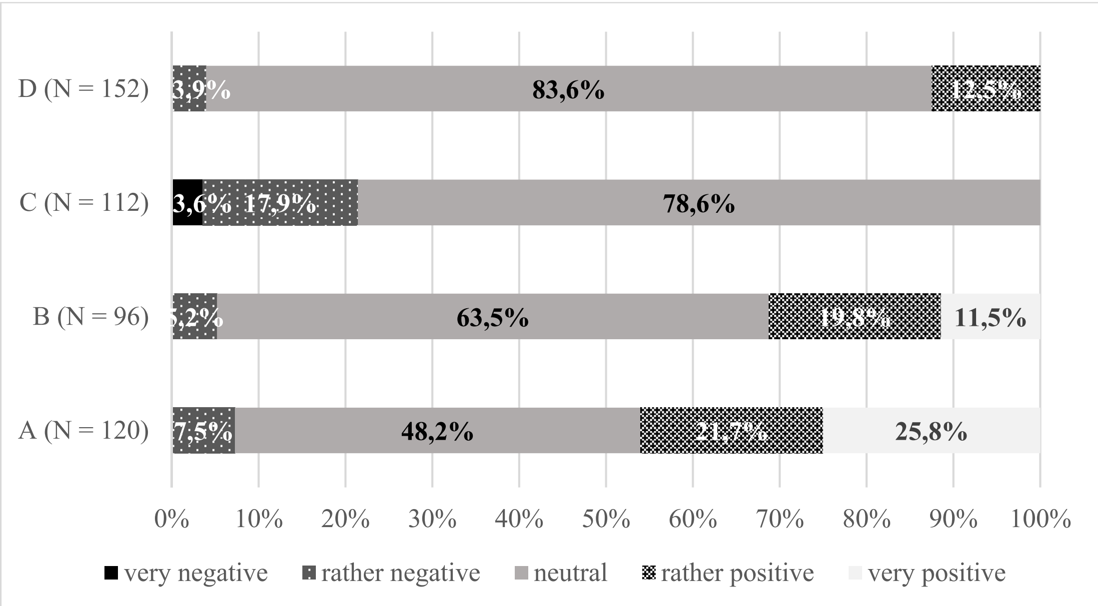

Figure 3. Presumable affective impact of the feedback provided on the student.

DISCUSSION AND CONCLUSION

The analysis of the feedback showed that the teachers tried to make their comments mostly formative. The exception is teacher C, who told the students where they had made mistakes and what to add to the protocol to make it correct. However, this was a mere statement, not a guide on how to do it on their own. Teachers A, B and D repeatedly explained the evaluation criteria to the students, justified why the student's solution was incorrect, and guided them to a different way of dealing with suggestions through stimulating questions. Introducing students to assessment criteria and explaining them are key steps in teaching. It is ideal to explain all the criteria before the activity (Sadler, 2015), which was done here, but emphasizing the criteria in the feedback is also beneficial because individual comments may relate to them.

Two teachers focused on finding out what the students had already achieved and tried to praise them. The affective connotations were rather exceptional in the feedback provided. To a greater extent, these connotations were rather vague formulations, especially of positive meaning, which were supposed to have a motivating effect on the students.

Assessment is deeply personal and can create strong feelings in the assessed individual (Crossman, 2007), but there is still little evidence of how emotions affect the way students are able to receive feedback and then work with it (Dowden et al., 2013, Rowe et al., 2014). Unfortunately, due to distance learning, we do not have exact data on how students responded to feedback. From the teachers' answers, it was only possible to assume how the students worked with the feedback, but the relevance of this information was also influenced by the distance form of teaching.

Even negative emotions can lead a student to talk to the teacher, which in the case of a constructive discussion can help the student to understand his own mistakes (Nicol et al., 2014). However, it must be acknowledged that affective connotations can lead to a strong subjectivity of such an assessment. The subjectivity of the assessment has often been seen as an obstacle, while in formative assessment it can be a tool that reflects personal needs, identities, interests, or attitudes. And emotions in that case can give such feedback the right charge. For example, Gates (2016) supports the use of subjective evaluation in creative areas of human activity, for example, in art education. However, more scientific evidence is needed to determine the precise mechanisms of the processes involved and contribute to the development of new frameworks that better explain the relationship of emotions to the cognitive, motivational, neurological, and social dimensions of feedback and assessment. (Rowe, 2017, p. 169)

Reflections from teachers themselves have shown that it is generally difficult for them to write a comment to make sure that students understand it. In this case, the teachers preferred to provide oral feedback, where they could explain everything to students immediately. On the other hand, teachers A and B added that they tried more to assess subjectively and give at least some emotions in the feedback, because they realized that distance learning is very difficult for students. And they felt the need to work better with their mistakes, to explain everything to them more, but most of all to encourage them to continue working.

It is certainly not possible to generalize the results, as the data were obtained at a specific time and on a small sample of respondents, but the following study could focus on, for example, how students receive feedback with and without affective connotations.

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RISK PERCEPTION CONCERNING COVID-19 PANDEMIC, GLOBAL WARMING AND FOOD AND NUTRITION SECURITY BY PRESERVICE SCIENCE TEACHERS

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Manufactured risks, generated by scientific and technological progress, are increasingly present in modern social life. Dealing with those risks require the ability to understand complex contexts and make decisions based on judgments. To understand risk perception among students a survey was developed and applied using the Amplified Risk Perception (ARP) theory based on three different manufactured risks: Global Warming, COVID-19 Pandemic and Food and Nutrition Security. The students were asked to answer the survey before and after the course and to develop a Teaching and Learning Sequence (TLS) about one of these three themes. Preliminary results shows that pre and post-tests had statistically significant differences between each other, resulting in an increased risk perception. Both the course and the TLS' development were significant to increase risk perception as well as the ARP's diagram, which made possible to create an assessment tool to evaluate teaching-learning situations.

Keywords: Socioscientific Issues; Diagnostic Tools; Scientific Literacy

INTRODUCTION

The pandemic caused by SArs-CoV-2 virus is spread all over the word. After more than two years, people are still fearing death and lacking the ability to deal with uncertainties that came in simple tasks of daily life. A diffuse feeling of insecurity pervades people's minds when they need to face risky situations, i.e., problems with no clear boundaries that are involved in unpredictable consequences. Otherwise, science was seen as a source of certainty that humankind has used to overcome fear and feeling of insecurity. Notwithstanding the benefits developed by science and technology all over the last 300-hundred-year, people feel more vulnerable and exposed to more risks (Douglas 1994).

Nowadays, risk situations are characteristic of today's industrial society and it emerges from complex situations, where many dimensions of social life like health, economy, science, and others are combined. (Beck et al. 2013). For Ulrich Beck (1992), we are living in a Risk Society, characterized as an age of Reflexive Modernity (Beck, Giddens and Lash 1994). In this kind of Modernity, central concerns of society have changed from developing and implementing recent technologies to managing risks associated with already existing technologies. In Risk Society, it is possible to distinguish between two types of risks: *external* – generated from outside of modern social life – and *manufactured* – generated by progress of humankind social and technological development. The external risks are more accessible and easier to be evaluated with basic knowledge and scientific support. But manufactured risks are normally hidden behind the complexity of Contemporary problems, as for example in the case of Covid-2019 pandemic. Search solutions in this scenario of Risk Society and complex problems require to be prepared to deal with dilemmas: health x economy, or safety and earning money. Kolstø (2001), as expatiates on socioscientific dilemmas, shows that students question risk assessment sources and their trusty relation on scientist intentions. In the Risk Society, trust does not arise from precision and authority. Instead, it comes from the ability to perceive multidimensionality in different contexts and producing adjusts on the go (Christensen 2009). Christensen reinforces the relevance of themes related to risk situations in school training for citizenship as it can take off from science the full ability to explain, predict and control all kinds of problems.

With this investigation, we aim to understand how manufactured risk may be an educational issue for science education. Specifically, we would like to develop teaching and learning sequences (TLS) to prepare students to perceive manufactured risk associated with Contemporary problems. Also, we may want to develop a tool to evaluate risk perception to be used in science classes/courses.

RATIONALE

Christensen (2009) argues that students' analysis is weakly grounded in their science knowledge or their understanding about the problem in place when they make risk assessment. The perception about risk is important in its management. It presumes to be able to discriminate distinct aspects presented in the situations, to evaluate consequences using reliable sources, and make a decision based on judgment. Simplistic causal relations, readily taking few available elements in the account must be avoided (Hansen and Hammann 2017). Thus, we adopt the diagram of amplified risk perception (ARP) (Pietrocola at. al, 2020), shown in Figure 1, to follow the way people's perception about manufactured risk may evolve. The ARP is a three-dimensional risk perception space indicating a group's ability to perceive risks related to a particular situation. *Access* is associated with rational thinking supported by scientific cognition. *Urgency* defines a hierarchy of risk connected with values and practices in each culture. *Range* relates to the ability to make impact assessments either in a close or far perspective. This three-dimensional risk perception space indicates one's (or group's) ability to perceive risks related to a particular situation.

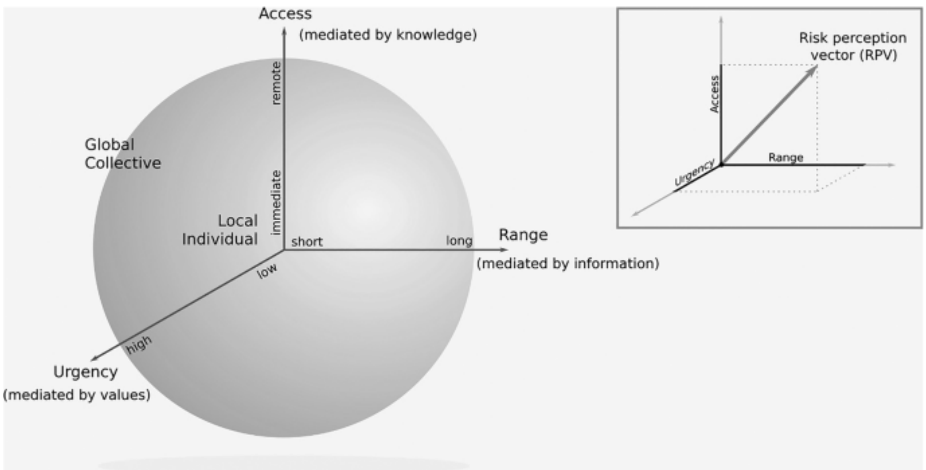

Figure 1. The Amplified Risk Perception (ARP) diagram.

In a course dedicated to prepare Pedagogical interventions in science classes, pre-service science teachers prepare Teaching and Learning Sequences (TLS) about the themes: (i) Global warming (GW), (ii) Covid-19 Pandemic 2019 (PCOV) and (iii) Food and Nutrition Security (FNS). They all three are defined as a manufactured risk (Giddens, 1990), and representing risk situations faced in the present moment (PCOV), immediate past (GW), and in immediate future (FNS). During the course, students were asked to read articles about risk perception and management, to choose a risk situation related to one of the three main themes and to make their own risk management's matrix, based on their appropriation of the subject. Later, each student chose one of the 3 themes to develop a TLS for science classes at High School level. In groups of 10 to 12 they were able to discuss which subjects were more significant to their TLS.

RESULTS

In this first analysis, we used the ARP diagram to identify and locate students within the Access, Range and Urgency axes through the risk perception survey. To calculate these indexes, we considered the simple average responses, according to the degree of agreement. Figure 2 shows the distribution in both pre and post-tests.

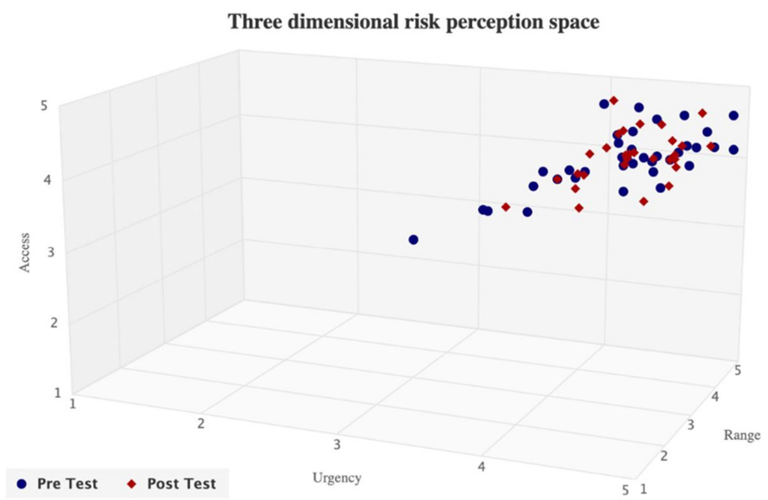

Figure 2. Students' distributions according to the ARP diagram.

Visually, we were able to notice a greater dispersion of students in the parts closer to the axes in the pre-test, compared to the post test result, indicating that there was an increase in the risk perception throughout the course. Additionally, we used the Wilcoxon signed-rank test to determine statistically whether there were significant changes in risk perception, comparing the results before and after the course, using the computer software Jamovi, assuming the hypothesis that the post-test means (M2) are greater than pre-test means (M1), which indicates an increase of risk perception. Table 1 illustrates this data.

Table 1 – Paired Wilcoxon result comparing risk perception before and after the course.

	Pre-test	Post-test				
	Mean (M1)	**Mean (M2)**	**N**	**Statistics**	**p**	**Effect Size**
Urgency[1]	4.26	4.32	29	56.50	0.107	-0.3392
Range[2]	4.05	4.09	29	80.00	**0.040**	-0.4203
Access[3]	4.11	4.18	29	53.50	0.143	-0.3007

1 – 11 pairs of value are tied; 2 – 6 pairs of value are tied; 3 – 12 pairs of value are tied

Note: $H_a\mu_{M1 - M2} < 0$; $H_0\mu_{M1 - M2} = 0$

It was observed there was a meaningful change in all axes of the ARP diagram, with a greater variation in the Range axis. The Effect Size values indicates moderate (between 0.3 and 0.5) change directed to M2 which denotes greater risk perception, assuming there is a notable change between the pre and post-test means. The p-value for the Range axis represents statistical significance (< 0.05) against the null hypothesis and strong evidences that the students had their risk perception affected by the course. Although, the same result was not observed for the Access and Urgency axes.

Individually, each questionnaire had equivalent results, with meaningful p-value and Effect Size in one axis. Tables 2, 3 and 4 show Covid-19 Pandemics, Global Warming and Food and Nutrition Security results, respectively.

Table 2 – Paired Wilcoxon result comparing Covid-19 pandemic's risk perception before and after the course.

	PCOV Pre-test	PCOV Post-test				
	Mean (M1)	**Mean (M2)**	**N**	**Statistics**	**p**	**Effect Size**
Urgency[1]	4.37	4.39	29	36.50	0.473	-0.0641
Range[2]	4.19	4.14	29	83.00	0.789	+0.2206
Access[3]	4.34	4.41	29	02.50	**0.052**	-0.7619

1 – 17 pairs of value are tied; 2 – 13 pairs of value are tied; 3 – 23 pairs of value are tied

Note: $H_a\mu_{M1 - M2} < 0$; $H_0\mu_{M1 - M2} = 0$

Table 3 – Paired Wilcoxon result comparing Global Warming's risk perception before and after the course.

	GW Pre-test	GW Post-test				
	Mean (M1)	**Mean (M2)**	**N**	**Statistics**	**p**	**Effect Size**
Urgency[1]	4.25	4.35	29	09.50	0.066	-0.5778
Range[2]	3.79	3.92	29	00.00	**0.004**	-1.0000
Access[3]	3.87	3.90	29	49.00	0.275	-0.1833

1 – 20 pairs of value are tied; 2 – 14 pairs of value are tied; 3 – 22 pairs of value are tied

Note: $H_a\mu_{M1 - M2} < 0$; $H_0\mu_{M1 - M2} = 0$

Table 4– Paired Wilcoxon result comparing Food and Nutrition Security's risk perception before and after the course.

	FNS Pre-test Mean (M1)	FNS Post-test Mean (M2)	N	Statistics	p	Effect Size
Urgency[1]	4.17	4.22	29	05.00	0.074	-0.6429
Range[2]	4.36	4.50	29	06.00	**0.002**	-0.8857
Access[3]	3.94	3.97	29	14.50	0.100	-0.4727

1 – 22pairs of value are tied; 2 – 15 pairs of value are tied; 3 – 19 pairs of value are tied

Note: $H_a \mu_{M1 - M2} < 0$; $H_0 \mu_{M1 - M2} = 0$

The results show that the increase of risk perception is not homogeneous between the themes either the axes of the ARP diagram. Students' risk perception in the PCOV theme had a meaningful change in the Access axis whereas GW and FNS themes had significant change in the Range axis; which shows that the course improved their knowledge about the COVID-19 Pandemics, whereas expanded their information to Global Warming and Food and Nutrition Security. For the other two axes of the ARP diagram in each theme we cannot assure statistically that the course has affected students' risk perception since there is not significant p-value (>0.05) or have low Effect Size value (below 0.3).

Also, in all three groups, it was observed that students changed their perceptions both in the theme in which they worked, as in the others. It can be noted that the justifications addressed aspects of the discussions held during the course activities. The FNS group showed the greatest increase in risk perception associated with its own theme. But this result was not repeated for the other two themes, since the GW group showed the greatest increase in the risk perception associated with COVID-19 and the increase in perception regarding global warming was not homogeneous between the axes, with GW group showing a greater increase in the axes of access and urgency, but in the axis of range was the FNS group.

CONCLUSION

The results obtained allowed us to conclude that the ARP diagram can be used as an assessment tool in teaching-learning situations. The technique we used to associate dimensions of the diagram with assertions and degrees of agreement allowed us to obtain a semi-quantitative indicator that represents the amplitude of students' risk perception. We were also able to verify that the course had a decisive effect in amplifying students' risk perception, and the production of the TLS allowed them to apprehend complexity of risk situations. Contrary to what common sense might indicate, there was no direct correlation between the topic studied and the increase in the perception of risk about it. Although it is only a preliminary result, risk perception should not be seen as a local skill. In other words, it does not work as in the solution of traditional problems where there is a delimited epistemological profile. The result obtained reinforces the idea that risk situations should be treated as complex problems and it is important to develop global skills of analyses and decision making.

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Part 12 / Strand 12

Cultural, Social and Gender Issues in Science and Technology Education

Strand Chairs: *Lucy Avraamidou & Allison Gonsalves*

Part 12. Cultural, Social and Gender Issues in Science and Technology Education

Equity and diversity issues: Sociocultural, multicultural, bilingual, racial/ethnic, gender equity studies and science education for the special needs.

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EPISTEMIC REFLECTION AS AN EMERGING TEACHING PRACTICE IN CULTURALLY DIVERSE CLASSROOMS

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Nowadays, classrooms are culturally and epistemologically diverse. When teachers confront this diversity, they might enact an exclusionary or inclusive relationship between such epistemologies. This research aims to identify emerging practices when science teachers use the Epistemological Bridge (EB) approach between the epistemology of science and traditional epistemologies. The EB is a didactic process during which teachers engage students in producing learning outputs by establishing an inclusive relationship between the epistemology of science and traditional epistemologies. Three teachers participated in a qualitative study on their practices guided by the EB. Teachers conducted students in explaining phenomena from chemistry and indigenous epistemologies. As a result, the three teachers enacted an 'epistemic reflection' because they addressed with students the nature, structure, and use of each epistemology's ideas, practices, and explanations. This emerging practice is framed into the Nature of Science (NOS) approach. When teachers teach the NOS, they can guide students in deconstructing science and understanding its domain compared to other epistemologies. Additionally, this emerging practice has support in empirical evidence from other studies. For example, some researchers sustain the positive effect of the teaching practice of 'making the rationale of scientific explanations explicit' on the student's explanations.

Keywords: Cultural Diversity, Epistemology, Teaching Practice

INTRODUCTION

Epistemological reflection emerges as a teaching practice by enacting an inclusive relationship between epistemologies from different cultures in the science classroom. Nowadays, classrooms are culturally diverse because of the plural population composition and or the immigration processes. This cultural diversity means that the epistemology of the subject matters and the epistemologies of the students'- teachers' cultures coexist in the classroom. When teachers experience this diversity, they might enact an exclusionary or inclusive relationship between such epistemologies. This research aims to identify emerging practices when science teachers use the Epistemological Bridge approach between the epistemology of science and traditional epistemologies.

To study the interactions between epistemologies in the science classroom is an issue related to social justice. Collste (2019) argues that some cultures consider others as inferior in culturally diverse societies. In this scenario of injustice, the majority dominates the epistemologies of the minorities. For the author, overcoming the epistemic injustice is reciprocal recognition and respect. To this perspective, Walsh (2009) adds that it is also necessary to recognise the unequal power relationships between cultures for social justice. In this way, teaching practices contribute to social justice when, in addition to science, they consider other epistemologies as valid curricular content (Rodríguez & Morrison, 2019).

Relationships between epistemologies (cultures) in the science classroom

Different theories or approaches describe the relationships between epistemologies in the science classroom. For example, in Brazil, Ludwig and El-Hani (2020) describe two central relationships between school science and local knowledge systems. One relationship is marginalisation, and the other is recognition. Thus, teachers can marginalise local knowledge systems by ignoring them or using them overlapped with science. Meanwhile, teachers recognise local knowledge when using it as content in the curriculum. In Canada, Aikenhead (1996) describes the possible bridge between epistemologies belonging to different cultures. Therefore, teachers might guide indigenous students to cross their cultural borders and enter the school science culture.

Likewise, in Colombia, Molina and Mojica (2013) identify two essential science education foci. The assimilationist approach happens when teachers solely take into account school science. Inclusive teaching occurs when teachers consider school science and Traditional Environmental Knowledge. This open view establishes different bridges between cultures in different levels (a) moral and human, (b) ontological and epistemological, and (c) social and contextual. Additionally, in South Africa, Mpofu, Otulaja and Mushayikwa (2014) describe possible integrations between epistemologies in a science classroom (a) substitutive, (b) divergent, (c) parallel, and (d) convergent. Teachers enact a convergent integration when they establish dialogues between epistemologies.

The epistemological bridge (EB) to design epistemologically inclusive practices

The Epistemological Bridge (EB) is a didactic process (planning, teaching, learning and assessment) during which teachers engage students in an inclusive relationship between the epistemology of science and traditional epistemologies (Tovar-Gálvez, 2021 a). The traditional epistemologies might encompass the thought systems from indigenous, afrodescendants, farmers, immigrants and other communities (different to the modern Western culture). Communities achieve the inclusive relationship when they reciprocally recognise the existence of diverse epistemologies, validate their contribution to understanding or intervene in reality, and participate in them (Tovar-Gálvez & Acher, 2019). The students' learning outputs mediated by the EB could be –explanations, models, problem-solving, and projects. The bridge is a common way-connection between different endpoints-epistemologies.

When teachers guide their practice (planning, teaching and assessment) from the EB, they recognise that there are other epistemologies in addition to the epistemologies of science. Likewise, teachers validate the contribution of the diverse epistemologies to the school curriculum. Additionally, teachers use such epistemologies as content for the students' learning output. When students use the EB, they participate in every endpoint-epistemology, and for this, they use common elements between epistemologies (walkway) to transit among them.

To support teachers in using the EB for planning and enacting epistemologically inclusive practices, Tovar-Gálvez (2021 a) proposed two practical principles. Those principles describe practices' characteristics from the EB:

A) Epistemological Independence: the epistemologies have their own domain (ideas, practices, instruments, aims, norms and values). Using this principle, teachers identify the domain of every epistemology as content to teach. Those domains are the endpoints of the bridge. There are as many endpoints as recognised cultures in the classroom.

B) Epistemological Similarity: the epistemologies have elements in common that allow communities to establish epistemological interaction. Using this principle, teachers identify elements from each epistemology that resemble each other. The walkway to transit between one epistemology and others are those commonalities. Communities might transit in any direction and moment. The common elements could be values, ideas, practices, procedures, aims, norms, artefacts, and others.

METHOD

Three chemistry teachers from secondary schools in Colombia participated in this study. The researcher supported teachers in planning and enacting the Epistemological Bridge to conduct students to propose explanations on a situation (Tovar-Gálvez & Acher, 2021). Such a situation should be an unknown phenomenon for students but daily. Students should explain this situation by using chemistry and traditional epistemologies. Teachers 1 and 2 chose chemistry and the epistemology of the Muisca indigenous community. While teacher 3 selected chemistry and the epistemology of the farmers and the Wayú indigenous community. Finally, students should produce two explanations on the same situation, one from the scientific referent and another from the traditional referent.

Teachers provided the researcher with the lessons' planning, recordings (audio or video), field notes, pictures of the blackboard, and reflections.

The analysis used as sources all the information transcribed (descriptions in the case of pictures). The analysis consisted of grouping data by content until saturation (Páramo, 2015). Thus, epistemic reflection is an emerging category.

RESULTS

The three teachers enacted an "epistemic reflection" because they addressed with students the nature, structure, and use of the ideas, practices, and explanations of each epistemology in terms of their independence (to a large extent) and their similarity (to a lesser extent).

Teacher case 1

Example of when teacher 1 enacted epistemological reflection with the students:

> But on both sides, are we going to have the same liquid? [In this case] what happens is that I am analysing it from different ways of thinking, which is also the reality in knowledge. For example, Juan, two people can be analysing him. [In the] example, he [a third student] is a sociologist, and I am a scientist. The sociologist may be studying his behaviour, and I will be analysing his structure. These are ways of interpreting an object or a phenomenon. In this case, we are interpreting a single entity. […]. So, are both forms of interpretation valid? They demonstrated it because each of them has a way of interpreting the phenomenon […]. Ancestral thought does not lose its validity because it does not have numbers, nor does scientific thought lose its validity because it does not have a dialogue. [Both] are ways of seeing the world [...].

In the context of the extract, the teacher communicates to the students the work that they will develop the next few days. He highlighted that they would characterize a drink from two thought systems, the scientific and the indigenous. During this planning with the students, the teacher describes the dynamic of explaining the same element or entity from different viewpoints. He underlines the difference between the explanations and the validity of their domains. The teacher is enacting epistemological independence when he delimits the use of every epistemology and respects their domains. Likewise, he enacts epistemological similarity when he points to similar values: both viewpoints provide explanations, and both are valid.

Teacher case 2

Example of when teacher 2 enacted epistemological reflection with the students:

> Each of these two types of knowledge [from farmers and science] has or manages its own language. When we consulted or watched the video "Puros Criollos", how did they talk about the preparation of Chicha [corn drink]? What words were used? [Student says: we must let it "enjuertar"]. Perfect "su persona". They [the farmers] used everyday language. We watched that video produced in Boyacá. In what place was it recorded? Do you remember the man who was drinking the Chicha? In what place [were they]? [Student says: where the land is farmed]. They were in a Tejo court, playing Tejo and drinking Chicha. On the part of scientific knowledge, we consult some concepts related to fermented beverages. Then I explain: we will produce two types of knowledge: scientific knowledge and cultural knowledge.

In the transcription, the teacher evokes a video that she and the students watched the days before. The video is a chronicle regarding the Chicha production. Chicha is a corn-based fermented drink, sacred-healing for indigenous and traditional for farmers. In this case, the teacher addresses the difference between farmers' everyday language and scientific language. In general, she encourages students in using the language according to the cultural context. The teacher enacts epistemological independence when delimits the languages to the corresponding epistemological domains. In addition, she enacts epistemological similarity when making evidence that both epistemologies have languages as a common but different element between them.

Teacher case 3

Example of when teacher 3 enacted epistemological reflection with the students:

I want to remember our question, "Why can sea salt be good for cicatrizing?" And I want to know if you have identified a mistake. For the scientific production practice, what materials did we use? [Pointing to the board, the picture where the scientific and the traditional schemes are] [Students: materials of the scientists] True and did you remember that we said we should not mix them? And we also use the lab coat. Now, let's say what we used during the traditional practice. [Students: the meat, the Petri dish or box, the lab coat] Well, the meat, the lab coat, you said: "that box". That is not a box but a Petri dish, right?. Now, what is the mistake here? I will repeat. [Student: Petri dish] [Another student: [the mistake] is that we put the meat in this box]. And why putting it in this "box" is a mistake? [Students: because that is scientific and not traditional, it must have been on a platter]. Yes, because that is not traditional (element), and we had to put it on a platter or a table for salting. During the traditional practice, the farmers, natives and grandparents, did they use lab coats? What did they use? [Student: nothing]. They use nothing or an apron. So, do you realize that we mixed things up? And we made a mistake there. What have we to take into account? We mixed the elements of the traditional (domain) with the scientific (domain).

In the previous example, the students had finished the scientific production practice. After the chemistry lab, they kept the materials and immediately developed the traditional production practice. However, the students forgot to take off their lab coats during traditional practice. In the next session, the teacher motivated the students to deliberately reflect on the nature of production practices and on a lack of the principle of epistemological independence. The teacher takes up in the class the events of the production practices carried out last week and not only limited to the contents. She also worries about doing epistemological surveillance and identifying that the mixed elements correspond to epistemologies of different nature. Thereby, the epistemology becomes explicit and is part of the content to teach.

DISCUSSION

The epistemological reflection that teachers involved students with might be part of the Nature of Science (NOS) frame. Studies such as those of Schwartz and Lederman (2002) and Akerson and Hanuscin (2007) demonstrate the positive effect of NOS on the teachers' and students' science learning. Teachers have included NOS explicitly in the science curricula in two ways (Khishfe & Lederman, 2006): integrated (in a context) and non-integrated (analysing science structure), with positive results on students' learning in both cases. In the case of Meyer and Crawford (2011), they use the NOS as a way in which teachers involve students from diverse cultures in deconstructing science. The effects that the authors argue for students are (a) they can distinguish science from other epistemologies, (b) this is an opportunity to transit between cultures, and (c) they will understand science as a way of knowing.

In the three cases, the teachers explicitly address with students the nature, structure and dynamics of science and indigenous-farmer thought systems. This explicit NOS goes beyond the research field limits because this is a comparison-based epistemological reflection. Moreover, this epistemological reflection is on epistemologies with different natures and cultural backgrounds. Thus, this NOS is in the context of the epistemological bridge through the epistemological independence and epistemological similarity principles. Therefore, the epistemological reflection probably contributes to students learning from a culturally inclusive point of view.

Likewise, the reflection made by the three teachers regarding the nature and structure of the explanations is consistent with the studies of McNeill, Lizotte and Krajcik (2005) and McNeill and Krajack (2008). The authors studied the effect of instructional practices on the students' explanations. They provided evidence on the positive effect of the practice of "making the rationale of scientific explanations explicit" on the student's product. The same studies support the researcher's recommendation to teachers 2 and 3 regarding using the examples of explanations provided as part of the planning and enactment (Tovar-Gálvez, 2021 b). The expected effect was that they reflected explicitly with the students on the explanations' structure within the EB framework and worked on models of explanations. The evidence provided by McNeill et al. (2005) and McNeill and Krajack (2008) demonstrated a positive effect of the practice of "modelling scientific explanations" on the students' product.

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CONDITIONS OF INCLUSION IN THE CONTEXT OF VOCATIONAL EDUCATION

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Vocational schools in Germany play a major role in preparing young people for the labor market since they offer a large variety of courses, which are mostly job-related but also lead to general educational qualifications. In view of demographic change and the lack of skilled workers in many professions, it is even more important to make the education system and thus the labor market more accessible (Heinrichs & Reinke, 2019). However, a large variety of courses results in a significant diversity among students, necessitating the implementation of inclusive teaching (Euler & Severing, 2014). Inclusive teaching for heterogeneous students, asks for improved institutional framework conditions and especially a sufficient knowledge and an open mind-set of teachers (e.g., Amrhein, 2011). Studies show that attitudes, self-efficacy and willingness are relevant variables when analyzing teachers' decisions and actions in the classroom concerning inclusion (e.g., Lambe & Bones, 2006; Schlüter, 2018). In this project, the perspectives of various actors in the vocational school context are examined to uncover inclusion-related needs at vocational schools as well as analyzing and comparing pre-service teachers' planning and conducting competences for inclusive lessons.

Keywords: Inclusion – Vocational Education – Universal Design for Learning

THEORETICAL BACKGROUND

Perspectives on Inclusion

"[T]he concept of inclusion […] emphasiz[es] the need to reach all learners, on the assumption that every learner matters equally and has the right to receive relevant, quality, equitable and effective educational opportunities." (UNESCO, 2020: 5)

This definition of inclusion put forward by the UNESCO, represents the wide understanding of inclusion adopted in this study, whereby neither gender, social or economic prerequisites nor special educational needs hinder a person to reach his or her potential. Following this ideology, diversity is seen as a chance rather than a challenge that needs to be overcome (Reich, 2018; UNESCO, 2020). Another pillar for inclusive education in Europe is the Sustainable Development Goal 4 within the 2030 Agenda for Sustainable Development which aims to "[e]nsure inclusive and equitable quality education and promote lifelong learning opportunities for all" (UNESCO, 2020:2). The agenda was adopted by 184 member states in 2015 and sets goals to fight poverty on a global scale. These UNESCO goals go a step further than the UN Convention on the Rights of People with Disabilities (UN-CRPD) and do not only include people with disabilities and handicaps but all people with their differing abilities and socio-economic background. In Germany, efforts to implement inclusion in education and at the workplace have been especially strong since signing the UN-CRPD in 2009.

Universal Design for Learning (UDL)

The framework Universal Design for Learning puts forward a possibility to minimize barriers in educational contexts to facilitate learning for all. It is a general pedagogical approach structured through guidelines and checkpoints, which can be adapted and applied for any discipline and subject, enabling students to "access and participate in meaningful, challenging learning opportunities" (CAST, 2018) in the areas of representation, expression and engagement (Spooner et al., 2007; Meyer, Rose & Gordon, 2014; CAST, 2018). UDL takes the needs of all learners into account and aims to provide the most accessible approach to educational content for all students. The checkpoints to each guideline offer concrete advice and examples on how to cater for diverse students and guide teachers through planning and delivering a lesson with "maximum accessibility" (Wember & Melle, 2018). Meyer et al. (2014) base their research on neuroscientific evidence whereby the areas of representation, expression and engagement can be allocated to three networks of the brain (Fig. 1).

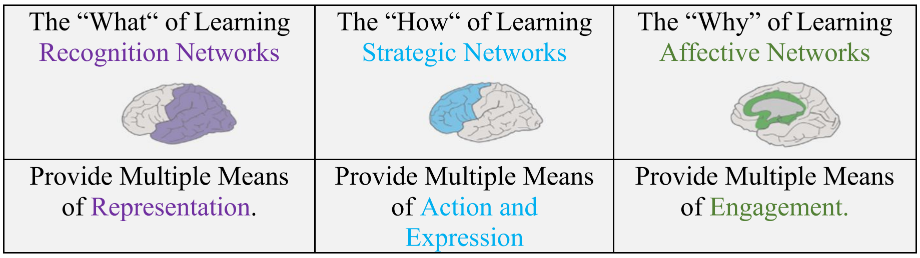

Figure 1. The three Networks of Learning and the Basic UDL-Principles (cf. CAST, 2018).

The framework is divided into the three networks and principles with three guidelines and three to five checkpoints each. In Figure 2, a part of the framework's structure is shown considering the Affective Networks and one of their principles.

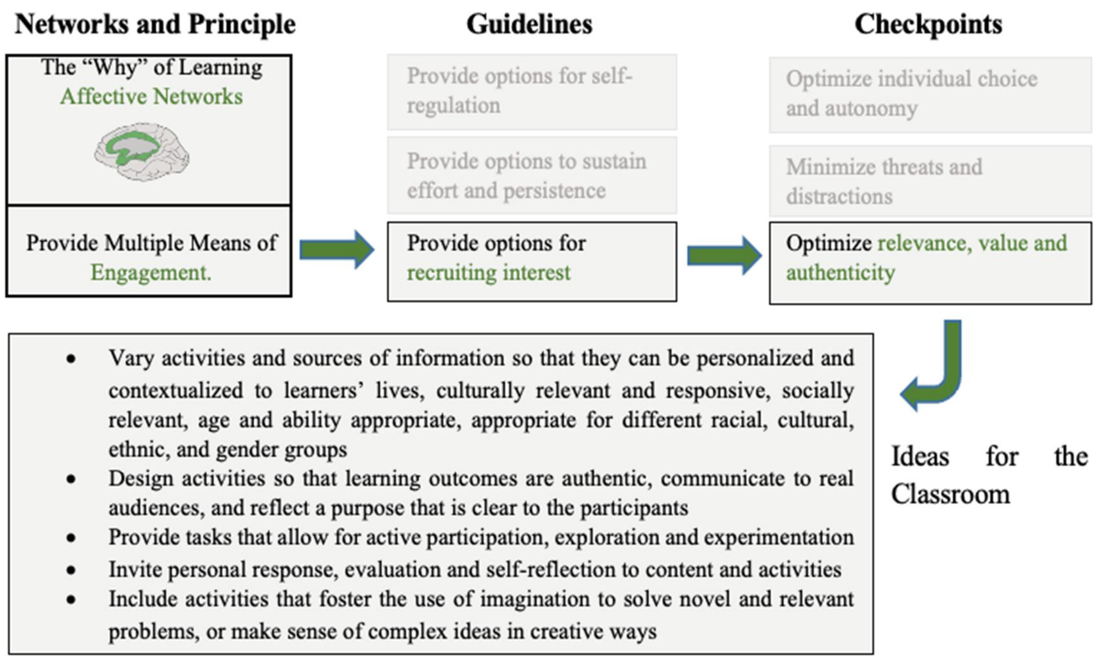

Figure 2. Example of a UDL-principle, guideline, checkpoint and ideas for the classroom (cf. CAST, 2018).

The effectiveness of UDL on the learning process of all learners has been proved by several studies and especially in the USA it is a teaching methodology applied from elementary to tertiary education (Al-Azawei, Serenelli, & Lundqvist, 2016; Capp, 2017). Additionally, UDL is especially effective when focusing on the social and emotional well-being of students and teachers leading to a more productive classroom environment and improving student's instructional engagement as well as their academic achievement. For teachers, planning and conducting their lessons according to the UDL-principles reduces stress, increases job satisfaction, and improves teachers' self-efficacy related to inclusion (Hymel & Katz, 2019).

Vocational Education and Training (VET) in Germany

In Germany, VET plays a major role in preparing the future workforce for a wide variety of jobs. The main goal of VET is the provision of comprehensive vocational, social and personal competences and the preparation for lifelong learning, enabling graduates to participate and actively shape increasingly international developments in society and business (APO-BK, 2019). Internationally, Germany is known for its dual system, which combines theoretical learning at vocational schools and practical learning at the workplace. However, vocational schools also offer certificates for single and double qualification courses and general education qualifications. Thus, vocational schools are an important part in the education system, giving people with low initial qualifications the opportunity to receive vocational and general education with the possibility to attend university. A large variety of courses makes for a diverse group of students, even within a single class. Therefore, heterogeneity is an everyday reality for teachers at these schools. In the effort for inclusion across all educational institutions, vocational schools have rather been underrepresented in research and politics (e.g. Smith & Bell, 2015). Nevertheless, the parties involved agree that modern vocational education and training needs to cater for all needs and that young people should be offered opportunities in the regular system of VET wherever possible, instead of setting up special paths (i.e. SEN schools) and measures that do not lead to the initial training market and finally the labor market. The focus should be on the resources and talents of all young people, especially in light of the current debate about skilled workers and demographic change (Gillen & Wende, 2017).

Research Question

The identified research needs in the context of VET and inclusive teaching put the focus of this study on the evaluation of conditions of inclusion at vocational schools from multiple perspectives, aspiring to create a detailed insight into the current situation. In this paper, the emphasis lies on the following research question: What difficulties do masters' students and pre-service teachers face when planning and implementing inclusive lessons at vocational schools?

METHOD AND INSTRUMENTS

For this study, pre-service teachers' written lesson plans (N=30) were examined with a focus on the consideration of heterogeneity among students. The UDL framework functioned as a guideline for the deductive development of a coding manual, which was adapted for the vocational school context. Two raters conducted the rating of the written lesson plans. From this sample of 30 individual lesson plans, a sub-sample of n=8 was further analyzed. The analysis includes a paper-pencil questionnaire for participants, which surveys attitudes, self-efficacy and willingness with regard to inclusive teaching using Likert-scale and open question formats (cf. Schlüter, 2018). Additionally, a non-participatory, structured and overt observation of the lesson corresponding with the written lesson plan using a slightly altered coding manual is carried out. Whenever the Covid-regulations allowed, this observation was done with two raters. At the end of the lesson, a paper-pencil questionnaire was distributed to students of the documented lesson regarding the perceived adaptivity of the lesson and their personal attitude towards the conducted lesson. The in-service teachers' point of view was evaluated through a short interview directly after the lesson. To conclude the study, a structured interview with participants was scheduled to reflect on the lesson. The sample consists of masters' students of the biotechnology teacher training program at university and of pre-service teachers with the study courses biotechnology, biology and chemistry. Data collections was finalized at the end of 2021. For this paper, some assorted findings on prospective teachers' competences in planning and conducting a lesson are presented.

ANALYSIS AND FINDINGS

To take a closer look at the planning competences of participants, an analysis of 30 lesson plans was carried out by two raters resulting in an intercoder reliability between .73 and .96 (Kappa). Six lesson plans were by university students in their practical semester at a vocational school; the other 24 lesson plans were provided by pre-service teachers currently in the last stage of training at a vocational school. Overall, 655 codes were distributed, ten being the lowest and 39 being the highest number of codes in one lesson plan. Figure 3 visualizes the distribution of codes on the UDL principles and guidelines.

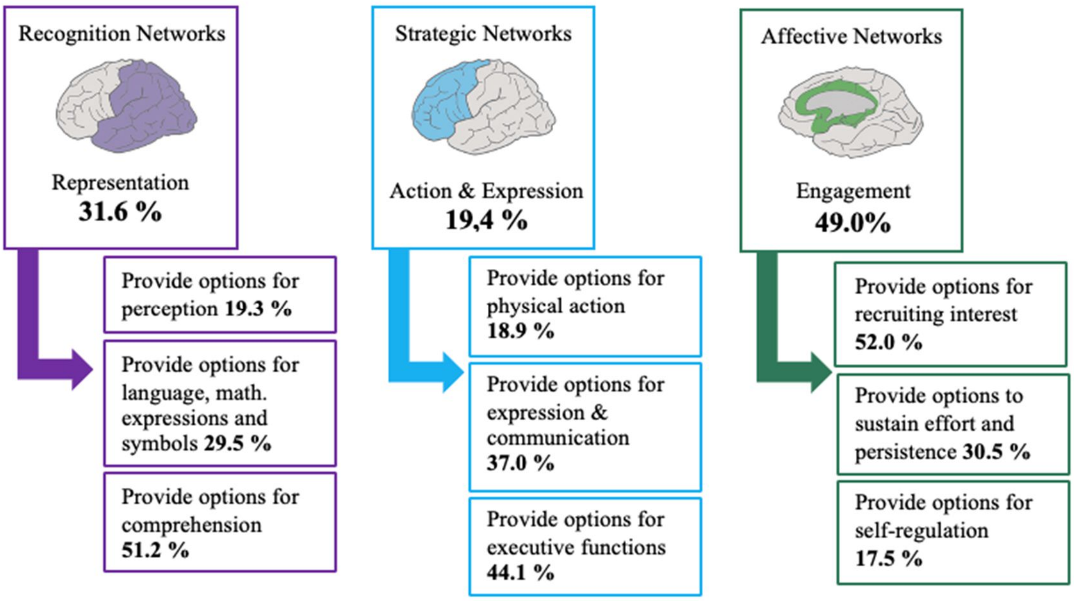

Figure 3. Distribution of codes in the written lesson plans on the UDL framework.

When it comes to written lesson plans, participants incorporate inclusive measures mainly through targeting the affective networks. The guideline "Provide options for recruiting interest" makes for half of the codes distributed for this principle and manifests itself through offering relevant and authentic lesson content closely related to the specific vocation. Around 30 % of the codes for the affective networks can be found in the guideline "Provide options to sustain effort and persistence", where prospective teachers plan to create a space of collaboration and community fostering motivation, e.g., when using scenarios that simulate what could happen at the workplace, employing methods to activate students and to reflect about their own experiences as well as collaborative methods. Following the affective networks, the second highest number of codes is reached in the recognition networks (31.6 %). Here, participants especially target the guideline “Provide options for comprehension”, e.g., supporting students’ comprehension processes through activating prior knowledge and guiding information processing. Furthermore, they facilitate understanding for students of all language levels and use visual aids (guideline: “Provide options for perception”). Other forms of representation and visualization for the recognition networks include methodological or content-related lists of criteria, Advanced Organizers that help students to keep track of topics and methods, using practical exercises (e.g., role-plays or training of job-specific handicrafts) and visual aids like posters, flipcharts and the black board. Only around 20% of all codes went to the strategic networks. Nevertheless, some participants plan to guide appropriate goal-setting through transparency of the lessons’ aims and contents (guideline: “Provide options for executive functions”) and use multiple media to address multiple learning types (guideline: “Provide options for expression and communication”). Examples from the lesson plans include clearly stating the topic and learning outcome of the lesson and giving a brief overview of the progression of the lesson, sometimes using visual tools. Some participants also plan to keep the grading process transparent for students. In addition, media used by the participants and offered to the students are among others: laptops and tablets, using a handwritten notebook as a memo technique, showing videos, visualizing handwritten documents by students through a smart cam or using a virtual classroom tool.

Further analyses revealed that participants with less experience, i.e., university students in their practical semester, integrated fewer measures of differentiation or individual support for students with an average of 16,3 codes. The average increases to 21,8 codes for pre-service teachers who have already served half their practical teacher training at a school and is the highest (24,6) for participants at the end of their practical teacher training program. Additionally, the descriptions of classes from the written lesson plans were analyzed wherever possible to take the actual heterogeneity into account. Three levels of heterogeneity were established based on the following characteristics: prior education, (prior) knowledge, language abilities and motivation to learn.

Table 1. Levels of heterogeneity and the number of codes on average.

Level 1: mostly homogeneous according to all characteristics (n=8)	Ø 16,25 codes
Level 2: heterogeneous, but few pupils with major difficulties and most are motivated to learn. (n=8)	Ø 18,75 codes
Level 3: very heterogeneous in all areas, difficult to motivate. (n=13)	Ø 24 codes

Table 1 shows an increase in codes on average for more heterogeneous classes, suggesting that the participants try to adapt their lesson planning to meet all students’ needs.

From the large sample of lesson plans and participants’ planning competences, a sub-sample (n=8) was taken to examine how the planned lessons translate into the classroom context. The sub-sample consists of four university students in their practical semester with the subject biotechnology and four pre-service teachers with the subject’s biotechnology and chemistry. There are six female and two male participants, ranging between 25 and 37 years of age. Five test persons have a vocational background in the areas of medicine (medical-technical assistant and geriatric nurse), chemistry (chemical-technical assistant), biology (biological-technical assistant) and biotechnology (hairdresser). The coding manual was adapted to allow for quick and easy application in the classroom, leaving only the checkpoints without explicit subcodes. There was enough room for notes on each checkpoint. In the eight observations, a total of 150 codes was allotted with an average of 18.75 codes per lesson, the minimum of codes being 16 and the maximum 24. To recognize parallels between the distribution of codes for the written lesson plans and the observation of the lesson, the same figure as above was used:

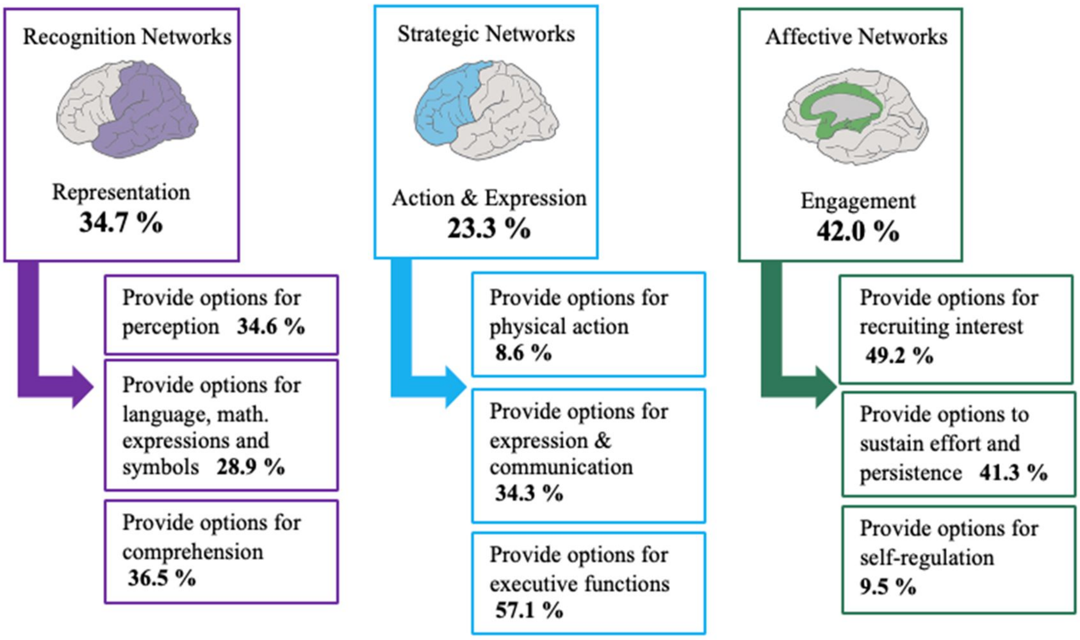

Figure 4. Distribution of codes for the lesson observations on the UDL framework.

The Affective Networks remain the strongest area with 42.0 % (49.0 % for the written lesson plans) combining the guidelines “Provide options for recruiting interest” (49.2% / 52.0 %) and “Provide options to sustain effort and persistence” (41.3 % / 30.5 %). A slightly lower percentage is reached for the guideline “Provide options for self-regulation” (9.5 % / 17.5 %). This last guideline manifests itself more in the written lesson plans than in the actual lessons. This is mainly due to a lack of time to implement thorough and effective methods of (self-)reflection in the lesson even when planning to do so in the lesson plan. Furthermore, efforts to integrate students’ opinions and observations through evaluation sheets (e.g., when observing a role-play) sometimes fall short of their initial appeal, when they end up being unstructured and too little acknowledged in the final discussion. In the lessons, different means of representation play an important role, which shows in the number of codes in the Recognition Networks (34.7 % / 31.6 %). Here, the distribution on the three guidelines is more balanced than in the written lesson plans. While “Provide options for comprehension” stays in first place code-wise (36.5 % / 51.2 %), the guideline “Provide options for perception” (34.6 % / 19.3 %) accumulates significantly more codes. The options for comprehension include the activation of prior knowledge at the beginning of the lesson, accompanying the students’ learning process and maximizing transfer and generalizations. In this case, the percentage of codes is again higher in the written lesson plans which can be explained by the plans of the prospective teachers to structure and accompany students' process throughout the lesson but managing only to do so at the beginning and sometimes after the introductory phase. The options for perception on the other hand, are more pronounced in the lesson observations, since the representation of information through font sizes, color contrasts or well readable writing on the board can to a large extent only be perceived in the actual lesson and to a lesser extent in the materials attached to the lesson plans. The least used measures for inclusive teaching stem from the Strategic Networks (23.3 % / 19.4 %), where physical action (8.6 % / 18.9 %), expression and communication (34.3 % / 37.0 %) as well as options for executive functions (57.1 % / 44.1 %) play a major role. The guideline "Provide options for physical action" is represented by the checkpoints "Learning materials and students' answers" as well as "Access to different resources". Both checkpoints manifest themselves more in the written lesson plans because the role-plays in the observed lessons were usually limited to two or four students, giving solely those the opportunity of expression through physical action. Furthermore, some digital tools, like QR-codes for links to further information on a topic are usually redundant since they are ignored by students. Additionally, student autonomy for presenting results is claimed in some lesson plans, but this is only true for decisions involving one medium, like videos and not the choice of any media desired by the students.

DISCUSSION AND OUTLOOK

In the analysis of 30 written lesson plans, all prospective teachers incorporated elements of the UDL-framework thereby making their teaching more accessible to a heterogeneous student body. Most frequently, they integrated methods of recruiting students' interest through relevant and authentic lesson contents. Results also show that more experienced prospective teachers use more methods of differentiation than less experienced teachers do. The same is true for the level of heterogeneity in a class: the higher the overall heterogeneity of a class, the higher the number of codes in the lesson plans. In the following lesson observations in eight classrooms, the prospective teachers' competences in conducting a lesson were documented. While the overall tendencies and distributions are similar in both cases, there are some differences worth considering: prospective teachers seem to struggle with limiting their lesson time to 45 minutes and incorporating everything they put forward in their written lesson plans, they sometimes lack the flexibility to make adjustments for better accessibility of their lesson and they use digital tools mostly without reflecting their advantages and disadvantages.

In addition to the findings above, the in-service teachers' interviews and students' questionnaires on each lesson will be considered. Further insights into the test persons' point of view will also be gained by analyzing the interview with each participant at the end of the study and their answers on the questionnaire of attitudes, self-efficacy and willingness towards inclusion.

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MAPPING RURAL PRIMARY SCHOOL STUDENTS' SELF-POSITIONING IN RELATION TO SCIENCE

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Students from rural areas are underrepresented in the fields of science and technology. This underrepresentation is associated with the incompatibility between the cultural perspective of science and their local community culture. Drawing from relevant literature on positional identity the present study aims to map rural primary school students' self-positioning in relation to science and its development through the interaction with agricultural scientists. Twenty three 5th to 6th grade students from a semi-mountainous rural village of Crete participated in this case study. Data collected through students' artifacts and interviews indicate that rural students possess important funds of technical knowledge through the agrarian activities they engage with, however they themselves don't perceive that knowledge as compatible with school science. However their interaction with agricultural scientists who acted as role models contributed in confining the stereotypical characteristics students held for science and scientists and in bridging the seemingly incompatible contexts of local culture and science.

Keywords: Science and Culture, Primary School, Equity

INTRODUCTION

Science and technology are now integrated into modern society to such an extent that it is necessary, from a social and political point of view, for citizens to possess basic scientific knowledge but also to be able to make informed decisions on both every day and wider societal issues. Given this, equity in access and engagement of all students (regardless of gender, cultural or social background) with science is a critical issue (Bianchini, 2017). However, girls and students from non-dominant cultural and low economic background, are underrepresented in the fields of science and technology (McGee & Bentley, 2017). Growing research evidence supports that this underrepresentation is associated with the incompatibility between the cultural perspective of science and the community culture (in other words the norms, values and conventions) of the aforementioned groups (Archer et al., 2010) and directly affects the ability of students to identify themselves as science-persons and build their scientific identity.

Based on Carlone & Johnson's (2007) approach to students' scientific identity, the construct involves three overlapping dimensions: competence, performance, and recognition. Competence describes one's capacity to understand scientific information, performance is related to one's capacity to appropriately engage in scientific activities while recognition refers to one's opinion of oneself as a "science person," and others' perceptions of oneself as a "science person". This model's three aspects openly relate how students navigate our society's cultural norms to develop science identities.

According to the theoretical framework of cultural border crossing (Aikenhead, 2001) the incompatibility between the cultural perspective of science and community culture rises cultural borders that students have to cross in order to engage with science-related activities. However, the fact that a local culture may differ from that of science or school science doesn't mean that this culture is deprived of funds of knowledge that can be utilized as valuable resources in the context of science culture (Seiler, 2013).

Focusing specifically on students from rural areas, research shows that they exhibit higher rates of school dropout and follow less frequently science professions in comparison with urban students (Young, 2000). Nevertheless, at the same time rural science education research highlights the fact that many elements of local rural knowledge may be used as funds of knowledge for science learning (Avery, 2013) encompassing farming and agriculture activities.

Therefore, given the need to strengthen rural students' science identity, as a means to enhance their overall engagement with school science, this work is part of a larger project that studies the factors that act upon the development of rural students' science identity. Drawing from relevant literature on positional identity (Rahm, 2008) and taking into account previous research that employs scientists as role models for this purpose (Kenneth Jones & Hite, 2020), this paper examines how rural primary school students self-identify with science and explore the potential of students' interaction with scientists – experts on topics related to their rural daily life, as a means of enhancing aspects of their scientific identity. The research questions that guide this study are:

(i) What are rural primary students' perceptions of science and scientists?
(ii) What are rural primary students' perceptions of themselves in relation to science?
(iii) What are rural primary students' perceptions of their participation in science-related activities?
(iv) How do these perceptions evolve through students' interaction with agricultural scientists?

METHOD

Context of the study & Participants

The methodology used for this research study lies within the tradition of ethnographic case studies. The study took place in a village of about 600 residents in a semi-mountainous rural area of Crete. In this area the main occupation of the residents is farming, dairying, agriculture and vinification. Children from an early age participate in the agrarian activities of their parents. The local culture requires boys usually to follow the family occupation and the girls to marry and start a family at a much younger age compared to their urban peers. Moreover, the administrative district where the school belongs has the highest nationwide student dropout rate from high school (10th to 12th grade) according to the latest report of the Greek Institute of Educational Policy (2019).

The local primary school, where the researcher also worked as a teacher during the school year 2021-2022, hosts in total 70 students. The participants in this study were 23 students (10 girls and 13 boys) from 5th and 6th grade.

The scientists selected to interact with the students were a biologist postdoctoral researcher in the Laboratory of Plant Biomolecules and Biotechnology at the University of Tours on the field of oenology and processing of vines with biostimulants and an agronomist researcher and lecturer on Agricultural Engineering and Soil Microbiology.

Research design

At first, during the orientation phase, the driving question of "How can we improve the agricultural production of our area?" was posed and the students were invited to turn to the local community, in order to collect the relative problems their community faced and the questions that they would like to ask a specialist.

Afterwards, two 90-minute tele-meetings with the scientists took place who, having been informed about the aims of the current research, were asked to prepare a brief presentation of their research field with emphasis on its usefulness in agricultural production. The students also had the opportunity to ask them about possible solutions to their community's problems as well as about more personal and social aspects of their daily lives as scientists.

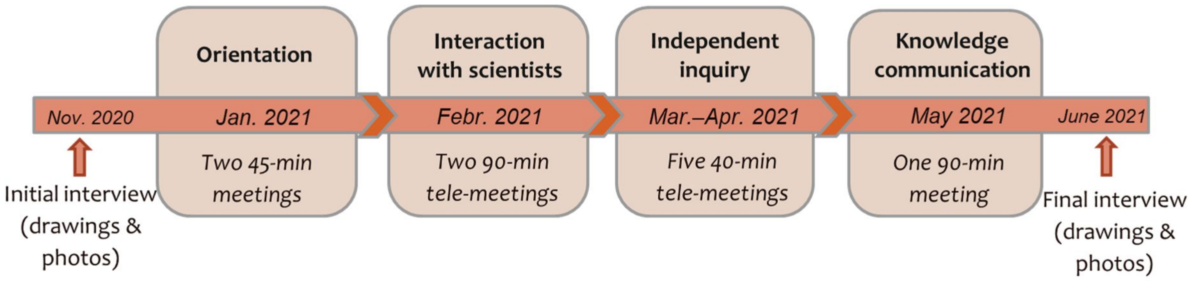

Figure 1. Overview of the students' process.

Students were then guided through webquests in search of more information on the issues raised during the discussions with the scientists and their findings were discussed during five 40-minute on-line meetings.

Finally, the students shared with their local rural community the findings of their research and key-elements of their discussion with the scientists through posters and an on-line event where students, their families and members of the local authority took part.

Data collection and analysis

For the purpose of our study, a multidimensional data collection was carried out using different collection methods that contribute to a more thorough understanding of students' self-positioning towards science as well as to greater validity and reliability of the research findings.

At first, before the orientation phase, we administered a variation of the "Draw A Scientist Test". Students were also called to take photographs of what they believe constitutes a scientific activity in their everyday life.

Then interviews in groups of three took place which were assisted by the aforementioned artifacts and allowed us (i) to clarify details on the students' drawings and the respective perceptions of scientists and scientific activities, (ii) to discuss their identification with their perceived image of science and scientists and their interest in following a science-related occupation, (iii) to elaborate further on the perception of their participation in science related activities in their everyday lives by discussing on the photos they took and on presented images of farming, dairying, agriculture and vinification activities. Similar interviews assisted by new students' sketches of scientists and photos of scientific activities were also conducted after the completion of the program.

Moreover, on-line and face-to-face students' meetings with the teacher/researcher and the scientists were also audio-recorded. Information regarding students' personal and family background were collected through the researcher's participatory observation and her interactions with their parents throughout the school year.

Qualitative methods of content analysis were employed to analyze the data from various sources. Data analysis was based on Carlone & Johnson's (2007) conceptualization of science identity as well as on STEM identities theoretical model of Kang et al. (2019) according to which students' identities are formed through constructs as their personal and familial background, their participation in science-related activities, their perceptions about self, science, and scientists' work and their interest in following a science-related job.

Transcriptions of the interviews constituted the main data set. Hence, data from students'-teacher's conversations during the meetings were used to crosscheck the themes that emerged during the analysis of the main data set. Afterwards, the transcriptions were read repeatedly and examined in terms of students' conceptualization for scientists & science, their self-perception of their performance and competence in science, their self-recognition as science persons and their scientific ambitions.

RESULTS

Students' initial drawings and follow-up interviews revealed that rural primary students held stereotypical perceptions of scientists. In most of their drawings scientists were presented as white, middle-aged men, with white lab coats and eyeglasses, conservative, untidy appearance and serious face expression, in the foreground of a laboratory with bottles, test tubes and organization folders. During the follow-up discussions, perceptions of scientists as important, prestigious but at the same time lonely, familyless individuals came upon. At this point it bears mentioning that solitary life, not having children and diverging from housewife/fatherly duties are characteristics radically opposed to the local culture's values and are attributed a negative connotation. Students' final drawings and interviews, after the completion of the program, revealed a mitigation of stereotypical features of scientists. Moreover, while scientists continued being perceived as prestigious persons, they were now described as more familiar figures with common interests and social life as theirs.

Regarding their self-perceptions on aspects of their science identity, rural students' perceptions on their competence weren't significantly altered and continued in their majority to underline a difficulty in understanding science concepts and to characterize themselves as not particularly academically successful in science classes. On the other hand, their perceptions on their science performance seamed to develop through the program. Initially, their photos of scientific activities depicted in their majority school laboratory equipment and secondarily technological applications/ products they use such as cars, mobile phones, video games consoles etc. In the interviews that followed they stated that they were not frequently involved in science-related work outside of school. When they were presented with photographs depicting tasks such as making yogurt, distilling raki and wine fermentation, they could describe the processes almost accurately (especially the older students) but without any scientific explanation or terminology. Furthermore, they did not recognize in any case that these activities could be related to aspects of science. After their interaction with the scientists and their investigation on the topic, the majority of the students recognized aspects of their community's agricultural work as relevant to science and conversely, they recognised agricultural science as relevant and useful for their community's activities. Finally, as regards their (self-)recognition as science persons, the majority of students after the program continued not identifying their selves as "belonging" to science however more than half of the them declared they felt like being recognised as potential future scientists by their parents after the communication of science-based solutions to the community's agricultural problems, as a result of their discussion with the scientists and the autonomous investigation they conducted on these issues.

As regards their scientific professional ambitions, rural students found science interesting and important to society in general, however initially they couldn't trace its importance for them personally. Moreover, the vast majority of the students stated that they couldn't imagine themselves being a scientist in the future as that would mean that they would have to study all the time, instead of being occupied with their own interests and creating a family. However, after the completion of the program more students started conceiving science as useful for their local community and for the improvement of the agricultural production of their area and considered engaging professionally with science as a more possible outcome than before.

DISCUSSION AND CONCLUSIONS

Rural students' initial perceptions of scientists were consistent with the results of respective studies in terms of their appearance and lifestyle (e.g., Kenneth Jones & Hite, 2020) and therefore they shared very few characteristics compatible to their local culture and values. At the same time, through the apprenticeship in their family's occupation, students had developed a technical know-how for many scientific activities that may serve as a very useful fund of knowledge for science learning. However, they themselves didn't recognize this kind of knowledge as congruent with science or school science, ending-up positioning themselves as outsiders in science (Avraamidou, 2020). Hence, the development of teaching approaches that integrate and give prominence to this fund of knowledge (e.g., Borgerding, 2017) and present students with suitable science role-models was required, in order to contribute to the development of scientific identity of rural students.

In such an attempt, in our research we employed agricultural scientists as role models and engaged students in searching for scientific solutions to their rural community's problems with their assistance. From our evidence derives that (i) the utilization of knowledge from the local context in the context of science, (ii) the proof of the usefulness of scientific knowledge in solving everyday agricultural problems and (iii) specific characteristics of the scientists that acted as role-models had an effect on rural students' identification with science. Particularly, those elements contributed in confining the stereotypical characteristics students held for science and scientists and gave prominence to the value of scientific knowledge to students' everyday life helping in this way to bridge the two seemingly incompatible contexts of local culture and science that rural students were called to respond to.

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THE ROLE OF LANGUAGE IN THE DEVELOPING UNDERSTANDING OF "ANIMAL": INSIGHT FROM SINGAPOREAN CHILDREN

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The formation of explicitly expressible conceptions begins early in the developmental trajectory such that by the age of 3 years children exhibit ideas that are incommensurate with accepted scientific views. Because of their early emergence, they tend to be highly resistant to change through instruction. An important factor in the development of these conceptions is language, both in terms of the use of language to express ideas and in terms of the formative linguistic environment through which knowledge is abstracted. One concept central to scientific learning is the animal, specifically about understanding what is an animal and what is not. Various studies have demonstrated that children's understanding of this concept emerges very early in development and is subject to changes over time through formal and informal instruction. However, they also demonstrate that this understanding also varies across linguistic contexts – children express different archetypal definitions of "animal" depending on the language they speak. Yet, there is a lack of understanding what impact multilinguistic exposure may have on the formation of such understanding, especially where the language of instruction differs from the language primarily spoken in the home environment – as is the case for a substantial number of children in Singapore. The multilingual exposure might strengthen their understanding, providing an advantage over monolingual children, but might equally lead to greater difficulty in overcoming misconceptions. This presentation will report on findings of a cross-sectional study conducted with children aged 4, 7 and 10, towards the aim of expanding our current understanding of scientific knowledge construction across early and middle childhood, and to subsequently contribute to further development of pedagogy across a range of relevant contexts.

Keywords: Conceptual development; elementary science; language

INTRODUCTION

Brief Literature Review

Scientific conceptions are often underpinned by the interpretation of everyday world experiences – even before children enter formal science learning contexts. These are formulated through experiences and discourses in everyday contexts and can result in wide range of preconceived scientific ideas about how the world works (Hast, 2014) and are based on unique experiences of those everyday contexts (Bliss, 2008), so ideas vary widely, in terms of content and degree of understanding. Many preconceived ideas are incommensurate with accepted scientific views and with the concepts that are, as a result, taught within classroom settings and are often found to be highly resistant to change through instruction, affecting subsequent learning of related concepts (Duit et al., 2013). This can pose a challenge for learners trying to organise their own conceptions, but also for teachers who need to organise that wide range of conceptions within a single shared educational setting. One of these foundational concepts is "animal".

Various studies have demonstrated that children's understanding of "animal" emerges very early in development and is subject to changes over time through formal and informal instruction. The general ability to form categories appears early in life, at least from two months of age onwards (Westermann & Mareschal, 2014), and even young infants demonstrate capacity for determining whether something is a living being or not (Träuble & Pauen, 2011), or that some animals are different from others (Furrer & Younger, 2005). But as language plays a more crucial part in interpreting the world, children seem to develop more archetypal definitions of animals. Three-year-olds appear to possess slightly less archetypal definition of "animal" than 5-year-olds do (Allen, 2015), which would correspond to the suggestion that an explicit formation of scientific misconceptions begins to show first signs before 3 years of age (Hast, 2018, 2019; Mandler, 2004), with the development of language playing a key role in the generation of such conceptions. Beyond this early stage, a range of studies in different linguistic contexts has demonstrated there is subsequently no single archetypal definition for the "animal" category in later development.

The Singapore Context

The Singaporean syllabus for primary science education requires students to learn about "living and non-living things" (Ministry of Education, 2014, p. 41), making specific reference to animals and their subgroups. This is a topic that is typically only covered in Primary 3 and Primary 4 (ages 8-10 years). But scientific concepts can already be deeply entrenched even by the time children begin formal education, often clashing with the accepted scientific viewpoints, including about animals. However, there is a lack of understanding what impact multilinguistic exposure may have on the formation of such understanding, especially where the language of instruction differs from the language primarily spoken in the home environment, which is the case for most children in Singapore. While the language of instruction in public schools in Singapore is English, there are four official languages in the country: English, Mandarin, Malay, and Tamil. And almost two thirds of Singaporean households speak a language other than English (Department of Statistics, 2016).

Problem Statement

Research has evaluated the development of children's understanding of the concept "animal" in the context of other languages, including Mandarin. However, there have been no direct language comparisons within studies. Allen (2015) does argue in his paper that the Mandarin *dòngwù* provides similar parameters to its users as "animal" does in English, but this is not entirely clear and can only limitedly be deduced across studies rather than being evaluated within individual children. Even a simple comparison of English and Mandarin studies would not give insight into this project's core matter of concern. Further, in existing studies, languages were always first language as well as language of instruction. Yet how is conceptual understanding impacted by exposure to more than one language? Do Singaporean children understand "animal" differently based on language – both across and within population groups? Does multilingual exposure provide a more coherent understanding of "animal" or does it present additional barriers to conceptual change?

Research Questions

Based on the lack of insight into cross-linguistic development of "animal", the study addressed two key research questions:

1) What is the relationship between understanding of "animal" in language of instruction and in language spoken at home?

2) How does children's monolingual and multilingual understanding of "animal" develop over time?

THE STUDY

A total of 312 children aged 4, 7 and 10 years took part in a cross-sectional examination. Children came from four different home language (HL) groups according to which language was most frequently spoken in their home environment – English, Mandarin, Malay, and Tamil. Each of the 12 overall groups (age x HL) consisted of an equal number of children. Using an online survey format, children were shown images of animals and non-animals, and they were required to decide whether the images showed an animal or a non-animal (see Figure 1 below). They completed tests in English as well as in their HL where English was not their HL. Tests were counterbalanced so that half of the children in each group completed the English version first and the other half the HL version first.

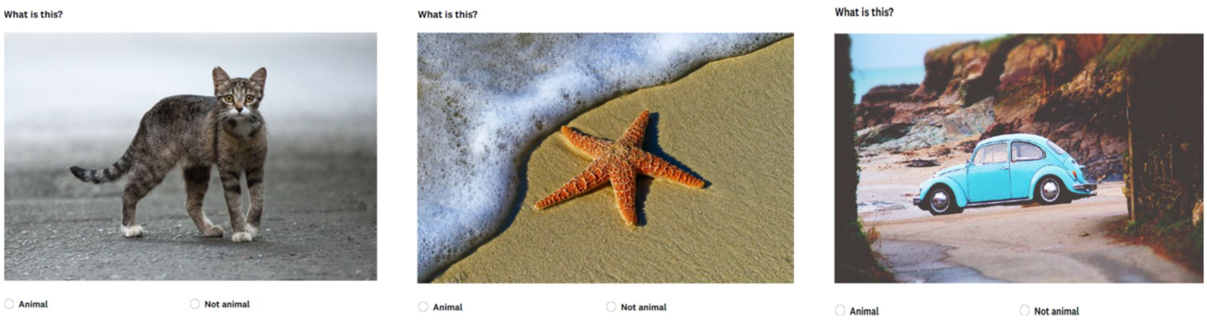

Figure 1. Examples from English version task, showing archetype animal (left), non-archetype animal (centre) and non-animal (right).

SUMMARY OF RESULTS

Correct recognition of non-animals was, as expected, very strong. When examining performance across the English tests, Malay-speaking children performed significantly better than all other three groups for all animals overall as well as for non-archetypal animals, but not for archetypes. The other three groups did not show significant variation. When examining performance across the different HLs, again Malay-speaking children performed better than all other three groups on all animals and on non-archetypal animals, but not for archetypes. Finally, while Mandarin- and Tamil-speaking children's performances did not differ significantly between English and HL tests, Malay-speaking children performed significantly better on the HL version than the English version. Out of the four languages, Malay has the broadest archetypal definition of "animal" that only excludes humans. As a result, it is perhaps not surprising that the Malay group showed a significantly higher correct score for non-archetypal animals than the remaining groups. Thus, home language exposure that has broader definitions may strengthen a child's understanding when also learning in the context of a different instructional language.

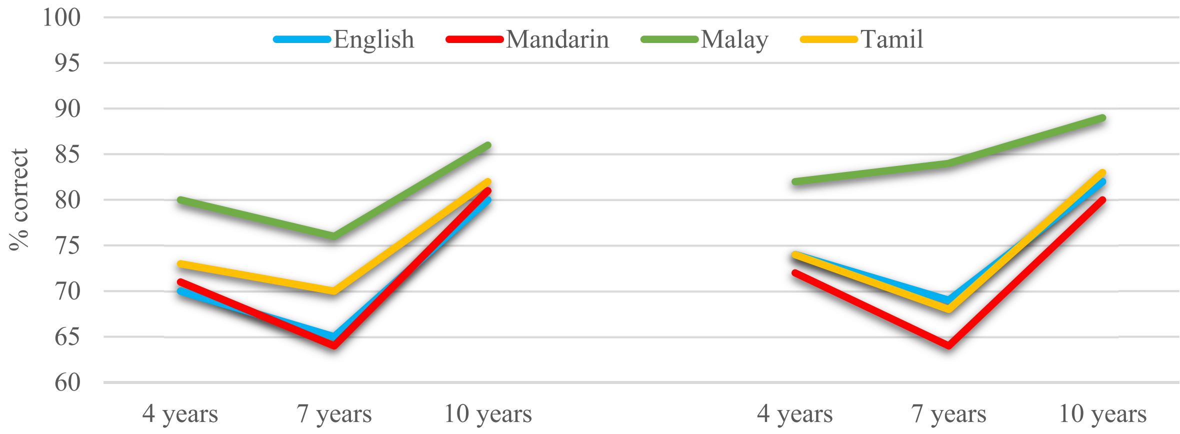

Figure 2. Performance across English version tests (left) and across different HLs (right).

Age-wise, both analysis sets showed the oldest children consistently performing significantly better than both the 4- and the 7-year-olds, but no significant differences between the two younger groups. Nonetheless, patterns emerging suggest a U-shaped performance curve, with 4-year-olds mostly scoring slightly higher, on average, than 7-year-olds. This seems to be in line with the suggestion that archetypal definitions begin to emerge around 3-4 years of age. The notable exception was again the Malay-speaking group, which did not follow the same U-shape trend. The older children's significantly improved performance can be associated with educational experience as their testing occurred after having been taught about animals in school, as per the national syllabus.

LIMITATIONS

The study brought forward some limitations in its scope for conclusion. First, the results illustrate a linguistic effect for only one specific scientific concept. Further studies will need to consider a broader range of scientific domains to examine for consistency of the current observations. Second, the study does not offer qualitative insight into children's understanding of "animal". However, such an understanding might show a more nuanced cross-linguistic differentiation. Third, the study required an explicitly expressed understanding of animal. Studies in other domains have shown children's expressed ideas may differ from their underlying understanding of the same ideas, which can be more accurate (e.g., Hast & Howe, 2015, 2017; also cf. Hast, 2020). Examining an underlying awareness of "animal" might provide more detailed insight into conceptual development role played by language.

CONCLUDING REMARKS

Overall, the study may have a variety of implications for understanding the role of language in the formation of scientific concepts as well as for instructional approaches. For instance, similar to the Finnish inter-disciplinary teaching and learning approach that addresses transversal competences (Lavonen, 2020; Vahtivuori-Hänninen et al., 2014), the role of Mother Tongue classes in Singaporean schools could find a new role in the context of scientific pedagogy. In turn, scientific literacy may be a way to support Mother Tongue learning as well. Beyond Singapore, the findings may lead to more careful consideration of pedagogy in increasingly diverse classrooms due to globalisation and global migration as a direct result of dispersion following recent conflicts. Finally, an important implication is that generating a stronger understanding of how the specific concept "animal" develops could potentially impact areas around conservation and pro-environmental behaviour (Cornelisse & Sagasta, 2018; Melis et al., 2020). For instance, recognising that invertebrates, generally viewed negatively, fall under same umbrella "animal" as more endearing species, such as mammals, can improve attitudes towards them, even in pre-schoolers (Borgi & Cirulli, 2015).

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PROMOTING GIRLS IN OUT-OF-SCHOOL SCIENCE LABS AFTER THE TRANSITION FROM PRIMARY TO SECONDARY SCHOOL

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The underrepresentation of women in science and the increasing shortage of skilled workers in STEM are still evident. To counteract this trend, extracurricular programs in out-of-school science laboratories have been implemented to foster girls' interest in science and in a science oriented-career. Compared to boys of the same age, girls with equally high science competencies, an identical motivation to learn, and a positive ability self-concept are reluctant to imagine deciding for science-oriented careers. Furthermore, girls' interest in STEM careers decreases during secondary school. Accordingly, this exemplary case study focuses on current challenges of a chosen out-of-school science lab regarding the addressing of girls in science and therefore its impact on gender in the context of science education after the transition to secondary school. Data is collected by episodic interviews with management and staff members as well as qualitative field observations. To analyse the episodic interviews in-depth the documentary method is conducted. The complementary qualitative analysis of the field observations is based on content analysis. Based on the results, previous evidence and current theory, a tailor-made program, which promotes girls after the transition from primary to secondary school, is developed following design-based research. In view of investigated science programs in out-of-school laboratories on secondary level, this study helps to identify valuable advice about how programs should be designed and run to actively promote girls after the transition to secondary school. Hence, this exemplary case study will provide a solid basis for following studies which further promote gender equity in out-of-school science education.

Keywords: Non-formal Learning Environments, Science Education, Gender Issues

INTRODUCTION

Over recent decades, more women acquired STEM qualifications and embarked on STEM careers. Thus, significant progress towards gender equity in STEM has been achieved in many countries (American Association of University Women (AAUW), 2010; Archer et al., 2013). Although an androgynous, science stereotype slowly developed over the last fifty years (Miller, et al., 2018), beliefs about gender-specific interests and competencies still have a negative impact on young women's science self-concept (McNally, 2020). Gender gaps still prevail in multiple STEM fields worldwide, especially in computer science and engineering (Master, 2021; Stoet & Geary, 2018, 2020). Focusing on the German context in particular, this international status quo is apparent in view of taking up studies in computer science, electrical engineering, and nautical science, as well as completing a generally STEM-oriented apprenticeship (Federal Employment Agency statistics, 2019). Based on recent evidence, neither the performance nor the competence of women justify their exclusion from various STEM professions; however, gender differences in preferences and choices are involved (Haffner & Loge, 2019; Dasgupta & Stout, 2014). According to international data on adolescent achievement, girls obtained similar or better results in science than boys in two out of three countries and, additionally, more girls, than enrolled, appeared to be capable of STEM on college-level in almost every country (Stoet & Geary, 2018, 2020). At the end of lower secondary school in Germany, girls achieve significantly better results and higher competence scores in science subjects than boys (Schipolowski et al., 2019). Nevertheless, even girls with equally high science competencies, an identical motivation to learn, and a positive ability self-concept as boys of the same age are reluctant to imagine entering a science-oriented profession (Wieselmann et al., 2020). Regarding the higher percentage of girls, who would like to be successful in STEM and enjoy corresponding study fields than the propensity of women graduating in STEM, many girls internationally lose STEM related career aspirations between secondary and tertiary education (Stoet & Geary, 2018, 2020). Consequently, this decrease might be partially caused by strong stereotypes regarding STEM fields, which are not only favoring boys, but also erecting barriers for girls against STEM-oriented careers (Master & Meltzoff, 2020). Master and Meltzoff (2020, p. 161, original emphasis) differentiate between "stereotypes about *interest*/cultural fit" and "stereotypes about *ability*", which, as they are combined, may cause worries of women concerning the lack of ability both identifying themselves with STEM representatives and succeeding in STEM. Referring to equity and gender within context of education outcomes, men's and women's different career choices are often made early in life (Schleicher, 2019). OECD (2019) exposed that across 67 countries the gender gap in STEM studies is already evident among 15-year-old teenagers. In Germany, girls more often choose linguistic subjects, while boys tend to choose scientific subjects already in school. These preferences persist beyond vocational training and result in a distinction between men's and women's occupations (Haffner & Loge, 2019) as well as aggravating the shortage of skilled workers in several STEM fields. "[Narrowing these gender gaps] requires concerted efforts by parents, teachers and employers to become more aware of their own conscious or unconscious biases so that they give girls and boys equal chances for success at school and beyond" (Schleicher, 2019, p. 32).

To counteract that growing lack of STEM workers in Europe and strengthen the motivation of women for a STEM-oriented career, extracurricular science laboratories have been implemented to promote young people in science (Hausamann, 2012). Without performativity and accountability, conventional education is characterized with (Stocklmayer et al., 2010), out-of-school laboratories play a major role as an educational supplement alongside school to both inform and inspire the youth about science (Ralle, 2020; Dawson, 2019). On site, children and teenagers should not only be encouraged to actively engage with scientific and technical issues and methods, but also gain authentic insights into STEM professions. Therefore, out-of-school learning environments mostly focus on experience-based learning to make STEM tangible through independent, experimental activities and projects (Euler et al., 2015). Young people can be supported to develop science identities by giving them opportunities to leverage their lived experiences as well as shared community wisdom while they are doing science. Additionally, receiving recognition for it is likewise important (Calabrese & Tan, 2018). The value of extracurricular science environments consequently lies in assets-based and participatory approaches, "which seek to respect and value youth and community knowledge and resources" (Archer et al. 2021, p. 168). Since extracurricular programs at the labs are made to adequately fulfil kids' and teenagers' individual learning requirements (Affeldt et al., 2018), Archer et al. (2021) as well as Ralle (2020) note a steadily growing heterogeneity of out-of-school labs, which results in diverse budgets, (lab) characteristics and different organizational and/or content-related approaches.

Despite international, significant improvements in gender equity within science over the last 40 years, entrenched gender differences are still reproduced (Archer et al., 2013). Mokhonko et al. (2014) speculate that the pedagogical design might be responsible for the low, positive effects of out-of-school programs. Recently published research show that out-of-school learning environments "tend to privilege dominant, western, and male forms of doing and knowing" (Archer et al., 2021, p. 170; Archer et al., 2016). Dominant approaches (see above), originally intended to broaden participation, rather maintain than reduce gendered hierarchies in informal science education (Archer et al., 2021). According to Bourdieu (1977) social reproduction emerges through the interaction of habitus (embodied, socialized dispositions) and capital (economic, social, and cultural resources) within a field (socio-historical spaces of positions and position-taking). Based on their socialization including implicit gender beliefs and gender related work, teachers, for example, still tend to have gender biases and discourage even girls who might have aspired to a professional career in STEM (Hand et al., 2017). Furthermore, gender biases influence performances including body language, facial expressions, or voice (Elsen, 2020). Regarding to less attention to girls, existent sexist language in classrooms as well as the absence of women in learning materials/books show that children are still socialized for traditional gender roles (Sadker & Sadker, 2010). Following Archer et al. (2021), who integrated a Bourdieusian (1977) approach with informal science environments' resistance to change, the "field" (e.g., power relations, values, structure, and actors) will play a major role in terms of equitable programs in out-of-school labs. Bourdieu consequently characterized "field" as a "social universe having its own laws of functioning" (Bourdieu & Johnson, 1993, p. 14). So far, research has strongly focused on the impact of lab programs on young people's motivation, identity, and interest regarding science. The influence of the out-of-school lab as "field", however, has not been investigated. Accordingly, this study focuses on the investigation of a chosen out-of-school lab ("field") regarding the promotion of girls in science.

The selected out-of-school lab for this study is in the north of Germany. It offers not only workshops for elementary school classes (grade 3 and 4, age 8-9), but also career orientation workshops for classes on secondary level (grade 8 and 9, age 14-15). In each of those workshops, four students are supervised by one staff member. Workshops, which children and teenager can attend to in their spare time, are additionally offered. Focus of the workshops is science and technology, e.g., building a plant watering system, learning to develop and to finally print an own 3D-figure or experimentally examining air and sound as natural phenomena in everyday life. While physics, chemistry and biology are taught in German primary schools as one combined subject named ‚*Sachunterricht*' (general science and social studies), they formally become separated subjects at the beginning of secondary school (grade 5 or grade 7 at the latest, age 10-13). This is opposite to other countries keeping the integrated science subject on secondary level and opposite to the chosen out-of-school lab.

According to staff, the number of girls attending workshops in their spare time is decreasing – workshops especially designed for girls (e.g., baking workshops) were only selected by boys. This suggests that the field, i.e., staff's orientations and how the workshops are run (use of material, workshop arrangements etc.) might be barriers against addressing girls.

The challenges at the selected out-of-school lab lead to our cooperation aiming at the following research questions:

1. Which factors induce that girls are (not) addressed by the out-of-school lab as "field"?
2. How can the influence of positive factors of the "field" be strengthened and that of negative factors be counteracted by a tailor-made program on site?

METHOD

To answer the research questions, an explorative case study is conducted. The study consists of four main phases following the design-based research approach (Design-Based Research Collective, 2003) to analyse practical problems and develop solutions (Figure 1). This process ensures the quality as well as the efficacy of the solution concept. In summary, the aims of the study are first to identify valuable advice on how the workshops should be designed and run to actively promote girls after the transition from primary to secondary school and second to develop a purposeful, precisely fitting program for a selected out-of-school laboratory.

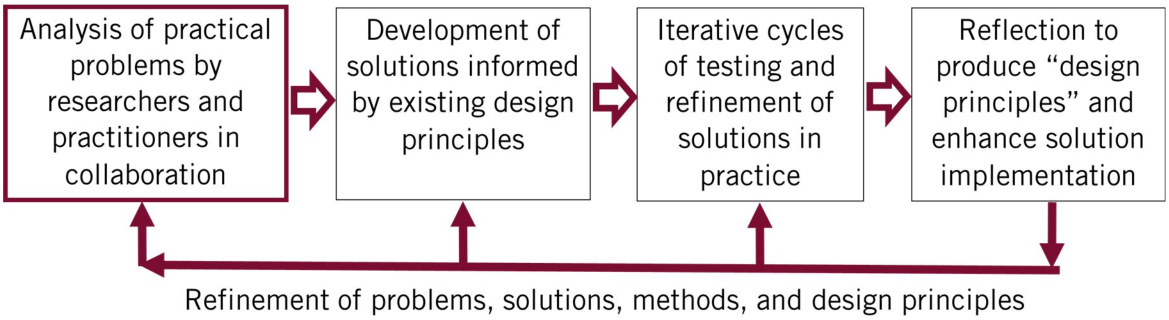

Figure 1. Design-based research approach (adapted from Reeves, 2006, p. 59).

To analyse the practical problems, episodic interviews (Flick, 2011) with staff members (n=4), who work at the selected out-of-school lab full-time, were conducted to investigate how and to what extent girls are addressed. In particular, the episodic interview is characterized by the combination of questions about subjective knowledge and narrative requests for the staff's subjective experiences during their work at the selected out-of-school lab (Flick, 2011). Thus, episodic interviews were not only conducted for precise information concerning knowledge and explicit attitudes, but also to ensure that multi-layered influences in the out-of-school lab are fully exposed during the evaluation. Examples of questions are as followed:

- How do you run your workshops?
- How do young women and men participate in your workshops?
- Based on the experience you just told me: What could be the reason for the girls' different participation during your workshop?
- Can you give me an example of how you deal with this as a teacher in that situation?

To complement the "field" with an overview of pedagogical approaches, use of materials, room arrangements etc., courses representing a cross-section of the lab's program were investigated by participatory observations (n=9) (Flick, 2018). The observations, mainly focusing on the staff's actions, are underpinning the interviews to allow additional factors to be considered. Pre-structured observation protocols and photographs were used for documenting the workshop performance, including shared material and a seating plan. The following data has been additionally collected during every observation: Workshop type, title and topic, participants' red gender, grade level, responsible staff member, further individuals, who watch the workshop activities. Staff members' verbal expressions related to addressing the as boys and girls read students during the activities (e.g., voice colour, length, and content of verbal interaction between staff member and child/teenager, type of (verbal) support) were described and documented as precisely and value free as possible.

To analyse the interview data, documentary method is applied (Nohl, 2010). This enables an in-depth insight into staff members' implicit orientations that influence the pedagogical arrangements and, consequently, whether girls are addressed in the "field". While staff members are aware of what they are saying in the interview, the documentary method allows access to a second meaning level of what is being said, as evidence of a certain attitude (e.g., a loyal attitude, a hypocritical personality) that they do not necessarily have access to. Through a "formulating interpretation", most important (sub)topics regarding their orientation about girls in STEM as research topic will be identified in order to establish, *what* the interviews are about (Nohl, 2010). The following "reflective interpretation" focuses on *how* these beliefs were elaborated and thus on the framework of orientation, in which the orientations are dealt with. Looking at the "modus operandi in which a topic is developed" leads to the focus on interviews' formal and semantic aspects in a next step (Nohl, 2010, p. 204). The observation protocols are complementarily analysed using qualitative content analysis (Kuckartz, 2019). This enables to examine the consistency of the staff's statements in the interviews, about how they support boys and girls to let them equally participate in the workshop activities, with their actual observable actions during the lab courses.

Following the design-based-research approach, the evaluation results gained in phase 1 will be used to develop a theory-based concept to solve the problems currently prevailing at the out-of-school lab (phase 2). The further phases will be successively developed based on the results of the previous phases.

RESULTS

The elaborate documentary analysis is pending. Only preliminary results can be presented. An initial review of the interview material suggests that all full-time staff members, according to their own statements, intent no (conscious) distinction between girls and boys during their workshops. Gender differences in workshop activities are not attributed to the biological sex per se, but rather to stereotypes, role expectations, and "how the students grew up". All interviewed staff members reported about their deliberate use of measures to enable girls and boys to equally participate in their activities. Moreover, information about gender and science education as the interviewers' research fields as well as rough (and well-considered) knowledge of the divergent development of girls' and boys' interest in science, the first author shared in the first meeting, must have influenced the interviewees' choice of words. Three interviewees independently adopted the phrase "historically conditioned" during the meeting, to underpin their attitudes related to the existing gender segregation in STEM. In contrast to her colleagues, one staff member did not take part in the first ever meeting and did not use corresponding formulations. Concurrent with her different choice of words this staff member additionally told the interviewer about stereotypical attitudes of the management about girls in STEM and their existing effect (especially) on the female team members. Consequently, it seems reasonable to both analyse the conducted interviews in-depth and do further interviews with the management (n=2) with an adapted interview manual. Whether and to what extent more interviews are necessary with other staff members, will be determined by following analysis steps through the documentary method for a deeper elaboration of the staff's implicit orientations.

Furthermore, preliminary impressions already exposed due to non-standardised, participatory observations. Indications of differences in addressing girls and boys through the shared material, the use of space, or the staff's body language could not be determined at first glance. In contrast, notable differences on verbal level could be exposed between the addressing of girls and of boys by one staff member, who was the only one with a pedagogical background by studying educational science. For instance, three girls and one boy (grade 8) attended a career orientation workshop to build a plant watering system. In pairs, the teenagers had a laptop to electronically report the solutions for the associated tasks on a learning platform. Both teams sat opposite from each other on the group table. When the girl, who was in a team with the boy, asked the staff member, how she could log in the learning platform, he enumerated the buttons to press on the keyboard and, as if giving step-by-step instructions, told her which words she needed to type in one by one. The boy also seemed to struggle with using the learning platform, as he asked questions about how to select and upload images. In contrast to helping the girl, the staff member first looked at the laptop screen, waited and told him which buttons would be helpful instead. Through observation, it can be additionally surmised that the supervisor mainly responded to the teenagers' actions rather than actively engaging them in the activities. By exclusively asking questions for a deeper understanding of the tasks and working with the platform, mainly the boy interacted with the staff member. The girl, who was grouped with the boy, repeatedly ran with both of her hands through her hair in front of her face or twisted several wires of the electronic circuit between her fingers while sitting between the supervisor and her team partner. Without having analysed the scene in detail so far, this observed behaviour could indicate that she was not addressed by the supervisor by then. In comparison, the other two girls took on the task without asking questions. Two to three times the supervisor approached to them and inquired how the task was going. It was recognizable that the girls spent a large part of the workshop watching the other group. When the teenagers were already gone, the girls' behaviour was described by the staff member as restrained, not interested, and/or unmotivated. Indications of no interest, motivation, or restraint on side of the girls were not observable at first sight. It is also interesting to note at this point that the staff member seems to measure interest in a STEM-topic by the number of times the student participated in the workshop by asking/answering questions. In this context, the as "interested" characterized boy's inquiries were not content-related but administrative regarding how to use the learning platform. Whether and to what extent these initial assumptions can be confirmed must be examined by the qualitative content analysis.

Accordingly, following analyses will focus on the verbal interaction between the full-time staff and the children to further deepen the comparison of their statements about their addressing measures with their actual actions by the qualitative content analysis.

DISCUSSION

A significant number of established out-of-school science environments all over Europe shows that promoting girls and boys in science is an international matter (Hausamann, 2012). The pedagogical approaches of extracurricular concepts in out-of-school learning environments differ sharply, even though they pursue the common, major goal of not only promoting children's and young people's interest and openness towards science and technology, but also enabling inquiry-based learning in authentic learning environments (Ralle, 2020). Because of these differences, it is quite impossible to evaluate and compare their effectiveness by means of empirical studies. Accordingly, an exemplary in-depth analysis of a chosen out-of-school lab, where girls decreasingly attend workshops in their spare time, is conducted to further analyse influencing aspects, for instance the usage of materials or room arrangements, in terms of addressing girls in STEM. Regarding primary impressions without deeper analysis steps, staff members' (verbal) actions towards girls in STEM can be identified as one influencing factor of the chosen out-of-school lab. It seems important for the staff to attend a pedagogical workshop about supervising children in a learning environment and being aware of their influence on children in general. Based on the girls' observed behaviour, the staff member did not seem to address her by his verbal expressions. Accordingly, following analysis steps will focus on further differentiating the influence of staff members' verbal expressions. Consequently, preliminary results not only confirm Arthur et al.'s (2021) approach about the individual influence of out-of-school labs as "field". By an exemplary, in-depth analysis of the staff members, the used material and room arrangements as influencing factors of a chosen lab, the results will also widen the current research about extracurricular learning environments, which particularly examined the effectiveness of implemented programs on site so far.

Once a thorough analysis of the situation on site can be made, specific problems will be chosen to be considered and solved in the developed program. For instance, the program could include a new pedagogical design for the chosen out-of-school science lab, a workshop for the management and staff and other valuable advice on how programs could be designed and run to actively promote girls in science.

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A CARD GAME FOR FOSTERING SUPPORT BETWEEN FEMALE STUDENTS AND PARENTS IN SCIENCE VOCATIONAL ORIENTATION

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Girls and young women of non-dominant ethnicity are less likely to aspire to a career in science. This results in a gender misrepresentation that needs to be addressed in vocational orientation. Research has shown that parents play a major role in vocational orientation in science. Further, talking about science with family and friends contributes to science career plans regardless of parental education. In the research project "DiSenSu - DiversitySensitive Support", this knowledge was used to develop a card game for vocational orientation in science. The game intends to stimulate talking about vocational orientation in the field of science between young women and their parents. It can be used on various occasions outside of school, with or without parents. The goal is to encourage young women with a migration background and their relatives to reflect on science careers. The present study analyses how the card game fosters support between daughters and parents through initiating conversations between the players about science careers, their experiences with science, and their feelings towards the subject. The game was evaluated using quantitative data obtained through game statistics and a questionnaire with Likert items. In addition, qualitative data were collected using recordings of three conversations between daughters and parents while playing the game combined with researchers' observations. The results show that the card game has the potential to initiate conversations about vocational orientation and thereby foster support in vocational orientation in science.

Keywords: Vocational Education, Parental Involvement in Learning, Gender Issues

INTRODUCTION

Career orientation programs are part of everyday school life in secondary schools. In this context, the highest authorities in German education policy, the Ministers of Education, agreed on a resolution that requires all teachers and other professionals involved in school to actively engage in career orientation (Kultusministerkonferenz, 2017). Moreover, the Ministers stated that teachers and other professionals involved have to take into account the identity formation processes of young people because the goal is to allow students to choose a career regardless of stereotypes (Kultusministerkonferenz, 2017). This is an important yet challenging goal for science teachers who are mainly trained for their subjects and often do not learn how to do vocational orientation appropriately (Küsel, Hönig, Rüschenpöhler, & Markic, 2021).

A major challenge in vocational orientation in the field of science and technology is the phenomenon that career aspirations are strongly influenced by gender, class, and race (Archer et al., 2013; Archer, Dewitt, & Osborne, 2015; Archer, DeWitt, & Willis, 2014; Carlone, Webb, Archer, & Taylor, 2015). Women tend to have lower science career aspirations than men (Archer et al., 2010). This translates into a gender misrepresentation in science professions in which women are often underrepresented, especially in Western countries (OECD, 2009). One reason for this could be the very limited range of accepted female science identities (Archer et al., 2013). Similar difficulties are documented for people of the working class and non-dominant ethnicity (Archer, Dewitt, et al., 2015; Carlone et al., 2015).

In the project "Diversity Sensitive Support: vocational orientation in STEM for female adolescents with a migration background in cooperation with parents (DiSenSu)" (Technical University of Darmstadt and Ludwigsburg University of Education; www.disensu.de), career orientation interventions were conducted targeting young women with migration background. The goal was to allow for a vocational orientation for science professions, considering the influence of existing stereotypes in this field on young women.

Certain aspects of the interventions are based on the concept of Science Capital (Archer, Dawson, DeWitt, Seakins, & Wong, 2015), such as the interviewing strategies (Rüschenpöhler, Küsel, Hönig, & Markic, 2020) and the collaboration with parents. Science Capital describes the influences of gender, class, and race on science identity formation as well as on chemistry identity formation (Rüschenpöhler & Markic, 2020). Science capital can be understood as the resources that have value in the field of science. The concept, thus, shifts the attention to the resources that students have. Further, it can guide how to support students in their acquisition of these resources (Rüschenpöhler & Markic, 2020).

Parents and other relatives play a central role in young people's career choices (Esch & Grosche, 2011). This can be problematic because knowledge about science professions is scarce in socially disadvantaged families (Archer, Dewitt, et al., 2015). However, parents can also provide science capital and thus strongly influence their children's career aspirations toward science. Some parents have science qualifications or a science-related job. But even without this science capital, parents can provide resources for their children: talking about science with family and friends can lead to an emotional attachment to science (Rüschenpöhler & Markic, 2020) and thus potentially influence career choices toward science.

In the project DiSenSu, these insights were used to develop an intervention to support young women with migration background in their vocational orientation in science: a card game was designed to initiate conversations between young women and their parents or relatives about science careers. It is based on the science capital approach and was developed, tested, and evaluated.

This article presents the playing cards, the rules of the game, and how this game can be used in practice. Further, the results from the evaluation show how the players evaluate the card game and how conversations about science professions can be initiated. The complete game in German language can be found in Hönig, Küsel, and Rüschenpöhler (2021).

THE GAME

The card game (fig. 1) seeks to foster the Science Capital of the players by initiating conversations about their attitudes and feelings towards science careers. The card game is, therefore, based on certain aspects of Science Capital (Archer, Dawson, et al., 2015), stimulating mutual support between the players in career orientation in science.

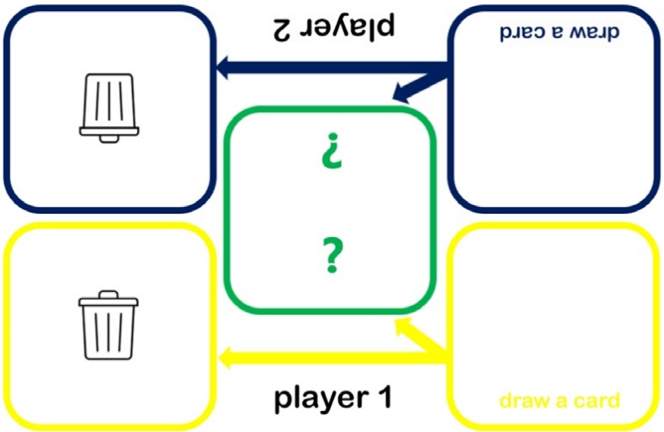

Figure 1. Board of the game for game variant A (a young woman plays with a parent).

In particular, the game is designed to stimulate

- conversations about the players' emotions regarding careers in science,
- conversations about knowledge regarding professions in science, and
- joint action for the career orientation of the young women.

Two variants of the game were developed. Variant (A) was developed for games between a young woman and a parent or some other relative. This variant of game can, therefore, be used in a variety of contexts where parents are present with their daughters, e.g., at career orientation events, at school parties, at clubs, or it can be played individually at home. Variant (B) was developed for games between two young women e.g., during career orientation weeks at school.

The conversations during the game are guided by four types of playing cards:

- *Type 1: Reflection on science professions*. Some cards of this type provide information about a specific science job, combined with a question. Other cards in this category are designed to initiate the players to share their knowledge about and experiences with science jobs.
- *Type 2: Obtaining feedback*. These cards stimulate the players to give each other feedback, e.g., on the person's strengths or if they could imagine the other person working in science.
- *Type 3: Reflecting on the process of career orientation*. Cards of this type contain questions about the process of career orientation in science or on the process in general. Some cards focus on the thoughts and feelings of the players.
- *Type 4: "Imagine…" – adopting the perspective of a person working in science*. These cards stimulate a change of perspective. The players are asked to imagine being in a certain situation or working in a science-related job. Some cards contain questions that stimulate a reflection on gender stereotypes.

Examples of the cards can be found in table 1. Before starting to play, each player mixes the cards of all four types for his/her stack. Then, every player draws a set of cards from his/her stack, and the players play them alternately: player 1 chooses a playing card and presents it to player 2, who has to answer the question. During the turn, player 1 also dismisses a card that he/she does not want to play. Then the game continues with the turn of player 2. The game ends either (i) when all cards have been played/dismissed (ii) when the time is up (this can be defined by the organiser) or (iii) when the players do not want to continue. No one can win or lose the game.

Table 38. Examples for the four categories of cards (Hönig et al., 2021).

(1) **Imagine working in this job.** **What would that be like for you?**  © *Portra/DigitalVision* **Angelina, lab technician specialised in lacquers** I develop new lacquers and monitor their quality. I work both in the lab and on the production site where we test the lacquers. **Tasks.** Developing lacquers, testing, and optimising the formulae, monitoring their quality.	**(2)** **In which field can you imagine me working later?**  © colourbox.com
(3) **What fears do you have regarding your career choice?**  © *colourbox.com*	**(4)** **Imagine you work in a job that you don't like at all. What does this job look like? What don't you like about this job?**  © *colourbox.com*

RESEARCH

For evaluating the game, two aspects were investigated:

(i) Which card types help young women and their relatives to engage in meaningful conversations about career orientation in science?

(ii) How do the players support each other during the game and thereby promote Science Capital? This question was also investigated regarding the specific playing cards which tend to initiate mutual support.

METHODS

Due to the COVID-19 pandemic, an online version of variant (A) of the card game was programmed, which allowed parents and daughters to play the game at home ($N_{parents} = N_{daughters} = 13$). Variant (B) for two girls was piloted as a career orientation intervention in a class of ninth graders (N = 27, mean age: 14) in a secondary school with a high proportion of students with a migration background ($N_{migration\ background}$ = 17; 63 %; $N_{girls\ with\ a\ migration\ background}$ = 9). Since variant (A) for a young woman with a parent and variant (B) for two girls have the same focus and are in many aspects very similar, it is assumed that the research on both variants provides evidence for both research questions. The collected data of the two variants will be analysed separately but discussed and interpreted jointly.

A mixed-methods study with triangulation was conducted using quantitative and qualitative data:

(a) A *questionnaire with Likert items* was used to collect quantitative data from the players of both variants after playing. In the first part of the questionnaire, the players were asked to give feedback on the individual cards and the four card types. In the second part of the questionnaire, the players were asked how far they had shared emotions and knowledge about the process of vocational orientation and professions in science, in the sense of Science Capital. Further, the players were asked if the players could imagine continuing to work together with their game partner in career orientation.

(b) *Descriptive statistics of the gameplay* were recorded. These data were available because it was played online. It was measured which cards were played or dismissed by the players. This served as another source of evidence for the quality of the cards, complementing the self-report data from the questionnaire (a).

(c) *Five conversations were recorded as audio files* ($N_{students}$ = 10). This was possible only for variant (B) for two girls which was played face-to-face in school. The audio data were transcribed and a qualitative analysis was conducted according to Mayring (2014). In the analysis, we focused on the sharing of emotions and knowledge, and which playing cards stimulated the conversations. Further, we tried to determine if the players planned joint action in vocational orientation.

RESULTS

(i) *The four types of playing cards*. The cards were rated differently by the parents and the young women. The analysis of the parents' cards shows that they rated the cards of type 3 (Reflecting on the process of career orientation) as particularly fruitful for the conversation with their child (51% of the played cards; conversation stimulus rating: 2.3 on a scale of 1-3). Card type 3 contained questions such as "What is most important to you regarding your future career?", "Do you talk to your friends about what you want to do when you grow up?", or "Why do you think (or do not think) a science career would suit you?". For the daughters, all card types seemed to be similarly interesting, but getting feedback on how their parents perceived them seemed to be most relevant. The cards of type 2 (Obtaining feedback) were perceived as particularly conducive (36% of cards played, conversation stimulus rating: 2.67). Examples of very popular questions of this card type are: "What type of career can you imagine for me in the future?", "What field do you imagine me working in later?", or "What science careers that you know of could suit me?". In variant (B) for two girls, the results show that the most popular card types among the adolescents were type 3 (Reflecting on the process of career orientation) and type 4 ("Imagine…" – adopting the perspective of a person working in science). Regarding these card types, the conversations were particularly lively in the audio recordings, and 25% of the students expressed in the questionnaires that they would like to have more cards of these types in the game. The other card types (1 and 2) were less popular so that 32% of the students stated they would prefer fewer cards of these types in the game.

(ii) *How the players support each other during the game*. The parents experienced more sharing of emotions ($M_{parents}$ = 3.09; scale of 1-4) than of knowledge ($M_{parents}$ = 2.89) in the conversation. In contrast, the daughters experienced little sharing of emotions ($M_{daughters}$ = 2.21) and more sharing of knowledge ($M_{daughters}$ = 2.72). The potential of the game to stimulate the players to joint action in vocational orientation seemed to be rather limited; parents and daughters could imagine engaging in joint action only little ($M_{parents}$= 2.58; $M_{daughters}$ = 1.95). In variant (B) for two young women, a similar picture emerged for sharing knowledge ($M_{students}$ = 2.32) and the stimulation of joint action ($M_{students}$ = 1.91), with the exception that they experienced a strong sharing of emotions ($M_{students}$ = 2.92).

The descriptive statistics of the online gameplay between parents and daughters indicated that many cards primarily stimulated emotional and content sharing. In contrast, the cards encouraged the players only a little to engage in joint action for vocational orientation. The parents' playing card that particularly prompted the players to share emotions was "What do you wish from us, your family, regarding your future career? How important is our opinion about your career choices to you?". 80% of parents stated that this card fostered emotional support in the conversation. The daughters' playing card which seemed to stimulate sharing of content was the question, "Imagine you were at my age again and you would have to decide on a career path. Would you be interested in a science career? Why (not)?". 36% of the students confirmed this after having played this card. Finally, some cards stimulated conversations in all three aspects, e.g., "What field do you see me working in later?" When this card was played, it promoted either emotional (50%) or content-related sharing (17%) or a shared action (33%).

These results are consistent with the qualitative analysis of the conversations between the players in variant (B) for two girls. The players expressed genuine interest in each other and thereby provided emotional support. In many conversations, while playing, it became apparent that the players' emotional support was not science-specific but referred to career choices in general. For example, they wished the other person a fulfilled future, that his/her profession shall be fun and fulfil his/her wishes. Some playing cards stimulated a sharing of knowledge and attitudes concerning specific scientific professions. However, in variant (B), this exchange was rather superficial and based mainly on the information on the playing cards. They talked very generally about the professions they did (not) wish for and justified this with a corresponding activity mentioned on the card. Rarely did they speak about their own experience. No joint action (such as doing more research together or visiting a career fair) was planned in the game talk.

DISCUSSION

The results show that the card game can initiate conversations about career orientation in science without third parties being present (career counsellor, teachers). The game provided parents and other relatives the opportunity to take an active role in the career orientation of young women. Social Science Capital (Archer, Dawson, et al., 2015) could be promoted. The game encourages young women with migration background to talk about and reflect on professions in the field of science. In particular, it creates a space in which the players can support the young women emotionally by expressing their feelings regarding science. In some cases, we also observed an exchange of knowledge and other content related to professions in general and the science professions presented on the playing cards. Thereby, the young people can develop new resources in the sense of Science Capital. The card types 3 *(Reflecting on the process of career orientation)* and 4 (*"Imagine…" – adopting the perspective of a person working in science*) seemed to be most effective to initiate conversations about career orientation in science between young women and their relatives (variant A) or two young women (variant B). Both variants of the game can be found in Hönig et al. (2021).

The evaluation also showed that, before playing the game, it would be important to clarify what science is and what professions might be science-related. If this is not clear, it is difficult to use the game in a way that is beneficial for all participants. When analysing the qualitative data, we noticed that many students lacked this knowledge, which made it difficult for them to engage in meaningful conversations. Moreover, some showed a low science self-concept and some stereotypes ("you have to be smart for that") or misconceptions ("being a doctor is not a scientific profession") and could not use the game fruitfully.

Therefore, it would be beneficial to discuss in class what science is and what professions are science-related, before playing the game. Alternatively, the game could be used at the end of the school career of students who have already dealt with these issues more intensely in school and in their free time. At this stage, more knowledge could be available among the young people to initiate good conversations while playing the game. However, this runs the risk that students have already made their choices.

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INVESTIGATION OF THE EFFECT OF UNDERGRADUATE STUDENTS' HIGH SCHOOL PHYSICS IDENTITIES ON THEIR CAREER SELECTIONS

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In this study, the aim was to form a casual path model with a mediator variable for career choice, which involved the variables of career outcomes, high school physics experiences, high school physics identities as the multipredictors of the career choice of a group of undergraduate students. The direct, indirect and total effects of career outcomes, high school physics experiences, high school physics identities on career choice in the pertinent model were examined in the research which was set up as a predictive correlational research model. The study group of the research was determined by stratified objective sampling method. The study group consists of a total of 693 first year students of which 77.8% (n = 539) female and 22.2% (n = 154) male in a state university. The students continue their education in physics, mathematics, chemistry, biology, physics teacher, mathematics teacher, chemistry teacher, biology teacher and science teacher. Demographic Information Questionnaire, High School Career Output Expectations and Physics Experiments Questionnaire and Physics Identity Scale developed by the researcher were used in obtaining research data. Data were tested via path analysis. This research has achieved two conclusions. The first result is about whether the physics identity scores of students according to sex differ or not. Unlike other researches, in this study, girls had higher scores in physics identity and in all sub-identities than boys. This result, which is different from other researches, may be a new and different experience for researchers and teachers. The second conclusion is that physics identity is a strong predictor of students' career choice in areas related to basic sciences. This conclusion emphasizes the perceptions of students about physics and the importance of those perceptions on career preferences. These findings provide a basis for future research as well as directing educators and researchers to understand how they could affect students' physics identity

Keywords: Pre-service teacher education, Gender issues, Quantitative methods

INTRODUCTION

The development of physics science as a field lags behind the growth of other science, technology, engineering and mathematics (STEM) fields (Irving & Sayre, 2015). Therefore, the number of students who choose to be a physicist is also less (Woolnough, 1994; Seymour & Hewitt, 1997; Hazari & Potvin, 2005; Oon & Subramaniam, 2011). It is reported that the number of university students who choose to work in the fields of physics, engineering and mathematics has decreased in many countries in Europe (Osborne & Dillon, 2008). However, although students who are successful in physics are more likely to turn to STEM fields (Tyson et al., 2007), it is seen that the problem of keeping students in the field of physics negatively affects the rate of development of this field (Irving & Sayre, 2015). In this manner, professional identity development is an important element that can affect students' academic and future career development.

Identity, which researchers especially emphasize and perceives as an analytical tool in order to understand the school and society, is an element that has many different meanings. The concept of identity has a quality that takes its roots from Lev Vygotsky and Erik Erikson and is associated with psychological and sociological processes. Identity is defined as the participation of individuals in the world and how this participation is interpreted by others (Erikson, 1980; Gee, 2000). It is suggested that the effect of the interaction of individuals in the social environment in the development and transformation of the concept of identity has a function in terms of raising the awareness of individuals themselves. In this sense, it supports the argument that individuals' identity is shaped as a result of sociocultural influences in the fields of education and training, career choice, and may tend to make choices accordingly (Irving & Sayre, 2015).

Expanding the identity development approach developed by Carlone & Johnson (2007), Hazari et al. (2010) listed the processes that affect students' physics identity development as follows: • Interest was defined as the personal desires of individuals to understand and learn more about the field of physics and the voluntary activities they exhibit in this field. • Competence is defined as people's beliefs about their ability to understand the contents of physics. • Performance is defined as the beliefs of individuals in their ability to perform tasks related to certain physics issues. • Recognition is characterized as recognition of people as physicists by others.

Within the framework of these concepts, Hazari et al. (2010) consider the concepts of interest and recognition to be the main factors in students' self-definition as individuals from the field of physics. In addition, they argued that the concept of physics identity is "quasitrait" and is an element that can change over time with different learning experiences.

Gillibrand et al. (1999) examined the participation of female students in physics lessons in single and mixed schools, and in the study, they conducted in England, female students were discussed in terms of self-confidence and perception of success. In the study, it was stated that female students were less prominent than male students in physics lessons, and this gender imbalance was higher in upper grades. Haussler and Hoffman (2000) conducted an intervention study in Germany in order to increase the interest and success level of female students in physics lessons and to ensure the formation of self-concept. It has been mentioned that it is important to create an educational environment where changes are made in the curriculum depending on the students and their experiences. In addition, it is thought that teachers should be competent in supporting female students in terms of developing self-concept and physics identity, and the school should have different conditions in order for female students to have the opportunity to develop physics identity. In the intervention study developed in the context of these goals, the sixty-hour physics course was restructured, and then the students were measured about the achievements in the course. According to the results obtained, it was determined that the lessons that were restructured considering the orientation, experience and interests of female students gave successful results. In another study, which deals with the effects of high school physics courses and emotional factors on the development of physics identity, it is discussed whether the gender difference in terms of these factors causes a significant difference among the students who take the physics course, which is given as an introductory course in the first year of universities. Hazari et al., in this study conducted in 2007, applied questionnaires to 1973 university students who took physics courses at the beginner level. Variables related to demographic and previous learning of students were also examined (Hazari et al, 2007). In line with the results obtained, it was seen that the physics course and emotional experiences taken in the high school period had different results in terms of predicting the performance of female and male students. It was determined that the variables that were predicted at different levels in girls and boys were long written problems, cumulative exams, father's encouragement of his child and family's thought that it is good to have a career in science. On the other hand, the factor that has been found to have a similar effect for female and male students is that high school mathematics education, which is one of the previous learning, affects the physics performance at the university (Hazari et al, 2007).

In summary, students do not feel that they belong to basic sciences, they are not interested and they do not see themselves as talented. For this reason, what needs to be done is to ensure that students develop an identity for basic sciences starting from high school and even primary education. In this context, this study will make an important contribution to increase the interest in basic sciences, as it will be determined how the students' high school physics identities develop and how much it affects their career choices. The high school physics identity scale developed within the scope of the study will provide information about the high school physics identities of first year university students.

METHOD

In this study, a model was developed for investigating the effect of high school physics identities on career choices of university students, and a multi-factor complex predictive correlational design was used to examine the structural relationships between career outcome expectations, high school physics experiences, high school physics identities and career choices (Fraenkel, Wallen, & Hyun, 2011). The working group of this research is the first-year students of the Physics, Chemistry, Biology and Mathematics departments of the Faculty of Science and Arts at a state university and the Physics, Chemistry, Biology, Mathematics and Science Teaching Department of the Faculty of Education. 712 participants were included in the study. The responses of the participants to the data collection tools were subjected to pre-evaluation and 19 observations that left the child of the items blank (at least 5%) were excluded from the analysis. Analyzes were conducted with 693 participants. In the study, the High School Physics Identity Scale and the High School Career Outcome Expectations and Physics Experiences Questionnaire were used. High School Physics Identity Scale is a 5-point Likert type scale consisting of 22 items developed to measure the high school physics identities of university students. The validity and reliability studies of the scale were carried out by the researchers and it consists of 3 sub-dimensions: interest, recognition and competence-ability. The High School Career Outcome Expectations and Physics Experiences Questionnaire was also developed by the researchers to measure the high school career output expectations and physics experiences of university students and consists of 111 items.

RESULTS AND DISCUSSION

The model created to determine the factors affecting the High School Physics Identity is given below.

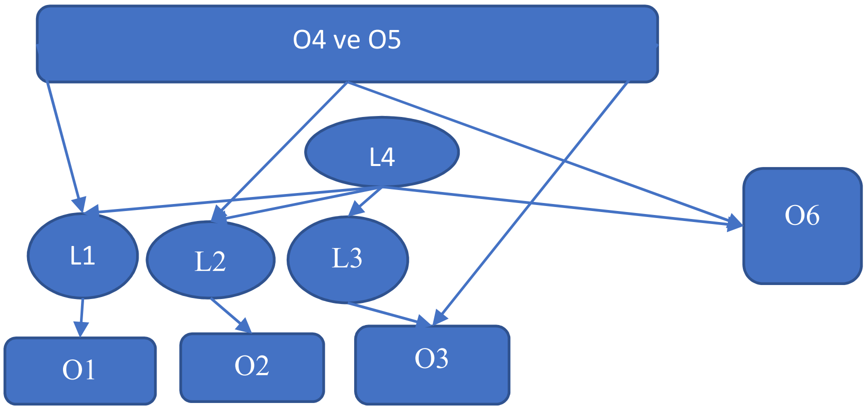

Figure 1. Generated Structural Equation Modelling for the research and the Path Diagram.

O1: Observed Variables 1 - Variables Forming Recognition Sub-Dimension; O2: Observed Variables 2 - Variables Forming Interest Sub-Dimension; O3: Observed Variables 3 - Variables Forming the Competence / Performance Sub-Dimension; O4: Observed Variables 4 - High School Career Outcome Expectations Variables; O5: Observed Variables 5 - High School Physics Experiences Variables; O6: Observed Variables 6 – Division/Program Variable; L1: Latent Variable 1 - Recognition; L2: Latent Variable 2 – Interest; L3: Latent Variable 3 - Competence / Performance; L4: Latent Variable 4 - High School Physics Identity

The hypothetical model created based on the relevant field literature and given in Figure 1 has been tested. All t values in the model obtained are statistically significant. After determining that the t values of the created model were statistically significant, the goodness of fit values of the model were evaluated. the goodness of fit indices of the physics identity measurement model can be said to be at the perfect fit (TLI=.935; CFI=.941; SRMR=.030; RMSEA=.029; $\chi 2/df = 1.51$). In this framework, it can be said that the model created as a result is confirmed. The coefficient of determination of the created and validated model was obtained as .165. According to this statistically significant result, the Physics Identity variable explains 16.5% of the variance in the department variable of the first-year university students forming the research group. The effect value of Physics Identity, which has a direct effect on the department they chose, was .406. Some other variables were found to have indirect positive effects and some indirectly negative effects.

In the relevant literature, it is stated that female students show a lower level of interest in science than male students. In this study, the high school physics identity scores of the female students were found to be higher than the scores of the male students. Peter and Horn (2015) stated that women's career interest in many fields has increased, but this interest has not yet turned to physics and engineering fields, and moreover Sadler et al. (2012) stated that gender difference in STEM career choices of male and female students is more prominent in the field of engineering rather than basic sciences.

When the high school physics identity scores of the students according to their departments are examined, the high school physics identity scores of the students studying in physics and physics teaching were found to be significantly different from the students of other departments. The difference between the scores of physics and physics teacher students is not significant.

This situation can be seen as an indication that high school physics identities have an effect on the choice of physics and physics teachers in choosing these departments. Again, it was determined that the high school physics identity scores of mathematics, mathematics teacher and science teacher students were significantly different from the high school physics identity scores of biology and chemistry students. This may be an indication that high school mathematics and physics courses affect the choice of career in physics and mathematics together. In parallel with this finding, Lock et al. (2013) state that mathematics interest positively affects physics career choice. Again, Godwin et al. (2016) stated that both physics and mathematics identity affect the career choice in engineering and Godwin et al. (2013) found in their structural equation modelling study that the engineering identity is formed by the effect of physics, mathematics and science identities.

Many other studies in the related literature (for example, Lock, Hazari, & Potvin, 2013; Hazari et al., 2010; Carlone & Johnson, 2007; Shanahan, 2007; Barton & Yang, 2000) also show that students' high school physics identities are effective in their career choices related to science. Again, Tai et al. (2006) found in their longitudinal study that middle school eighth grade students' high science identity predicted their choice of science career at university.

CONCLUSIONS AND RECOMMENDATIONS

This research has achieved mainly two conclusions. The first result is about whether the physics identity scores of students according to sex differ or not. Unlike other researches, in this study, girls had higher scores in physics identity and in all sub-identities than boys. This result, which is different from other researches, may be a new and different experience for researchers and teachers. The second conclusion is that physics identity is a strong predictor of students' career choice in areas related to basic sciences. This conclusion emphasizes the perceptions of students about physics and the importance of those perceptions on career preferences. These findings provide a basis for future research as well as directing educators and researchers to understand how they could affect students’ physics identity.

Although there are sub-dimensions of interest, recognition, competence and performance in the conceptual framework of physics identity defined by Hazari et al. (2010), competence and performance dimensions could not be differentiated in this study and emerged as a single dimension. In other words, students see understanding physics and performing in physics as one thing. Studies can be conducted on why students cannot separate these two dimensions. Because, in the study of Carlone and Johnson (2007) with scientists, it was determined that these two dimensions were separated from each other. In the light of the findings obtained in that study, it can be suggested as a hypothesis that students combine understanding physics and performing in physics in one dimension due to the measurement and evaluation methods used. Future studies can be conducted in this direction.

The results of this study showed that physics identity development is a complex process and high school physics identity has an impact on career choice in basic sciences. The model obtained in this study, which reveals the high school physics identity scale and the factors affecting high school physics identity for university students, gives important clues for physics educators, other field educators, physics teachers, families and policymakers.

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AN INFORMAL PHYSICS CLUB WITH YOUNG WOMEN LEADERSHIP: A COUNTERSPACE FOR DEVELOPING PHYSICS IDENTITY

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Research shows that by the time female students reach high school age they are much less likely than other students to see themselves as "physics people," and are less interested in pursuing physics majors or physics-related careers as they enter higher education. This lack of interest, which is often the result of societal and cultural factors, contributes to the persistent marginalization of women in physics. In addressing this historical problem, physics teachers can play a critical role in engaging young women and challenging stereotypic ways of thinking about and doing physics. In particular, by disrupting traditional cultural messaging and norms, teachers can facilitate young women's physics identity development. However, the existing culture of power in many physics classrooms, structural constraints of formal schooling, and often restricted curriculum may not provide a safe space for female students to enact physics identities in ways that are personally meaningful. Thus, we argue that counterspaces beyond existing classrooms are needed to create and sustain engagement. In this exploratory investigation, we examined the characteristics of an informal physics club initiated by a high school physics teacher and run by his female students to understand if and how this club emerged as a counterspace that promotes physics identity development for female students. This paper focuses on data from a focus group interview with five leaders of the club and the physics teacher. We show that recognizing and celebrating communal goals in this club, along with young women's leadership, were important factors in creating a counterspace for physics identity development. As such, we recommend establishing these types of informal physics learning spaces as counterspaces that can facilitate the development and expansion of physics identities among female students.

Keywords: Non-formal Learning Environments, Gender Issues, Physics

INTRODUCTION

Studies have highlighted the persistent underrepresentation of women in physics as well as the depressed opportunities for young women's physics identity construction (Hazari, Cass, & Beattie, 2015; Wang & Hazari, 2018). As a consequence, by the time female students reach high school age, they are much less likely than their male counterparts to see themselves as "physics people" (Nissen, 2019). Despite this fact, female students who choose to continue their physics education in college have been found to be strongly affected by their high school physics experiences (Hazari, Brewe, Goertzen, & Hodapp, 2017). This finding indicates that physics teachers can and do play a critical role in reversing a downward trend in attitudes towards physics. As such, a national project was launched to mobilize high school physics teachers to begin addressing deep-seated historic issues of gender bias and facilitate physics identity development, particularly for female students (Cheng et al., 2018; Potvin et al., 2022). Drawing from critical race and feminist theories, the resources provided by this project focus on presenting counternarratives that disrupt normative stereotypic narratives about who does physics and what physics is. These classroom resources have been shown to have significant positive effects for female students' physics identity development and intentions to continue studying physics (Cheng et al., 2018). However, the existing normative nature of school science often transmits a culture of power (e.g., curricular boundaries, lack of student agency, teacher-centeredness) (Barton & Yang, 2000). Therefore, it is difficult to sustain counternarratives or disruptions to normative identities/content/practices without creating new spaces. Prior work, which mainly focused on the college-level or workplace, found that "counterspaces" were a critical solution for establishing and sustaining counternarratives (Ong, Smith, & Ko, 2018).

COUNTERSPACES, COUNTERNARRATIVES & COUNTERSTRUCTURES

Solorzano, Ceja, and Yosso (2000) defined counterspaces as spaces in which there are active or proactive attempts to prevent the reproduction of marginalizing patterns and that allow minoritized groups to engage in learning and reflect on their experiences in ways that help grow their sense of belonging and nurture their multiple identities. In the context of physics education, counterspaces can create an environment where historically marginalized groups (e.g., young women) can develop a shared physics identity beyond the normative stereotypic constructions. Ong et al. (2018) posit that counterspaces are a critical refuge from negative and marginalizing experiences in STEM, such as microaggressions and low sense of belonging, that lead minoritized groups to disengage from the discipline.

Within counterspaces, counternarratives that resist stereotypic ways of doing physics emerge and are supported. For example, physics is not perceived to be communal, either in terms of learning (e.g. working together) or what goals are valued by the field (e.g. helping others/society), but is perceived as individualistic, where demonstrating "innate ability" or individual mastery are centralized in both the learning process and what is valued (Carlone, 2004; Kessels, Rau, & Hannover, 2006; Leslie, Cimpian, Meyer, & Freeland, 2015). These normative patterns of what it means to learn physics and how that learning occurs can be disrupted within counterspaces creating new counternarratives about physics learning.

We also draw on the concept of a counterstructure, which can be conceived as a characteristic of counterspaces. It is defined as active institutionalized attempts to support marginalized groups' efforts by shifting control from brokers of power within traditional structures (e.g., white males, teachers) and centering agency and control amongst the marginalized (Lee & Harris, 2020). In traditional science classes, including physics, normative power structures typically prevail due to the constraints imposed by historic educational and curricular standards and expectations (Barton & Yang, 2000). Thus, counterspaces are often necessary to enable counterstructures of power to form and over time influence change in other spaces. Guided by these theoretical concepts, we examine the development and impact of an informal physics club for female students that was initiated by a high school physics teacher. This exploratory investigation examines how the club served as a counterspace for physics identity development and if and how counternarratives and counterstructures were supported.

METHOD

As an exploratory investigation into a physics club of predominantly Latinas (that had been independently initiated by a physics teacher and which had rapidly grown over three years), we conducted a narrative-focused group interview to begin understanding the ways in which this club may be creating a counterspace for young women of color. Previously we had informal conversation with the physics teacher and administered a pre-post survey on physics identity among club members. However, the data for this study came from a 90 minutes focus group interview. The interview was conducted with the physics teacher and five student club leaders, all-female, four in 12th grade, and one in 11th grade. All the students self-identified as Hispanic. Guided by our theoretical lenses, we used thematic analysis (Clarke & Braun, 2017) to identify features of the club that promoted physics identity development through shared multiple identities and sense of belonging among the members (counterspace), non-normative narratives with respect to physics and physics learning (counternarratives), and agential non-dominant structures (counterstructures). In the next sections, we introduce Mr. S, the physics teacher, and what inspired him to start a physics club, followed by findings of the analysis and emerging themes. Note that emphasis (bolding) in the quotes was added to illustrate central points related to the themes.

HOW THE PHYSICS CLUB STARTED

Mr. S was a teacher we had worked with as part of a larger study and contributed to the development of equitable/inclusive class resources. He has been implementing these co-created resources in his physics classes for four years (and still continues). Mr. S's background is in engineering and physics, and he has more than 35 years of experience teaching physics and other science courses (e.g., environmental science). His school is located in a large urban district with a high representation of Hispanic students (more than 90 percent). Prior to the physics club, Mr. S started an engineering club as part of the Southeastern Consortium for Minorities in Engineering (SECME). But since his participation in our larger study, he felt the need to go beyond the confinement of curriculum and class time to better engage and encourage his students, particularly young women, towards their physics learning and career pathways.

> The club is just to promote, just to do activities in the school and [...] students can see those activities. [...] I promote [physics] to everybody. **But the girls**, after the second lesson[10], **they're going to feel more attraction for [physics]** and [...] they realize they can do it. [The] lesson basically motivate many of my students to be part of the physics club. They ask me about that [...] **then I start to talk to them to participate in the club.**

[10] Mr. S refers to the Women in Physics Lesson, one of the class resources developed in our larger project. The lesson challenges narratives that relate physics to masculinity and frame physics as an individualistic pursuit of "pure" science as opposed to a culturally driven field and community and exposes the structural and cultural barriers that prevent many individuals, particularly women, from pursuing physics. Read more about it in Sabouri et al. (2022) and refer to the website for the full lesson (APS engage, 2022).

The club started with about 16 members and over three years it grew to 27, which was when we conducted the focus group interview. The club activities included participating in workshops, attending presentations by invited speakers from universities, organizing career fairs and science nights for parents and students, and participating in regional and national science competitions. These activities can be characterized as normative types of physics activities (e.g., competition or presentation). However, after analyzing the interview transcription, two themes emerged indicating how the club was a counterspace with a counterstructure promoting new ways of learning physics, hence disrupting normative narratives of physics: (1) the leadership by young women, and (2) the communal culture of the club. Next, we further explain these themes and present evidence from the interview data.

GIRLS' LEADERSHIP CREATED A COUNTERSTRUCTURE

Since the establishment of the club, Mr. S has been purposefully encouraging his female students to join the club. Moreover, he identified those with strong leadership skills and invited them to take the club's management role (e.g., president).

> I give [my female students] the chance to have the position, [...]according to the history in this school, I really like to give [them] **an opportunity** [...] **that I think they deserve**. […] (Mr. S)

In addition to nurturing their skills and potentials, by positioning the young women as leaders, Mr. S anticipated that other students would see them as a role model which would encourage them to participate in club activities and experience physics learning, although they might not necessarily feel comfortable or confident to do so.

> If we do organize a club with a very good leadership, like [these students] are, **they [become] examples, you know, as a student**. [They] are responsible and **the other students see them as leaders** [and] they see that they can [be] [...] I know if I do this, we are gonna have a lot of people here [in the club]. (Mr. S)

Mr. S's recognition was not hidden but visibly noticed and acknowledged by the members.

> Mr. S approached me and (Angela) […] he asked us both because …well, I assume **he liked our work and how we work together** [...] he asked us to be president and vice president of the [club]" (Blanca).

Prior research studies showed that teachers' recognition in ways that are meaningful for students is a strong predictor of whether they identify as a physics person, someone who can learn and do physics (Hazari et al., 2017; Wang & Hazari, 2018). Drawing on these findings, in this club, we state that Mr. S's recognition and encouragement facilitated students' physics identity development, and that motivated other students, in particular female students, to join the club.

> I remember having a friend of mine **at first, she was so confused and she didn't understand Physics**. And then [...] she entered the [club] and actually organized the stuff and everything, she was just like… This is really interesting. And it's not as complicated as I thought (Cara)

By positioning female students as club leaders, Mr. S shifted the typical power structure, often seen in STEM clubs, where male students overtake the decision-making and material manipulation (Witherspoon, Schunn, Higashi, & Baehr, 2016). Cara, who did not initially see herself as a physics person, took on a leadership role (organized) which helped her more meaningfully engage in a way that she directed for herself. We argue that designating leadership positions (at least initially) to female students and recognizing their skills created a counterstructure for this club, which led to bringing other young women into the club to engage with physics learning and take leadership in this space.

COMMUNAL GOALS & AMBASSADORSHIP PROMOTE COUNTERNARRATIVES

Two existing narratives around physics are: (1) it is an individualistic field as opposed to a collaborative and communal discipline (Bruun, Willoughby, & Smith, 2018; Kessels et al., 2006), and (2) it positions innate ability found in a dominant group, mainly white males, or exceptional cases of other groups (e.g. women) as superior and necessary for learning and succeeding in physics (Archer, Moote, Francis, DeWitt, & Yeomans, 2017; Leslie et al., 2015). These normative narratives around physics often discourage female students, unconsciously and consciously, from engaging in learning physics (Diekman, Brown, Johnston, & Clark, 2010). In contrast, in this physics club, both of these narratives were challenged and disrupted.

> [T]he people in the club […] **were really welcoming. And if you didn't know the subject they would teach you**, help you to understand more. And that sense of community also really helps me […] want to stay here and I want to help others to understand and be more interested […], to share that common… like in the subject. (Cara)

Instead of identifying certain types of talents or "ability" in physics, the club members welcomed everyone and supported each other in learning physics. The "sense of community" as opposed to competing established the club as a counterspace. Moreover, members recognized the communal culture as a vibe of the club:

> …all of us in the club have that dedication, that time management, that ability to be flexible for the club and be able to stay after school and **show a love for the club** through lab demonstrations, **through helping other classmates with physics work**. (Angela)

These young women not only saw the club as a safe space to expand their physics identity and create engaging and meaningful learning environments for themselves, but they also became motivated to inspire others to pursue and persist in learning physics.

> I had this fire to show that women can also do it, to show others who have that idea and that stigma […] women aren't really seen and they shouldn't be in it. So that would **draw me to help the club be the best** it can just to show everyone that minority such as women and Latinos can also be a major role in Science." (Angela).

Angela felt that it was important to be an ambassador for others to disrupt normative notions about women and LatinX students' place in physics. Together with the communal focus of the club, this became a way in which the club promoted counternarratives that resisted dominant narratives about who does physics and how it is done.

CONCLUSION

Several research studies have shown the effectiveness of informal science programs (e.g., afterschool or summer camp) as a way of engaging young women in science learning and developing their science identities (Adams & Gupta, 2017; Riedinger & McGinnis, 2017). However, a limited number of studies have focused on physics learning and mainly explored the impact of informal programs on college-level students (Fracchiolla, Prefontaine, & Hinko, 2020; Hazari, Dou, Sonnert, & Sadler, 2022; Prefontaine et al., 2021). In this study, we aim at addressing this gap in the literature by examining the characteristics of an informal physics club that facilitated female students' engagement in physics activities and learning, particularly in ways that might disrupt normative conceptions.

The theoretical lens of counterspaces, and within them, counterstructures and counternarratives, guided our exploratory study utilizing a focus group interview with club leaders and the founding physics teacher. We learned that designating leadership positions to young women disrupted the normative power structure and created a counterstructure for this club. Unlike formal physics/science classrooms, where male students often dominate the conversation and the flow of the activities (Wieselmann, Dare, Ring-Whalen, & Roehrig, 2020), in this club female students were responsible for decision-making and setting the norms. This counterstructure, initiated by the teacher, encouraged female students who may not have seen themselves as a physics person to engage in the club and shifted their views about physics learning. Prior work in physics has shown that certain types of leadership ("inchargeness") can actually lead to more equitable interactional outcomes such as when the student leader distributes voice to others (Jeon, Kalender, Sayre, & Holmes, 2020). Similarly, the club under the leadership of highly communal young women became a counterspace for facilitating and nurturing female students' physics identity development. Additionally, all five club members emphasized that pursuing and promoting communal goals were at the heart of the club. The establishment of a collaborative and communal culture allowed the emergence of counternarratives about physics which, as a result, was encouraging others to join the club and see themselves as physicists.

We acknowledge the limitations of this small exploratory study and do not claim the generality of these results. Furthermore, while there were non-normative constructions of physics learning in the club, many normative approaches to physics were also upheld. For example, more work is needed to better understand how normative physics content can be disrupted within informal spaces. However, theorizing how structures/experiences within this particular club facilitated the development of a counterspace is important; by leading the club's activities, these young women created a joyful, safe and meaningful learning space for themselves. As such, we recommend that counterspaces with similar counterstructures in informal STEM education might provide a critical opportunity for challenging and disrupting normative physics narratives that marginalize young women from participation and pursuit of physics.

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SCIENCE EDUCATION FOR THE DEAF: THE USE OF THE MUSEUM TO PROMOTE POPULARIZATION OF SCIENCE

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This work aims to understand how Science Museums can promote the popularization of science, with focus on deaf visitors, through a case study conducted in Brazilian museums. Teaching science to deaf students in Brazil represents a challenge in Brazilian schools considering the lack of sign in the Brazilian Sign Language (Libras), causing the scientifical exclusion of deaf students in the process of learning and teaching science. Considering that, teaching science to deaf persons can make use of complementary resources, like Science Museums. Those are informal education spaces that acts on subjective aspects and allows the construction of collective identity, allowing the inclusion and, consequently, the popularization of science to the deaf community. This case study considers interviews with three professionals that work in Brazilian Science Museums and attend deaf visitor and was analysed by Analysis Content, and result in four categories, namely Measures of Accessibility, Visibility, Exclusion Factors and Access to knowledge. With this research, it was possible to recognize how Science Museums have promoted the inclusion of the deaf community through activities of Popularization of Science, but it was recognized that the development of research in the inclusion of the deaf in the field of science still needs to be carried out, in addition to projects to include this community in informal educational spaces, such as Museums and Science Centers.

Keywords: Inclusion. Informal Learning. Science Education.

THE POPULIZATION OF SCIENCE TO DEAF PERSONS IN BRAZIL

Teaching science to deaf students in Brazil represents a challenge, considering the lack of sign in the Brazilian Sign Language (Libras) that correspond to scientific terms (Rumjanek, 2011). The main cause is the historical scientific exclusion of deaf students in process of learning and teaching science, as described by Rumjanek (2011, p. 19) that says that "the exclusion of deaf on the scientific process made Libras be poor in scientific and technological terms, hindering the bilingual teach of science". Besides that, the complexity of the scientific concepts and the need of abstraction required to understand those concepts are also considered a challenge to teach science to deaf students.

Considering that issues, teaching science to deaf persons need to be made in their own sign language (Quadros, 1997) and make use of complementary resources, like visual elements and the use of different educational spaces, like Museums of Science and Technology (Gomes, Catão & Soares, 2015). Those spaces can arouse interest in science (Cnpq, 2015), becoming allies for science education aimed at deaf students, since they have a strong visual appeal, favouring discussions about scientific content.

Museums as allies to Science Education for Deaf visitors

Museums are informal educational spaces, it means that they are, by definition, different environments comparing to the school, and the process of education in these spaces occurs through "processes of sharing experiences" (Gohn, 2006, p.28). Besides that, the informal education acts on subjective aspects and allows the construction of collective identity, which is “one of the great highlights of informal education today” (Gohn, 2006, p.29).

Many Brazilian science museums are concerned about the need of producing content in English for its exhibitions ensuring accessibility for foreign visitors. However, the same doesn’t occur with Libras, the language of the Deaf community in Brazil, making the Deaf visitor feel like a foreigner in their own country, in a space inaccessible to them (Silva, Rojas & Teixeira, 2015). Thus, when the Deaf community has limited access to places that are social reference, frequented by Brazilian and even foreign visitors, they become socially vulnerable, failing to fully participate in the society in which they live, which leads to their exclusion (Aidar & Chiovatto, 2011).

Thinking about the inclusion of these visitors and promote science education, Chalhub, Benchimol & Rocha (2015, p.4) suggest that Museums can afford “the presence of fluent employees in the sign; the presence of guide interpreters for the deaf in the exhibitions; presence of video-guide, with signs and subtitled, explaining the exhibition; presence of SignWriting (sign language writing) explaining the exposed collection” and others. Thus, in addition to inclusion, Museums are also strong allies in science teaching because the proposals related to science teaching bring the need for the active involvement of students in the activities developed in those spaces.

CASE STUDY

Identifying the challenges described above, we carried out a qualitative survey to understand how Science Museums can promote the science popularization, with focus on deaf visitors, developing a case study with three professionals that work in Brazilian Science Museums and attend deaf visitors. Semi-structured interviews were conducted online and analyzed by content analysis, described by Laurence Bardin in 1979, between the months of July and August 2020.

To select the sample of professionals and educators who work with science popularization aimed at the Deaf in Museums and Science Centers, a search was carried out for accessible Brazilian spaces through the Guide to Accessible Science Centers and Museums in Latin America and from the Caribbean (Norberto Rocha *et al.,* 2017), carried out by the Accessible Science Centers and Museums Group (MCCAC Group). In this guide, there are identified 69 accessible scientific spaces in Brazil of which 18 present some type of activity for the Deaf. Considering the characteristics of each one, we selected three Brazilian spaces that promotes science popularization activities for Deaf visitors, namely: *Fundação Planetário da Cidade do Rio de Janeiro*, *Centro de Ciências da Universidade Federal de Juiz de Fora* and *Espaço do Conhecimento da Universidade Federal de Minas Gerais*.

After the interviews, the content analysis was carried out, which is a deductive and inferential process regarding the understanding of a given message and is divided into three chronological poles: pre-analysis; exploration of material and treatment of results, inference and interpretation (Bardin, 2011), resulting in four categories, described below.

RESULTS

The interviews were analysed by Content Analysis and resulted in a total of 321 registration units (R.U.). This data was organized into categories, originating 29 initial categories, which were again grouped into 12 intermediate categories to finally obtain four final categories: Accessibility Measures, Visibility, Exclusion Factors and Access to Knowledge (Table 1).

Table 1. Total categories and frequency.

Final Category	Intermediate Category	R.U.	Frequency (%)
Accessibility Measures	Accessibility measures Specialized service Partnerships with institutions and employees Opportunities for deaf visitors	110	34,4
Visibility	Representativeness Personal Motivation Dissemination	88	27,4
Exclusion Factors	Lack of accessibility and visibility Impediments Prejudice	78	24,3
Access to Knowledge	Science popularization Expansion of access	45	14

Font: Authors (2021).

Below are described the results of each category.

Accessibility Measures

The first category addresses measures related to accessibility in museum, considering the importance of having a specialized service, the realization of partnerships with institutions, employees and schools and the opportunities that are created to allow this accessibility. This category represents 34% of the total. Four intermediate categories were identified within Category 1. One, which gives this category its name, *accessibility measures*, addresses aspects related to attitudes, activities and efforts to allow accessibility in the studied science spaces that promotes de access to the knowledge and, consequently, the popularization of science. Among these measures, is the investment in accessibility and the production of accessible content. Another intermediate category refers to the *specialized service* that is dedicated to the deaf visitors. For this service, it should be considered, among other things, the realization of qualification and training with employees, as well as addressing issues related to their behavior towards deaf visitors. In order to allow the application of some accessibility measures, it was considered relevant to establish *partnerships with institutions and employees* who can assist in the development of inclusion activities. To conclude this category, it is also important to discuss *opportunities for deaf visitors* to work and those spaces, that are the result of the accessibility measures adopted.

With this category, it was possible to identify measures related to accessibility in museum spaces through attitudes, activities and efforts to provide access to all, considering the importance of having specialized care, establishing partnerships with institutions, employees and schools.

Visibility

The second category brings together aspects related to the visibility of the deaf and the Brazilian Sign Language and includes the personal motivations of the researchers and the interest in expanding access to the deaf through dissemination in digital media, favouring the visibility of inclusion activities that can arouse interest in science. This category corresponds to 27.4% of the total. This category is divided into the intermediate categories: *representativeness*, which is perceived when there is a recognition of the deaf person and his needs in these spaces, and which is reflected in the attitudes that are taken when attending them. It also discusses the personal experiences of the participants that led to decisions for the development of accessible activities, which expresses this concern with the accessibility to the science knowledge. Considering the visual aspects of museums, it is possible to adapt them to be more accessible to the deaf community, leading to their inclusion, promoting the popularization of science. The intermediate category called *personal motivation* is also part of Visibility, as it discusses the processes of searching for knowledge and the Motivations and personal concern that employees had and that made them seek accessibility measures. Finally, the intermediate category called *dissemination* addresses alternatives for reaching the deaf community, through dissemination of science measures on websites, apps, advertisements, in order to reach the deaf audience and thus make inclusion activities effective.

With this category, it was possible to understand how researchers' personal motivations and the interest in expanding access to the Deaf can promote the visibility. These professionals demonstrated an involvement that goes beyond the barrier of their work assignments, seeking alternatives that reach the Deaf public, even during the pandemic period. For this, they promote it on websites and social networks as a tool to reach the Deaf community and thus make inclusion activities effective.

Exclusion Factors

The third category addresses the exclusion factors considered by the participants, which are important for identifying the barriers that reduce the accessibility, and, consequently, the access of science knowledge, as well as attitudes that demonstrate prejudice and lead to exclusion. Category three represents 24,3% of the total. The *lack of accessibility and visibility* were the most frequent exclusion factors, in line with the communication difficulties resulting from this lack of accessibility. Some *impediments* were identified as exclusion factors, such as the closure of activities aimed at the deaf community, the lack of interest from organs and employees in popularization of science measures and the high cost of certain activities, which end up being closed due investment difficulties. Finally, it was recognized that *prejudice* is one of the exclusion factors while preventing visitation and excluding this community from cultural and scientifical activities.

This category managed to expose some of the barriers that reduce and impede access to these places, such as the lack of accessibility, visibility and difficulties in communication, as well as the presence of attitudes that reveal prejudice. This exclusion was also identified from the end of activities aimed at the Deaf community, due to the lack of interest of agencies and employees and the high cost demanded by some of them.

Access to Knowledge

Finally, the fourth category addresses issues related to access to knowledge, considering factors for expanding access and popularizing science, corresponding to 14% of the total. The last category recognized from the interviews addresses issues related to access to knowledge. This category has two intermediate categories: the *science popularization*, which brings together the statements related to measures to expand access to science, through the dissemination and popularization of science, and the subcategory *expansion of access*, which brings together aspects related to the frequency of visitation and measures to expand access on informal education spaces. The popularization of science is also related to the accessibility of terms and concepts, as, according to Moda (2017), the Deaf visitor can present difficulties in the formation of scientific concepts, due to issues related to language or lack of preparation in training employees for this attendance.

With this category, it was found that, in order to allow access to knowledge, attitudes should be developed to expand this access through science dissemination and popularization, considering that one of the functions of scientific communication is taking science to places where it is not accessible. The carrying out of educational activities in informal educational spaces can arouse interest in science, promoting the development of scientific culture and favouring the dissemination of science into the Deaf community, mainly due to its strong visual appeal. It was discussed that the realization of scientific literacy workshops and activities in non-formal educational spaces favours the visual experience of the Deaf visitor, making science understandable and meaningful for this visitor.

CONCLUSIONS

In this work, we approached the issue of education for the deaf in Brazil and we realized that even with the advances, the scientific educational process is compromised due to the greater investment in other disciplines, if not science. As discussed, this results in the restriction of the inclusion of deaf people in the scientific field and the deficit in the development of new signs in the area, which causes difficulties in teaching science, leading to scientific exclusion. From these considerations, we highlight the importance of using visual and spatial elements in the education of the Deaf. Thus, we suggest the use of different educational spaces, such as the Science Museums, to assist this process, as they have visual and interactive elements necessary for the education of the deaf, in addition to addressing the scientific content in a playful and interactive way.

Furthermore, we realize that from their scientific bias, Science Museums can contribute to the education of the deaf community in Brazil through activities aimed at social inclusion through science, by the popularization of science. The Content Analysis, which was carried out through interviews with three professionals and educators who work with Popularization of Science accessible to Deaf visitors in Science Museums, allowed to identify the relationship between the activities carried out in Science Museums and research on Popularization of Science. Science focused on the Deaf in these spaces.

With all the considerations so far, we believe that it was possible to recognize how Science Museums have promoted the inclusion of deaf visitors through activities of Popularization of

Science, but we also recognize that more research is needed in the area of the inclusion of deaf people in the field of science, in addition to projects for the inclusion of this community on informal educational spaces, such as Science Museums.

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Part 13 / Strand 13

Pre-service Science Teacher Education

Editors: *Maria Evagorou & María Ruth Jimenez Liso*

Part 13. Pre-service Science Teacher Education

Professional knowledge of teachers, pre-service teacher preparation, instructional methods in pre-service teacher education, programs and policy, field experience, relation of theory with practice, and issues related to pre-service teacher education reform.

Part 13. Pre-service science teacher education

Editors: *Maria Evagorou & M Rut Jiménez-Liso*

Introduction

The recent changes around the world, with the COVID-19 pandemic and the war appearing in Europe again after decades, have once more brought our attention to the importance of understanding uncertainty in science, being able to navigate in a changing world and supporting our students, as science educators, to become active and responsible citizens. Becoming active and responsible citizens entails focusing on social justice (Cho, 2017), developing critical consciousness, engaging in dialogue and taking action (Blackmore, 2016) and understanding the uncertainties of science (i.e., Osborne et al., 2022). Further changes in our field include the emphasis on interdisciplinarity, especially as this emerges from the new emphasis on STEM education (Alvargonzález, 2011) and the effort to support integrated STEM teaching. Therefore, as science educators working with pre-service teachers, we are called to support them: in (trans)forming their pedagogical skills, understanding and teaching in interdisciplinary STEM settings, and preparing them to enter the classroom as autonomous educators.

Strand 13 of the ESERA 2021 online conference invited science educators to submit research work focusing on pre-service teacher preparation, instructional methods in pre-service teaching, field experience studies and programs linked to science teacher preparation. This volume of the e-proceedings brings together 12 papers from across the world. The work included in this part of the volume provides an overview of pre-service science teacher education trends. Furthermore, it highlights how research in our Strand has adapted because of the changes in our world during the last two years. The topics are similar to previous years (modelling, argumentation, inquiry), but methods have shifted to accommodate the pandemic. Specifically, papers in this volume for Strand 13 include themes of digital media with an emphasis on COVID-19 as triggers, some of the studies on teacher identities and expectations to be teachers, whilst others focus on scientific competencies (i.e., modelling, argumentation, inquiry) and curriculum effects.

We hope that this group of selected papers will support us as science educators as we continue our conversations about how to assist future teachers in providing their students with the knowledge, skills and dispositions that will enable them to become scientifically literate and responsible citizens.

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DISCIPLINARY IDENTITIES IN INTERDISCIPLINARY TOPICS: CHALLENGES AND OPPORTUNITIES FOR TEACHER EDUCATION

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Interdisciplinarity (ID) represents nowadays a complex, multi-dimensional and timely challenge in STEM and, more in general, in STEAM education. If on one side ID is at the core of the most urgent societal issues, in schools and universities disciplines are almost exclusively taught separately and rigid boundaries are created. After a long period of good practices, researchers are more and more perceiving the need to develop theoretical frameworks to rigorously define what ID is and to recognize if and how interdisciplinary knowledge and skills can be developed in teaching. In this paper, four theoretically-oriented studies are presented as outcomes of the IDENTITIES Erasmus+ project aimed to develop an approach to design interdisciplinary teaching modules for pre-service teacher education.

Keywords: interdisciplinarity, pre-service teacher education, STEM education.

INTRODUCTION

The confrontation of the most urgent problems we face today, such as the pandemic and global warming, requires deep collaboration and integration between STEM disciplines. The emergence of new interdisciplinary fields like biomedical engineering, materials engineering, and artificial intelligence reflects this point as well. However, even though the increasing predominance of interdisciplinary discourses not only in professional and academic realms but also at the societal level, STEM education has been criticised for the disconnected teaching in schools and universities that perpetuates sharp separations between disciplines.

To face this challenge, one of the primary actions that need to be undertaken is a profound re-thinking of pre-service teacher education. Indeed, teachers and teacher educators have a disciplinary background and, usually, they are not educated to a fruitful interdisciplinary dialogue that is required to enter the recent emerging societal challenges. That is why innovating the path through which university students are prepared to become teachers deserves specific attention, first of all from the research community. This is the goal of the IDENTITIES

Erasmus+ Project (www.identitiesproject.eu) that has developed innovative and transferable teaching modules and courses to be used in contexts of pre-service teacher education. The modules' main objective is unpacking interdisciplinarity (ID) in STEM fields, illuminating the links and interweaving between physics, mathematics, and computer science.

Philosophers of science have discussed a lot on what ID is and how it can be characterised with respect to other forms of interplay among disciplines. The IDENTITIES theoretical approach considers the following definitions of inter-, multi-, and trans-disciplinarity: "Multidisciplinarity involves encyclopedic, additive juxtaposition or, at most, some kind of coordination, but it lacks intercommunication and disciplines remain separate [...]. True interdisciplinarity is integrating, interacting, linking, and focusing. […]. Transdisciplinarity is transcending, transgressing, and transforming, it is theoretical, critical, integrative, and restructuring but, as a consequence of that, it is also broader and more exogenous" (Thompson Klein, 2010 in Alvarogonzález, 2011). In the IDENTITIES' conceptualization of ID, it is crucial the metaphor of *boundary*, borrowed from the metatheory by Akkerman and Bakker (2011). It introduces two crucial terms in our framework: *boundary objects*, i.e., "objects that enact the boundary by addressing and articulating meanings and perspectives of various intersecting worlds" (p. 150) and *boundary-crossing mechanisms*, i.e. types of interaction between disciplines (collaboration, identification, reflection, and transformation) that lead to a scale of interdisciplinary learning potential.

In this paper, we present four research contributions that refer to modules developed within the IDENTITIES project and already implemented in local and international contexts. They differ and complement each other for several aspects. First of all, they focus on themes that deal with different types of ID. Two studies focus on advanced, intrinsically interdisciplinary, STEM topics that are societally relevant but difficult to include in official curricula: coronavirus evolution and nanotechnologies. Other two focus on curricular themes that curricula and teaching tend to separate in different fields: cryptography and parabola and parabolic motion. In the former cases, the studies discuss the role of S-T-E-M disciplines to unpack and exploit the complexity of the STEM themes. In the latter cases, ID is used as a *lever* to uncover the epistemological cores of the disciplines by confronting them on a common *boundary theme*. The four studies complement each other also for their research approach to didactics. The studies on coronavirus and cryptography implement research approaches elaborated within the didactics of mathematics: the Anthropological Theory to the Didactic and the Theory of Didactical Situation. The studies on nanotechnologies and parabola are, instead, influenced by approaches developed in science education: the Model of Education Reconstruction or the Family Resemblance Approach.

INTERDISCIPLINARITY IN ADVANCED STEM TOPICS

Design of an interdisciplinary module about modelling coronavirus evolution

The topic of modelling the evolution of coronavirus was chosen in part due to its intrusion into our daily lives at the beginning of 2020. We recognized in it an authentic example of STEM advanced ID, i.e., a major issue for the society that required the collective effort of putting different disciplines to react in front of unexpected questions. Indeed, the COVID-19 pandemic has shown more than ever that students and, more in general, citizens need to understand how mathematics and scientific advances contribute to the understanding of societal phenomena. In addition, “the pandemic illustrates perfectly how the operation of science changes when questions of urgency, stakes, values, and uncertainty collide” (Saltelli et al., 2020). Specifically, it has emerged the need to explore what kind of knowledge can models and modelling provide, how we may interpret their predictions, and more in general, what contribution they provide to the understanding of such a complex issue.

To present the design principles at the basis of the module, we use some notions proposed in the framework of Anthropological Theory to the Didactic (ATD). Within the ATD, the step toward a change of paradigm in teacher education in the so-called “paradigm of questioning the world” (Chevallard, 2015) is approached using the “study and research paths for teacher education” (SRP-TE) (Barquero et al., 2018). The SRP-TE is an inquiry-based process combining practical and theoretical questioning of outside- and inside-school scientific activities. The approach is mainly characterised by: i) the formulation of questions that are rich and relevant enough to be placed at the heart of pre-service teacher education programmes; ii) the facilitation, through the questions, of epistemological and didactic analysis tools of disciplinary and interdisciplinary knowledge at stake; iii) the detection of boundary objects and boundary-crossing mechanisms to switch on links between the disciplines and foster the analysis of interdisciplinary knowledge. In the case of the present module, the SRP-TE is structured in four submodules. Each of them asks participants to assume different roles with regard to their interdisciplinary inquiry.

In submodule 1, we start from a professional question related to ID in scientific practices and their conditions for transposition to school. Participants act here as “ID explorers”, reading a set of selected pieces of news and discussing questions like: *How have STEM disciplines contributed to the societal understanding of the evolution of COVID-19? How can this interdisciplinary practice be transposed to secondary schools?* From this first analysis, educators guide the participants to delimit possible lines of inquiry involving models and modelling as well as the interaction among different disciplines. These lines are the main object of Submodule 2 that asks participants to experience an interdisciplinary project, under the role of “ID student”, about: (1) The complexity of delimiting the system to model: analysing data; (2) The role of the equation-based models: what can we consider a ‘good’ model? what are models for?; (3) Agent-based models and simulations: Simulating scenarios to help to make decisions about societal restrictions. The main goal of this submodule is to make participants carry out an unfamiliar interdisciplinary activity that could take place also in the classroom. In particular, the participants explore the issue of COVID-19 evolution from three different (but complementary) points of view: the real data processing, selection of variables, and their statistical analysis; the use of equation-based mathematical models for disease diffusion and the interpretation of the models’ coefficients, accordingly to the data; and the implementation of an agent-based simulation using methods inspired by statistical physics to evaluate different types of social intervention.

In submodule 3, the participants become “ID analysts” since, in groups, carry out a meta-reflection on the previous activity on three different levels. The first level, using the tool of questions-answers maps (Winsløw et al., 2013), aims to sketch the process followed through the dialectics between the specific questions that the group has faced, and the answers obtained. The second level requires recognizing in the lines of inquiry examples of boundary objects. Finally, participants analyse the kind of interaction among disciplines (i.e. boundary-crossing mechanisms) that happens when boundaries are at stake and eventually overcome. In Submodule 4 some secondary school experiences linked to each line of inquiry are shared with participants. Then, they are expected to use the tools previously developed for interdisciplinary analysis to discuss the conditions to facilitate the implementation of ID in real classrooms, as well as the constraints hindering the chances for ID to happen.

STEM student teachers analysing ID in the field of nanotechnology

Nanoscience-Nanotechnology (NST) is one of the most contemporary and promising research fields in STEM. NST is a wide topic that relates to studying and manipulating matter at the atomic, molecular, and macromolecular levels in order to create materials, devices, systems in the nanoscale (approximately 1-100nm), with fundamentally new properties and functions (Roco, 2001). The rationale for choosing NST for STEM teaching relies on the fact that: a) NST is by nature an interdisciplinary field, in which many disciplines interact, b) NST is related to many contemporary real-world applications and breakthroughs, c) being an ongoing field of research, it gives the opportunity to students to discover new methods and new ways of thinking as well as to cultivate views of Nature of Science and Nature of Technology, and d) it can engage students in relevant socio-scientific issues and issues of responsible citizenship (Kähkönen et al., 2016; Stavrou et al., 2018).

The theoretical framework for designing this module is the Model of Educational Reconstruction for Teacher Education (Van Dijk & Kattmann, 2007), adapted to the needs of the present study. Therefore, studies concerning Pedagogical Content Knowledge and ID interact dynamically with the design and development of educationally reconstructed STEM learning environments from the student teachers in order to develop learning environments for STEM pre-service teacher training. Furthermore, the educational reconstruction of STEM learning environments has been carried out according to the Model of Educational Reconstruction (Duit et al., 2012), in which school students' ideas and attitudes, as well as empirical studies on teaching and learning, are also taken into account. Specifically, studies concerning ID include i) the taxonomy of ID by Thompson Klein (2010) to define ID, as well as ii) the boundary objects framework (Akkerman & Bakker, 2011) as a facilitating means to foster student teachers' views and understandings of ID. The module was divided into four main submodules following the rationale of SRP-TE (Barquero et al., 2018).

In the first submodule, student teachers are called upon to act as "ID explorers", by engaging in open discussions about contemporary real-world problems that NST research aims to address. Moreover, they are asked to give their initial views on concepts/methods/artifacts in which multiple disciplines are involved, as well as 'linguistic activators', i.e., terms that gain different meanings across different disciplines/communities. Subsequently, in the second submodule, student teachers take the role of "ID students", by engaging in interactive activities which include STEM artifacts related to cutting-edge NST applications, such as smart housing, alternative energy sources, metallic nanoparticles for medical treatment, and NST microscopes. The student teachers are then called upon to design the first draft of their own STEM teaching activities concerning NST, present it to peers in terms of microteaching, discuss, and take feedback.

In the third submodule, student teachers take the "ID analyst" role. The goal in this submodule is twofold: on the one hand, student teachers are called upon to recognise disciplinary knowledge and skills from each S-T-E-M discipline that derive from nanotechnology concepts/phenomena/applications in the STEM activities presented previously. Particularly, student teachers analyse the complex phenomena by using their existing "disciplinary lenses" in order to connect them to their already obtained areas of understanding, and, hence, foster a feeling of *comfort*. On the other hand, student teachers are called upon to recognise several *incidents* where disciplines interact in the STEM activities presented. In order to concretise this process, the module implements indicative concepts/methods/artifacts that were considered to act as boundary objects in NST, such as modelling (Develaki, 2020), instrumentation (Stevens et al., 2009), and biomimicry (Krohs, 2022). Hence, students reflect on how different disciplines coexist, interact, and interconnect through these boundary objects which are used as "interdisciplinary lenses". Subsequently, the module leaves space for student teachers to discuss further incidents of ID regarding their own developed teaching material that can also act as boundary objects. In the last submodule, student teachers are invited to revise their STEM teaching material through a second iteration as "ID designers" in which they reflect from an epistemological point of view on the model of STEM Integration (Ring et al., 2017) that they implemented.

INTERDISCIPLINARITY IN CURRICULAR TOPICS

Teaching cryptography to foster ID between mathematics and computer science

We choose cryptography as an example of a domain at the interface between Mathematics and Computer Science (CS). Both mathematical elements (like proofs, number theory) and CS elements (like computational complexity, systems design, programming) are fundamental to solving the relevant social, technological, and scientific challenges cryptography poses. Moreover, some cryptography elements encompass intertwined aspects of CS and Mathematics (for example, one-way functions are both well-defined mathematical functions and programs that satisfy specific security and efficiency criteria). In the current research, this stimulates a dialectic between the two disciplines, both from CS to Mathematics (e.g., requiring new research in elliptic curves) and in reverse (e.g., using theorem provers to verify cryptographic properties). On the other hand, cryptography allows for "disciplinary projections": inside the field, elements of the two disciplines are still recognisable. Learning about all this is relevant for those secondary teachers who may have to teach some cryptography either in Mathematics, CS, or interdisciplinary courses.

The design of the module relies on two main pillars. First, we consider the need to introduce cryptography as a social issue of contemporary society (ENISA, 2016) following a long-term presence in human history from ancient Greece to nowadays. The development of CS has put forward an increasing number of encryption methods, most of them relying on Mathematics and CS's close intertwining. Second, we choose the didactical engineering methodology relying on the Theory of Didactical Situations. As stressed by Artigue (2014), didactical engineering is structured into four main phases: (i) preliminary analysis; (ii) design and *a priori* analysis; (iii) realisation, observation, and data collection; (iv) *a posteriori* analysis and validation. Validation is internal, based on the contrast between *a priori* and *a posteriori* analysis, not comparing experimental and control groups. In the design of tasks and situations, particular attention is put on: the search for situations that capture the epistemological essence of the mathematics to be learned; the optimisation of the *milieu* to provide relevant retroactions for students' autonomous learning (*a-didactic* potential); the management of *devolution* and *institutionalisation* processes. Following Durand-Guerrier, Meyer, and Modeste (2019), we consider this relevant also for CS and, hence, for designing interdisciplinary teaching modules involving both disciplines. Inspired by the STP-TE (Barquero et al., 2018), the module is structured into five submodules.

Submodule 1 starts from a current social debate (pros and cons of end-to-end encryption in widely used instant messaging services) to make participants (i.e., student teachers) initiate the discussion on cryptography, get in touch with basic principles and terminology, and begin to reflect on ID by analysing a historical piece on the birth of asymmetric cryptography. Submodule 2, designed according to the Theory of Didactical Situations, makes the participants experience as students a didactical situation (a group activity based on the *Dominating Set Perfect Code* cryptosystem (Bell et al., 2003)), with a *milieu* where the students autonomously verify if they have solved a given problem (i.e., deciphering a message). We designed a different organisation of the *milieu* for each participants' group to lead to different perspectives and approaches to the task and help student teachers think about the interdisciplinary objects encountered (graphs, functions, algorithms, complexity). In Submodule 3, participants analyse the previous teaching proposal in light of didactic and epistemological aspects, engaging in interdisciplinary analysis. They make disciplinary projections (recognising CS and Mathematics fundamental concepts in cryptography) and identify interdisciplinary elements (like boundary objects and boundary-crossing mechanisms (Akkerman & Bakker, 2011) or what we call linguistic and epistemological activators - e.g., the different meanings associated with 'function' in CS and Mathematics, or the difference between a non-invertible and a one-way function) to explore the borders between the two. In submodules 4 and 5, participants design, implement and analyse *a posteriori* a new didactical situation on other proposed cryptography concepts.

In the whole module, we designed activities where disciplinary projections can shed light on important disciplinary concepts, like computational complexity for CS and graphs for Mathematics. Disciplinary projections can stimulate exploration and learning of some relevant topics and ideas of each discipline, not only in the specific scope of cryptography but also in other CS and Mathematics areas. Together with the work on boundaries, this can also foster the exploration of other interactions between the two disciplines.

Parabola and parabolic motion to cross boundaries between physics and mathematics

The topic of parabola and parabolic motion was chosen as very prototypical of what happens to ID in school transposition. The two are, of course, intrinsically related. However, school science, through habits, textbooks, and school practices, has consolidated two different disciplinary narratives that separate the two themes into disciplinary enclaves created by artificial barriers. On the contrary, the discovery of parabolic motion represents a crucial step in the historical co-evolution of physics and mathematics, and in the establishment of physics as a discipline (Renn et al., 2011). It led humanity to overcome the medieval distinction of "violent and natural motions" and to admit that mathematics can be applied to the imperfect sublunar world. Vice versa, Kepler and his studies in geometrical optics provided a fundamental contribution to reconceptualize parabola as *locus* and to pave the way for projective geometry. Despite their crucial roles in history, parabola and parabolic motion do not have, in class, a special role in defining the epistemic identity of physics and mathematics.

The module has been designed with the goal to base the search for a theoretical-based model of ID on a concrete example. The model is expected to orient the design of teaching materials able to: a) break down artificial school barriers between disciplines and b) exploit ID as a way to give back mathematics and physics their disciplinary identities. In order to reach these goals, we chose a historical approach that implies the analyses of historical cases through "ID lenses". The interdisciplinary lenses for the analysis have been built as a combination of three main frameworks: the Family Resemblance Approach (FRA) for the NOS by Dagher and Erduran (2016); the Thomson Klein taxonomy of ID (2010); the metatheory developed by Akkerman and Bakker on the metaphor of the boundary (2011). Since the latter have already been introduced, we provide some details about the FRA. It has been used to switch on, in the historical texts by Guidobaldo and Galileo, the dimensions that characterise the epistemic core of a scientific discipline: its aims and values, scientific practices, methods and methodological rules, knowledge (Dagher & Erduran, 2016). The application of the framework to the analysis of the history of parabola and parabolic motion led us to recognize two special cases of boundary objects – symmetry and proof – that, through mechanisms of identification and reflection, activated the appearance of the epistemic cores of the two disciplines. For this reason, the concepts were emphasised as epistemological activators.

The module is articulated in six submodules. In phase 1 the student teachers are asked to reflect on the metaphor of the *boundary* and on examples of boundary objects to position themselves on the theme of ID. Then the phases 2 and 3 concern both the historical analysis of the discovery of the parabolic motion and a two-pronged analysis of historical texts from Guidobaldo and Galileo: the FRA model is used to recognise the epistemological elements of the discourse; the Akkerman and Bakker's metatheory is used to point out the role of boundary object and epistemological activator played by the symmetry that Guidolbaldo experimentally discovered. Phase 4 regards the analysis of the different meanings of proof in mathematics so as to define criteria to analyse Galileo's proof of the parabolic motion and to exploit the structural role of mathematics in the establishment of physics as a discipline. In phase 5, different definitions of parabola as a mathematical object were given, influenced by the interaction between mathematics and physics over many centuries and to symmetry as a boundary object. In phase

6, a wrapping up lesson was designed to rethink the questions opened in phase 1 after the interdisciplinary activities.

DISCUSSION AND CONCLUSION

The four perspectives presented in the paper allow us to sketch common features of the approach to ID that the IDENTITIES project carries out. The first issue that deserves discussion is related to the importance of grounding an interdisciplinary reflection on the *identities of the disciplines* at stake. While acknowledging the limits of the sharp separation between STEM disciplines in schools and universities, disciplines are still fundamental for interdisciplinary education. A "discipline" is indeed a body of knowledge that has been historically organised to be taught and learned (the very same etymology of the term "discipline" refers to the Latin "discere", whose meaning is "to learn"); moreover, a discipline reflects a didactical organisation of knowledge that supports the development of a particular set of epistemic skills such as modelling, explaining, arguing, which take somewhat different forms in different STEM disciplines. These sets of epistemic skills are the basis of productive collaborations between disciplines in real-life problems, and the generation of productive ID. Hence, learning in the disciplines is crucial for maintaining productive ID. Learning in schools is institutionally organized around separate disciplines. Fostering interdisciplinary learning in this educational context is challenging, since teachers and students often misinterpret the institutionalized separation between classes of different disciplines in school, as an intrinsic feature of the topics they learn in each discipline.

When focused on disciplines, students should be guided to recognize the types of *interactions between disciplines* that occur in interdisciplinary contexts. The shift from separate disciplines to ID in the four modules was afforded by the focus on boundary objects, boundary-crossing mechanisms (Akkerman & Bakker, 2011), and "epistemological activators" i.e., key concepts, methods, or themes that characterise each discipline and invite meaningful reflective comparisons between and across disciplines (Ravaioli, 2020). Additional support for this shift was achieved by supporting students in identifying "linguistic activators" i.e., concepts, categories, or forms of linguistic representations that are used differently in different disciplines. The explicit comparisons of the entailed meanings ascribed in each discipline, help students unpack additional layers of the interaction between disciplines.

The last point that we want to stress is related to the protagonists of the IDENTITIES approach: the *student teachers*. Teachers are the most important agents of change in students' learning. Hence, if we want students to develop interdisciplinary skills, we should start by teaching this in our pre-service teacher education programs. That is why the design process not only includes the reconstruction of disciplinary and interdisciplinary issues in the modules, but also implementations in teacher education that require the preservice teachers to take different roles with respect to what is learned. Student teachers engage in exploring case studies of ID through explicit discussion of boundary crossing, epistemological activators, and linguistic activators, then in instructional design that highlight aspects of ID, in collective reflections on this design, followed by microteaching and further reflections.

Notes

The four sections of the paper have been authored by the team of designers of the four IDENTITIES modules. For the COVID-19 module: B. Barquero, E. Barelli, O. Romero, M. R. Aguada, J. Giménez, C. Pipitone, and G. Sala-Sebastià; for the nanotechnologies module: A. Nipyrakis, A. Kokolaki, I. Metaxas, E. Michailidi, and D. Stavrou; for the cryptography module: M. Lodi, M. Sbaraglia, E. Bartzia, S. Modeste, S. Martini, and V. Durand-Guerrier; for the parabola module: S. Satanassi, L. Branchetti, O. Levrini, P. Fantini, and V. Bagaglini. Kapon's contribution has been included as the discussant at the symposium that was chaired by Levrini and Branchetti.

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SUPPORTING PRE-SERVICE ELEMENTARY TEACHERS TO PLAN MODELING-BASED INVESTIGATIONS

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Learning to plan science lessons to engage young students in modeling-based investigations (MBI) is challenging for pre-service elementary teachers (ePSTs). We designed a set of three teacher education pedagogies grounded in biology-specific work to support ePSTs in planning MBI. The study aims to characterize how ePSTs learn with this support in the context of a science teacher education course. Using professional vision as the theoretical framework, we examined ePSTs highlighting, coding, creating, or using material representations to understand biology core ideas, scientific modeling, and the teaching practice of planning MBI. Findings illustrate two learning characteristics: a) the integration of biology core ideas into explanatory models of biological phenomena, b) the delineation of learning targets for students by deconstructing those models. We discuss these findings, emphasizing how pedagogies grounded in biology-specific work supported the groups' epistemic and pedagogical negotiation of meanings to build shared understandings of planning MBI.

Keywords: Teacher Education Pedagogies, Pre-service Elementary Teachers, Modeling-based Investigations

INTRODUCTION

Learning how to plan science instruction to engage young students in MBI entails three main challenges for ePSTs. These challenges are particularly relevant when they use online videos as resources to deepen their understanding of disciplinary core ideas (Baltaci-Goktalay & Ozdilek, 2010). First, ePSTs need to see these ideas not as isolated entities but linked with how they are generated, for example, through participating in the scientific practice of modeling (Acher et al., 2007; Manz, 2012). Second, ePSTs need to see that for students to participate productively in scientific modeling and learning disciplinary core ideas; it is necessary to structure an investigation where they can develop their explanatory models of phenomena (Campbell, Gray, & Fazio, 2019). Third, it is important they see themselves as professionals, defining their goals as a community and making sense of their experiences (Gunckel, 2013). This implies they can negotiate meanings through discourse to shape and contest understandings of planning MBI (Goodwin, 1994). These challenges suggest it is critical to design supports like teacher education pedagogies that effectively aid ePSTs learning of disciplinary ideas and practices associated with planning (Davis, 2020).

BACKGROUND

Pedagogies designed by teacher educators have been used to support pre-service teachers to engage more directly in teaching, enacting particular components of the practice to learn in, from, and through practice (McDonald, Kazemi, & Kavanagh, 2013; Windschitl, Thompson, Braaten, & Stroupe, 2012). Based on this practice-based view, our stance is towards teacher education pedagogies as supports for ePSTs learning to plan MBI. First, pedagogies are *authentic* approximations for pre-service teachers to enact key teaching practices and to make their own decisions with some professional purpose (Grossman et al., 2009). This authentic character provides pre-service teachers with the opportunity to enact "real" teaching activities and manage specific situations and thus gain the experience they need for future practice (Forzani, 2014). Second, these pedagogies entail a *situated* way of learning. Pre-service teachers' enactment of pedagogies depends on the social situations that they create in a context. Inside this context, pre-service teachers as learners construct meanings and define goals through negotiations (Brown, Collins, & Duguid, 1989). From this perspective, authentic and situated pedagogies have the potential to support ePSTs to collaboratively enact and co-construct their professional understandings of the practice, specifically concerning planning MBI. These pedagogies include the activities ePSTs undertake based on critical components of this practice, so they learn from their own experiences (Grossman, Schneider, & Pupik, 2018).

Teacher Education Pedagogies for planning modeling-based investigations

Planning a modeling-based investigation is a key teaching practice that consists of structuring science lessons to support and maintain students' engagement in investigations of natural phenomena by developing explanatory models. Within designed pedagogies, teacher educators can coordinate particular activities that focus on essential components of planning a MBI to help ePSTs engage in deliberate practice (Grossman et al., 2009). At the earliest stage of planning a MBI, it is important to help ePSTs define a natural phenomenon, so they learn to pose the goals students will achieve throughout the investigation (Campbell et al., 2019). It is also important to help them frame modeling-based questions so they are prepared to guide students to understand what they need to investigate (Passmore, Schwarz, & Mankowski, 2017) and facilitate students' posing questions by themselves when developing models (Manz, 2012). Furthermore, ePSTs need help for establishing a coherent sequence of the activities that looks for students' engagement throughout modeling-based investigations (Schwarz, Passmore, & Reiser, 2017). In addition to supporting ePSTs in these three components of planning a MBI, pedagogies can guide their participation in the modeling practice. This firsthand experience allows them to identify the issues and problems they would face in their future classroom and understand how to address them appropriately.

Discipline-Specific Epistemic Tools

We conceptualize scientific modeling as an epistemic practice that consists of building knowledge as the integration of disciplinary ideas with the process of developing models to explain natural phenomena (Schwarz et al., 2009; Berland & Crucet, 2016; Louca & Zacharia, 2015). In this context, we build upon the work advanced in science education and the use of epistemic tools to support ePSTs' participation in the modeling practice as part of their learning to plan MBI. Epistemic tools are resources that support collaborative knowledge construction while students are engaged in scientific discourses and processes consistent with scientific practices (Ke, Sadler, Zangori, & Friedrichsen, 2020; Kelly & Cunningham, 2019). In this study, we emphasize that discipline-specific epistemic tools have the potential to help ePSTs participate in the modeling practice. With the support of epistemic tools, they can learn to integrate disciplinary core ideas into explanatory models, which serve as a foundation for planning how to engage and support students in this practice. *Transformation Boxes (TBs)* (Acher & Arcà, 2020) is a discipline-specific epistemic tool that guides ePSTs to integrate biology core ideas into explanatory models of biological phenomena. TBs are the "uses" of a simple representational form (See Figure 1) that guide ePSTs to explain biological phenomena by putting biological transformations at the center of the dynamic exchanges of matter, energy, and information between organisms and their environments.

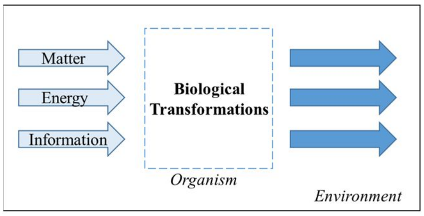

Figure 25. Simple representation of a TB: an organism in a dynamic exchange of matter, energy, and information with its environment. (From Acher & Arcà, 2020).

THEORETICAL FRAMEWORK

We take a sociocultural perspective and consider that learning implies a process that involves negotiation of meanings through discourse. Therefore, we use professional vision (PV) as a framework (Goodwin, 1994) to theoretically and analytically examine ePSTs' discourses around planning a MBI. In particular, we use the three discursive practices of this framework: highlighting, coding, and material representations (MRs). Highlighting refers to making prominent aspects that concern the profession. Coding constitutes ways of making meaning of what is highlighted. Material representations are the external objects that embody an intentional organization of the meanings made. We specifically address the following question: How do ePSTs learn to plan a MBI with the support of teacher education pedagogies grounded in a biology-specific epistemic tool?

METHODS

Context

This qualitative study examines ePSTs learning to plan MBI through designed teacher education pedagogies. Twenty-four ePSTs enrolled in a science teaching education course participated in the study. They worked in groups, and for this manuscript, we selected one group to analyze their discourses in detail to better characterize their learning to plan a MBI. Four ePSTs (under the pseudonyms Anne, Ellen, Hallie, and Kali) constituted the selected group. They worked on the biology core idea concerning the interdependent relationship of organisms in an ecosystem (National Research Council [NRC], 2012, pp.147-148) and the specific phenomenon "how some plums that hang on the same tree and change, while others do not".

Design Study

Table 1 specifies the features of our intervention. Our ePSTs enacted each of the designed pedagogies, working independently during three different sessions. We provided a paper-based object (i.e., a document) with the activities ePSTs had to undertake in each pedagogy, but we did not intervene. These activities in each pedagogy focus on one component of planning a MBI and embedded elements of the biology-specific epistemic tool. Finally, ePST used online videos as content resources. For the selected group, we provided two videos[11] to help ePSTs focus on the main aspects of the biology core idea they were working on in their planning. We expected that ePSTs enacting each pedagogy engage them in discourses. These discourses emerge as the process through which ePSTs negotiate meanings to build understandings regarding their profession.

Table 39. Intervention features.

ePSTs' work	Designed pedagogies	Processes emerging from the supported learning	Professional learning
Engagement in one pedagogy at a time **Use of a paper-based object**	Session 1: Pedagogy for characterizing stability-change features of biological phenomena.	Discourses around: a) defining a phenomenon, b) framing a productive driving question.	Understandings of biology core ideas and scientific modeling.
	Session 2: Pedagogy for constructing an explanatory model via TBs.	Discourses around: a) generating a concrete interpretive form of the phenomenon.	
Focus on a planning component and participation in scientific modeling via TBs **Use of online videos as science content resources**	Session 3: Pedagogy for structuring a coherent modeling-based sequence.	Discourses around: a) establishing a sequence of intermediate questions, b) establishing a sequence of partial models/explanations.	Understandings of structuring and sequencing coherently a MBI.

Data Collection

Since we were interested in the ePSTs discourses, we video recorded the entire time the groups were engaged in each pedagogy and interacting with each paper-based object. We also collected the models as the material representations the group created while they were video recorded.

Data Analysis

We use the discursive practices of professional vision (Goodwin, 1994) as analytical categories: *highlighting* refers to the components identified as relevant for the group about the biology core idea, the modeling practice, or planning the MBI. For example, a group participant uses gestures to point something out, use colored markers, or accentuate specific words while speaking. *Coding* refers to the meaning that they negotiate or construct concerning the relevant aspects highlighted. *Materializing representations* refers to the creation or use of models.

FINDINGS

Two important characteristics emerged from our analysis of ePSTs discourses. First, ePST integrated biology core ideas into their explanatory models of natural phenomena through TBs. Second, ePSTs delineated learning targets for students by deconstructing those models. In order

[11] https://www.youtube.com/watch?v=_Yb3up2Iacs, https://www.youtube.com/watch?v=uagBeKYBBvI

to illustrate these two characteristics, we provide examples of the discourses (Table 2) and a explantory model (Figure 2) that the selected group created and used. We have added some descriptions of our interpretation, from which we have characterized ePSTs negotiation of meanings to shape professional understandings around planning a MBI.

Table 40. Examples of ePST discourses for delineating learning targets in a MBI and integrating aspects of the biology core ideas into explanatory models.

Lines	Discourses	Description
1 2 3 4 5 6 7 8 9 10 11	**Anne:** [While she starts drawing] So in the second model they [maggot and fungus] are still inside [the plum], so this [the second model] is a little bit connected [to the first model]. I draw the fungus right here and the maggot on the other side... (1) The feces (2) and the food (3). Do we also take different kinds of nutrients into account? (…) Okay, just wait. Nutrients in the form of vitamins, we can define them now more precisely. **Ellen:** I think that's not really important. **Hallie:** But they [kids], do not have to know which concrete sugar it is, but that it's sugar.	**Highlighting** a specific aspect for the second model: fungi and maggot benefit with food from plum. **Coding** this aspect as a coherent continuation of the sequence without going into the details. It helps to interpret key changes: how the plum serves as an environment; and how fungi and maggot take nutrients from the plum. **Using the model** to establish the second step of the MBI.
12 13 14 15 16 17 18	**Anne:** Ok, So C1, I had denoted the consumer 1 [maggot (4)]. Are there anything else left? **Hallie:** We only had the feces. **Ellen:** And how about CO_2, because it [maggot] breathes too. **Anne:** If it [maggot] absorbs oxygen, yes [draws and arrow to indicate maggot takes in oxygen and takes out carbon dioxide (5)] **Ellen:** There is a transformation from there… (6)	**Highlighting** maggot as a TB. **Coding and materializing** the transformation in the maggot as it is interacting with its environment and surroundings. Maggot takes in food and O_2 then gives out feces. Association between the transformation of matter (from O_2 to CO_2) and the transformation of energy maggot need to grow and develop.

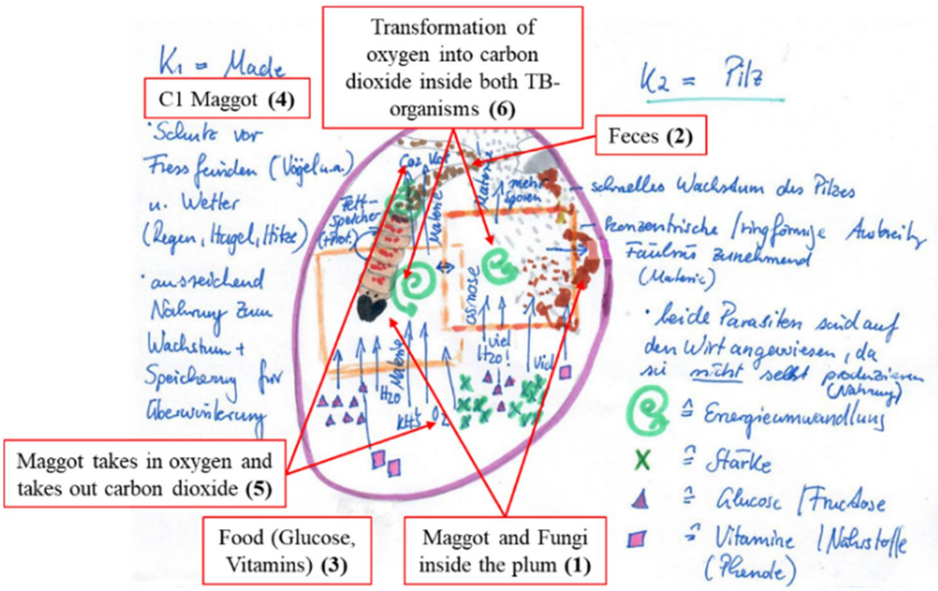

Figure 26. Model the group created and used to: a) delineate a learning target of the MBI; b) explain the second key ongoing transformation in the phenomenon.

During the first part of the discourses (lines 1-10), the group was working on one of the proposed activities for the third session: "*Look at the final model/explanation you reached and re-organize it into 3-4 partial models/explanations. Write short indicative sentences for each partial model that help to communicate the new organization."* By following the prompts related to the epistemic tool that supports this activity, such as: *Are the TBs, the connections/exchanges among TBs, the inputs or outputs of TBs, or the overall flux among TBs telling you how to chunk/re-organize the model?* the group was constructing the partial model on Figure 2. The group used this model to guide their negotiation of meanings to structure this part of the MBI. Anne's comment in lines 2 to 5 highlights that fungi and maggot are inside the plum, where both organisms have food and nutrients. Since she refers to the *"second model"* in her comment, the highlighted aspect corresponds to the learning target in the second step of the MBI. Then, when she says: *"so this* [the second model] *is a little bit connected* [to the first model]*"* she codes this step as keeping a coherent continuation to the first step. Anne leads the group towards a pedagogical purpose: how to structure the steps of the MBI coherently to help students interpret key changes of the phenomenon. In this case, they aim students can interpret changes in the plum, which serves as an environment from which fungi and maggot take nutrients. As the group discussed in lines 6-11, it was not appropriate for the MBI structure to detail the kind of food (e.g., sugars). Hallie's comment: *"But they [kids], do not have to know which concrete sugar it is, but that it's sugar"* reinforces the group's coding to help students interpret with the model the changes happening, rather than help them to learn detailed and disconnected disciplinary aspects. With this negotiation following the provided support, the group advanced in understanding the MBI for their future students as a coherent structure of well-delineated learning targets.

Then, in the second part of the discourses (lines 12-18), as the group went further in the discussion supported by the same prompt above, there was a change in the focus. This time the group focuses on the explanatory potential of the second model under development. In this case, they aim to interpret the plum, maggot, and fungi changes as biological transformations through TBs. They associated the maggot and fungi with TBs because, inside them, biological transformations occur (see the squares in Figure 2). Anne highlights in line 12 the biological role of the maggot as a "consumer" in relation to the plum. When she adds "*Are there anything else left?"* And Hallie replies: *"We only had the feces,"* their coding is for interpreting a biological transformation inside the maggot: the food into feces. Here, they integrated into the explanatory model the biology aspect that organisms grow and develop as they interact with their environment. In this case, the maggot is taking food from its environment, which can be used to maintain life functions.

From lines 15 to 18, the group continued with the interpretation of the maggot biological transformation. When Ellen says: *"And how about CO_2, because it [maggot] breathes too"* and Anne adds: *"If it [maggot] absorbs oxygen,"* they highlight the ongoing transformation of oxygen into carbon dioxide (matter). Then with Ellen's comment: "*There is a transformation from there…"* the group's coding was for associating the highlighted aspect with the transformation of the stored energy in the nutrients from plum into useful energy for the maggot. The spirals drawn inside the squares in Figure 2 represent the integration of the biology aspects regarding the relationship between the oxygen and nutrients transformation inside organisms to produce the energy they need. The group's negotiation in this second part of the discourses indicates advances in understanding biology aspects integrated into models used to explain a phenomenon. In this case, understandings around the dependence of the organisms (maggot and fungi) from their environment (plum) to obtain the matter and energy they need to grow and develop.

DISCUSSION

Integrating biology core ideas into explanatory models of biological phenomena and delineating learning targets for students by deconstructing those models was possible for ePST with the support of pedagogies grounded in biology-specific work. The proposed activities in each pedagogy guided ePST to negotiate meanings and advance their professional learning for planning a modeling-based investigation. Gunckel (2013) suggests that it is important to provide ePSTs with opportunities to understand science content as they learn to plan a sequence that engages students in scientific practices. Campbell et al. (2019) and Kenyon et al. (2011) suggest that ePST knowledge of scientific modeling is crucial. We suggest that ePSTs construct shared understandings that integrate biology core ideas when participating in scientific modeling. This co-construction could be supported by discipline-specific epistemic tools like TBs for biology (Acher & Arcà, 2020). The biology-specific epistemic tool of TBs have the potential to guide ePSTs' negotiation of biology and modeling meanings when using content resources like online videos. TBs also supported the negotiation of meanings regarding the delineation of learning targets for students throughout the investigation. The activities and prompts based on TBs guided ePSTs to understand how to structure a MBI for students to interpret key changes in the phenomenon. We argue that disicipline-specific epistemic tools have the potential to support ePSTs in integrating a biology core idea into their explanatory models and open up multiple possibilities to structure the MBI delineating learning targets for students.

Davis (2020) suggests that teacher education pedagogies or authentic approximations of practice support PSTs learning in a way close to the genuine work of classroom teaching. We found that activities focused on components of planning a MBI (e.g., re-organizing a final explanatory model into 3-4 partial models/explanations) supported the group in managing this practice favorably. We advocate for teacher education pedagogies that serve as the foci for PSTs to engage in the teaching work so that they can enact and co-construct meanings in collaboration with others (Forzani, 2014; Wickman, 2012). In such cases, through designed pedagogies that focus on key components of teaching practices, pre-service teachers not only enact these practices but engage in negotiations in authentic ways and for situated purposes.

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SCIENCE TEACHERS TRAINING PROPOSALS FOR THE DEVELOPMENT OF SCIENTIFIC COMPETENCES IN SECONDARY EDUCATION

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Research focused on learning through scientific practices to develop scientific literacy is increasing. The acquisition of scientific competences enables students to use knowledge to identify problems, acquire new knowledge, explain scientific phenomena, and draw evidence-based conclusions on science-related issues. However, science teaching-learning is still characterized by teacher-centered approaches and absence of innovation, affecting not only teachers but also the curriculum. Therefore, this study aims at analysing a collection of current educational articles on strategies to improve teacher training with the goal to promote scientific inquiry skills in secondary science students. In our work, the current state of educational research on the acquisition of scientific competences in the field of science at secondary education levels has been reviewed. Thus, a systematized bibliographic search on the contributions collected in the Web of Science database has been carried out. There are a total of 154 articles, among them 47 papers have been selected according to inclusion and exclusion criteria. These works address the need for training of secondary science teachers in the teaching of scientific competences. In addition, it provides different approaches to achieve this issue, such as: the nature of science, the use of educational methodologies that promote the active participation of students through the resolution of problematic situations while stimulating critical reasoning and argumentation, or the use of activities that raise social controversies with scientific links, among others. Finally, we consider the need for science teacher training in these aspects that highlight the importance of inquiry as a way of experiencing science in the classroom and developing scientific literacy.

Keywords: Scientific Competences, Secondary School, Teacher Professional Development

INTRODUCTION

Scientific literacy is one of the main aspects that students must acquire and develop during their education to understand natural sciences and be able to use this knowledge as perceptive, critical and sensible citizens (García-Carmona & Acevedo-Díaz, 2018). This literacy should allow students to reflect, reason and establish connections that will enable them to respond to all those situations they may face in their daily lives (Mkimbili & Ødegaard, 2019).

This perspective requires to build strong links between the content taught in class and the problems of the community; that is, between school science and their daily experiences. In this regard, it is usually intended that students understand the cause and effect of the phenomena that surround them, ask questions about complex problems that compromise their future, make predictions and develop their logical part from a scientific point of view to start functional learning through the development of scientific competence (Levrini et al., 2019).

It should be noted that the OECD includes in the term "scientific competence" both the capacity of inquiry in specific contexts and the integration of knowledge. Thus, it is considered the use that individuals make of scientific knowledge to identify problems, acquire new knowledge, explain phenomena and draw conclusions based on evidence (OECD, 2017).

More recently, the Next Generation Scientific Standards (NGSS) are committed to a vision of science teaching and learning that promotes the integration of scientific knowledge, that is, content knowledge, and practices necessary to participate in scientific research (Tekkumru-Kisa et al., 2019). The number of educational investigations and curriculum reforms that include scientific practices are emerging in many countries. Teaching 'scientific practice' is based on learning activities in which students are engaged. It implies the knowledge and skills combination in each practice and the recognition of a broad spectrum of scientific methods rather than a single or particular one (Halawa, Hsu, Zhang, Kuo, & Wu, 2020).

According to the National Reseach Council, NRC (2012), students learn and show proficiency through knowledge-building practices to make scientifically-based decisions. Therefore, learning science is a combination of knowledge and practice that cannot be completely appreciated by students without directly experiencing those scientific practices. Moreover, effective learning promotes students' motivation, being of great importance the use of socio-scientific issue-based teaching materials (Laius, Kask, & Rannikmäe, 2009).

Unfortunately, the situation in the classrooms in many countries is still far from achieving these targets and this perspective of work differs significantly from that usually followed in classes. As a consequence, the inquiry capacities are not developed as they should (Banet, 2010). Secondary teachers do not always include scientific practices in laboratory sessions (Boesdorfer & Livermore, 2018) or align classroom activity structures with the NGSS recommendations (Criswell & Rushton, 2014). Factors, such as lack of time for critical reflection and lack of knowledge about new teaching techniques may lead to teachers' scarcity for innovation. Thus, future teacher training should focus on disciplinary knowledge, socio-historical knowledge (i.e., proper contextualization of knowledge), and finally pedagogical skills.

It is suggested that the most successful method for Science teaching is inquiry-based learning, which is focused on the development of scientific capabilities, content knowledge understanding, knowledge contextualization, scientific literacy and professional Science practice (Busquets, Silva, & Larrosa, 2016). Innovative approaches, such as the Science–Technology–Society or inquiry-based curriculum approaches, have shown benefits not only in science teaching, improving teachers' attitudes towards teaching Science and their quality, but also in student outcomes (Zhang & Campbell, 2012). It is necessary to consider that the motivation to be a science teacher can vary not only from one person to another, but also from the different scientific disciplines (secondary chemistry, secondary biology, secondary physics, and primary science education) of the science teacher (Markic y Eilks, 2008).

Given its importance at an educational, social and personal level, different aspects of teacher training improvement to promote appropriate teaching goals and strategies in secondary education were examined. Hence, the particular question addressed in this research is as follows: What was the trend of science teacher training investigations in the reviewed articles?

Thus, it has been considered convenient 1) to know and analyse the research carried out on the training of teachers in scientific competences when working on some specific contents at the compulsory education levels; 2) to compare the strategies implemented in the training of teachers of science subjects of different disciplines such as biology, chemistry, physics and geology; and 3) to be able to advance on their teaching difficulties and the most appropriate strategies for their acquisition by students. A systematic review to address these issues has been carried out.

DATA COLLECTION METHODOLOGY

The authors of the research were involved in the data collection and analysis, as they are academics in Science Education from two Spanish universities. It was agreed on the following equations for the target article search in the Web of Science database:

Equation 1: TS = ("scientific competence" OR "scientific competencies" OR "scientific practices" OR "scientific competency" OR “learning skills” OR “scientific evidence” OR “PISA” OR “OCDE” OR “scientific literacy”) AND TS=(“inquiry” OR “assessment” OR "evaluation") AND TS=(“science” OR “sciences”)

To this first selection, the expressions "teacher" OR "teachers" were added to focus the search on those who address the participation or training of teachers in their contents:

Equation 2: TS = ("scientific competence" OR "scientific competencies" OR "scientific practices" OR "scientific competency" OR “learning skills” OR “scientific evidence” OR “PISA” OR “OCDE” OR “scientific literacy”) AND TS=(“inquiry” OR “assessment” OR "evaluation") AND TS=(“science” OR “sciences”) AND TS=(“teacher" OR "teachers”)

With the aim of comparing the number of published papers in each discipline, the term “science” was substituted for biology, chemistry, geology and physics. The results obtained by the second equation were filtered in order to include only social science articles and reviews written in Spanish or English. No restriction was applied on the temporality and the databases consulted (Wos, CCC, DIIDW, KJD, MEDLINE, RSCI, SciELO). After screening the title, abstract and keywords, a number of articles / reviews about teacher training based on scientific practices were selected.

RESULTS

The initial search identified a certain number of papers related to scientific literacy/scientific practices/inquiry teaching (table 1).

Table 1. Results of each discipline obtained in the initial search*.

	Science/sciences	Biology	Chemistry	Geology	Physics
Equation 1	4520	1849	561	23	253
Equation 2	668	83	69	3	72

*Accessed on 1 January 2022

After applying the aforementioned selection criteria to the results, articles related to the disciplines teacher training were selected (Table 2).

Table 2. The results of each discipline after including the aforementioned criteria.

	Science/sciences	Biology	Chemistry	Geology	Physics
Selection criteria	465	58	43	3	50

Articles related to the four science disciplines (biology, chemistry, geology and physics) were carefully analyzed by reading the title, abstract, keywords and full content, leaving the final sample showed in table 3.

Table 3. Selection of articles finally analyzed.

	Biology	Chemistry	Geology	Physics
Screening	16	18	1	12

The aforementioned steps are summarize in the figure 1.

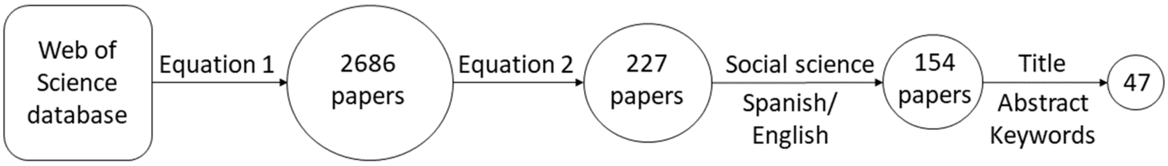

Figure 1. Flowchart through the different phases of the systematized bibliographic search.

The obtained works were published in different journals (Table 4).

Table 4. Summary of the articles based on the discipline and the publication journal.

	Biology	Chemistry	Geology	Physics
AIP Conference Proceedings				2
Asia Pacific Educational Technology Journal	1			
Asia-Pacific Education Researcher		1		
Biological Education Journal	1			
CBE Life Sciences Education	2			
Chemistry Education Research and Practice		3		
Enseñanza de las Ciencias		2		
International Journal of Assessment Tools in Education		1		
International Journal of Science and Mathematics Education		1		
International Journal of Science Education	3	4		
IOP Conf. Series: Journal of Physics				1
Journal of Baltic Science Education				1
Journal of Physics: Conference Series				1
Journal of Research in Science Teaching	1			
Journal of Science Education and Technology		1		
Journal of Science Teacher Education		1		2
Physical Review Physics Education Research				1
Research in Science & Technological Education		1		1

Research in Science Education	2	1		1
Research in Science Technology Education	1			
Revista Brasileira de Ensino de Física				1
Science & Education	2	1		1
Science Education	2		1	
Teacher Education and Training	1			
Tecné, Episteme y Didaxis: TED		1		

The studies came from different contexts since were performed in several countries (Table 5).

Table 5. Categorization of articles by disciplne and country of publication.

	Biology	Chemistry	Geology	Physics
Chile	1			
China		1		
Colombia		1		
Denmark	1			
Estonia		1		
Finland		1		
France				1
Germany	2	2		
Indonesia				3
Israel	1	2		
Korea		1		
Netherlands		2		
Slovakia	1	1		1
Spain		2		1
Thailand	1	1		
Turkey		1		2
United Kingdom	1			
USA	8	2	1	4

In further analysis, the definition of scientific competence used in each proposal, the subject matter, the objectives, the methodology, the instruments and conclusions, the number of participants, the geographical scope of the work and aspects, such as the economic funding received, public or private centers and the level of education at which the teachers work, together with the stage and course of the students that may be involved, were reviewed.

In this work we decided to focus on the approaches proposed to promote the acquisition of scientific competences by secondary school students in biology, chemistry, geology and physics (table 6).

Table 6. Approaches of the analyzed papers and its main features.

		Biology	Chemistry	Geology	Physics
Nature of Science	Influence on science teaching of approaches that take into account the nature of science (NOS) or orientation towards to teaching science (OTS) or the importance of the history of science (HOS)	6	3	1	1
Argumentation and Reasoning Strategies	Influence of strategies that promote reasoning and argumentation (SRA), thinking skills, use of argumentation templates, such as Science Writing Heuristic (SWH), or promote evidence-based reasoning	3	2		3
Problematic situations	Inquiry Based Science Education (IBSE)	1	5		1
	Inquiry-oriented Laboratory		1		

Table 6. *Cont.*

		Biology	Chemistry	Geology	Physics
Problematic situations	Problem-Based Learning (PBL)	1	4		4
	Investigation-Relation Experiences (IRE) in which students participated	1	1		1
	Laboratory Activities		1		
Social conflicts of a scientific nature	Activities based on controversial socio-scientific issues (SSI) in the classroom	1			
Other methodological proposals	Literature adapted from scientific or popular articles	1			
	Scientific skills assessment instruments used by students	1			
	Feedback between content knowledge and scientific research	1			1
	Improve attitudes towards science				1
	Analysing activity structures		1		

A considerable part of the contributions to promote the acquisition of scientific competences by students refer to the convenience of teaching approaches that take into account the nature of science in the classroom. On the other hand, it is also noteworthy the number of proposals that refer to the use of problematic situations (research activities, experiments or problems), the approach to controversial situations of social interest, the use of adapted scientific texts or the use of instruments that allow the assessment of the acquisition of research skills.

DISCUSSION AND CONCLUSIONS

A new challenge for teacher professional development should be focused on changing teachers' beliefs to develop scientific literacy. In general, appropriate methodologies for science inquiry should emphasize not only the content knowledge but also procedural skills and understanding in order to promote motivation to learn science (Busquets, Silva, & Larrosa, 2016). In this context, educational research on teacher training in the development of scientific competencies at secondary education levels has been reviewed.

In accordance with our objective 1, the selected articles include objectives focused on several aspects. Regarding the methodology used, scientific practices, inquiry-based learning activities, argumentation, problem-based learning (PBL), reasoning and creative thinking skills, the use of laboratory activities in the classroom or Science – Technology –Society instruction, among others, have been studied. Regarding the teacher competences, several articles have shown interest in analysing the teacher's strategies to guide participants in task-solving process and investigations, their question-asking ability or the teachers' views towards several learning and teaching strategies.

On the other hand, we have been able to establish that, although the interest in the development of scientific competence in students is common to all sciences worldwide, the effort dedicated to training teachers in their acquisition varies depending on the discipline. Thus, for example, of the articles selected, the majority belonged to the fields of chemistry (17) and biology (16), followed by physics (12) and far below geology, for which there was only one article.

With regard to the second of our objectives, there are also clear differences among the methodology used to promote scientific competence depending on the discipline. For example, in disciplines such as biology and geology (which only includes one article according to the selected criteria) the nature of science approach dominates, whereas the resolution of problematic situations is the most mentioned in chemistry or no preferences emerge in physics.

Inquiry experiences in high school science classrooms tend towards experimentation in dicordant methods between the different areas of science. Therefore, in some areas, the use of experimental methodologies is less frequent (for example, geology) and they are often not included in the experiences of inquiry that our students receive (Gray, 2014).

Finally, with regard to our third objective, despite the variety of proposed objectives in the studies analyzed, they coincide in the need that science teachers present to move from direct instruction towards student-centered scientific research and science-technology-society frameworks (Zhang & Campbell, 2012).

According to the main conclusions, there is a need to conduct special professional courses to encourage teachers to change their teacher-centered approach to a more student-centered orientation. Some difficulties were found to transform relevant theoretical knowledge into practical actions. Thus, teachers need training to support students for planning and carrying out investigations, especially in open processes which could benefit more the engaging in argument from evidence. Preservice teachers frequently guide science teaching between direct and guided inquiry and they hold heterogeneous beliefs about science teaching and learning, being Chemistry teaching more traditional than other disciplines. Inquiry- based teaching is effective on the preservice teachers' perceptions about their learning.

It is recommended for teachers to focus not only on content knowledge, but also on procedural and epistemic knowledge as well as on scientific understanding/explanation of phenomena with its proper interpretation. Nevertheless, the frequency of laboratory activities depends on teachers' ideas and monetary and time expenses impact on the specific choice of laboratory activities. Moreover, Teaching Nature of Scientific Inquiry is not a primary goal for teachers, although critical testing, hypothesis and prediction seem to be easily incorporated in the Chemistry classroom. The activity-based instructional framework in line with cultural historic activity theory is highly appreciated and it provides useful guidelines for the transformation of the scientific practices into high-quality context-based curriculum materials.

Regarding the improvements in teacher training, many teachers recognized their progress in developing inquiry, reasoning and creative thinking skills and appreciated real-life modelling scenarios. Moreover, PBL courses could have positive effects on creative thinking ability of preservice teachers and on the use of self-regulated learning strategies. On the other hand, the progressive construction of a Content Representation result to be optimal to help teachers with initial training, such as the development of pedagogical content knowledge (PCK). An Integrated Experiential Learning Curriculum improves teachers' attitudes on teaching science and its quality. Teachers' assessment knowledge was found to be a relenant stage in teachers' professional growth, thus being proposed as an instrument to determine their professional growth.

Teacher training should highlight the importance of inquiry as a way of experiencing science in the classroom and developing scientific literacy. In this respect, the bibliographic review carried out allows us to confirm that the use of teaching proposals based on scientific competences must begin in the first educational stages, bringing science and society closer to students. Studies aimed at proposing how training units and methods can be used to change the beliefs of preservice teachers are necessary, since the beliefs of teachers will determine the approaches used in the classroom (Markic y Eilks, 2008).

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EVALUATION OF A TEACHER EDUCATION PROGRAMME TO CONSTRUCT ARGUMENTS BASED ON ADEQUATE AND SUFFICIENT EVIDENCE

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A teacher's ability to construct an argument is said to also be important when introducing an argumentation (Zohar, 2008). Yamamoto and Kamiyama (2020) developed a teacher education programme for teaching argumentation in Japan and reported improvements in teachers' own ability to construct and assess arguments. However, there is currently no programme for increasing the level of argumentation in teacher education yet, despite the need for developing a coherent programme for stepwise instruction. To address this problem, a teacher education programme was developed to construct complex arguments without using experimental results that do not lead to one's own claims (adequacy) and by selecting as evidence all experimental results that lead to one's claims (sufficiency). A programme was conducted for sixteen pre-service teachers of the Japanese national university graduate school of teaching who plan on becoming primary school teachers. The programme was based on the activity by Yamamoto and Kamiyama (2020), and included an activity wherein teachers constructed their own arguments by examining the adequacy and sufficiency of evidence. The results of the pre- and post-programme analysis of the argument construction task showed that although there was no significant improvement in the adequacy of the evidence, about 3/4 of the pre-service teachers scored full marks in both the pre- and post-tests. Furthermore, there was a significant improvement in the sufficiency of the evidence ($p<.05$ $Z=-2.539$). Pre-service teachers were able to construct complex arguments about the post-test evidence by selecting several experimental results as evidence leading to a claim, instead of using the experimental results that did not lead to their own claim. This could be attributed to the effect of the programme activities wherein the pre-service teachers themselves examine the evidence, construct the arguments, and assess the learners' arguments.

Keywords: pre-service teachers, argument construction, stepwise instruction

INTRODUCTION

Argumentation in science is an important process, with one of the scientific literacies in PISA 2015 being 'Interpret data and evidence scientifically: Aanalyse and evaluate data, claims and arguments in a variety of representations and draw appropriate scientific conclusions.' (OECD, 2016: 20). Scientific knowledge is built on the explanations and agreements of scientists. Therefore, it is essential for science to persuade others by using data as evidence and reasoning about why it leads to one's claims, and there are many practices that introduce argumentation into this process (e.g., Iordanou & Constantinou, 2015; McNeill & Krajcik, 2011). In Japan, the course of study emphasises the importance of language activities of the children in accordance with the characteristics of the subjects, and using scientific terms and concepts to think and explain. (Ministry of Education, Culture, Sports, Science and Technology, 2017).

A teacher's ability to construct an argument is said to also be important when introducing an argumentation (Zohar, 2008). Yamamoto and Kamiyama (2020) have developed a teacher education programme for teaching argumentation in Japan, and have reported improvements in teachers' own ability to construct and assess argument. However, it only dealt with the simplest argument, which consisted of the following components: claim, evidence and reasoning. McNeill and Krajcik (2011) reported that there are levels (variations) of argumentation and suggested that they be taught in stages according to one's level of proficiency. They are based on the claim-evidence-reasoning component, with more complex arguments having more than one piece of evidence or reasoning, or a rebuttal. In fact, practical studies on Japanese primary school children have, in turn, raised this level to achieve more complex arguments for children (e.g., Kamiyama et al., 2016). However, there is currently no teacher education preogramme for increasing the level of argumentation yet, despite the need to develop a coherent programme for stepwise instruction.

To address this problem, we developed a teacher education programme to construct complex arguments without using experimental results that do not lead to one's own claims (hereinafter referred to as 'adequacy') and by selecting as evidence all experimental results that lead to one's claims (hereinafter referred to as 'sufficiency').

The research question was as follows;

Was the teacher education programme aimed at the stepwise teaching of the arguments effective in developing the teachers' ability to construct arguments based on adequate and sufficient evidence?

METHOD

Subject

The subjects of this study consisted of sixteen pre-service teachers of the Japanese national university graduate school of teaching who plan on becoming primary school teachers. A 90-minute programme by Zoom was conducted four times from May to June 2020 for a total of 360 minutes.

The programme

Table 1 shows the overview of the programme. The programme is based on activities proposed by Yamamoto and Kamiyama (2020) and includes an activity (Activity 7) wherein the teacher constructs an argument by examining the adequacy and sufficiency of evidence. This activity was based on the theme that water increases in volume when it freezes and that things dissolved in water do not disappear. The pre-service teachers were asked to select two or three pieces of evidence from the several experimental results as adequate and sufficient evidence to support their claims, and to describe their arguments by means of reasoning.

Test and survey

The sixteen pre-service teachers who participated in the programme were asked to complete an argument construction task before and after the programme. The duration of the task was approximately 10 minutes.

Table 1. The overview of the programme.

Time	Activity
1	Introduction
	Activity1: Lecture on the definition and significance of argument.
2	Activity2: Lectures and exercises on the realities of children's argument.
	Activity3: Exercises to give an experiential understanding of the teaching and assessment of argument.
	Activity4: Overview of actual augmentation teaching in primary school classes.
3	Activity5: Planning of teaching with the introduction of the argument.
	Activity6: Exchange and discussion of teaching plans with the introduction of the argument.
4	Activity7: Lectures and exercises on arguing for the adequacy and sufficiency of evidence.

The argument construction task was based on the one in the study by Yamamoto et al. (2013). Table 2 shows the results of the experiments presented and their adequacy. Pre-service teachers were presented with the results of six experiments on plant germination and growth conditions, and were subsequently asked to write an argument to answer the question: ‘Is it correct to assume that germination requires water, air, adequate temperature, and also fertiliser from outside?’ The answer to the question was the claim, and the scientific principle that ‘germination requires water, air, and appropriate temperature’ was the reasonig. As for the evidence, the participants were asked to select the experimental results which satisfied ‘adequacy’ and ‘sufficiency’ as evidence. Three cases related to the claim (germination condition) and three cases unrelated to the claim (growth condition) were prepared as options. The participants were asked to choose three adequate and sufficient pieces of evidence from the results of these six experiments, and to write their arguments freely.

Table 2. The results of the experiments presented and their adequacy.

Experiment	Experimental results	Adequacy
Germination conditions	Result 1: Green beans A and B germinated with and without fertiliser in the experiment with controlled conditions (table of results is presented).	Adequate
Growth conditions	Result 2: The germinated maize A and B grew more when fertiliser was applied (table of results is presented).	Inadequate
Germination conditions	Result 3: Maize C and D germinated with and without fertilizer in the experiment with controlled conditions (table of results is presented).	Adequate
Growth conditions	Result 4: The germinated beans C and D grew larger when fertilised (table of results is presented).	Inadequate
Germination conditions	Result 5: When the seeds of bean E were cut horizontally and dipped in iodine solution, they were found to contain a lot of starch, but the cotyledons, which had shrunk some time after germination, did not contain any starch.	Adequate
Growth conditions	Result 6: Loofah A has grown a bit bigger, so we replanted it in the field with fertiliser.	Inadequate

Table 3 shows the rubric for scoring the free statements. Participants with correct answers to the question (claim) and the scientific principle (reasoning) were awarded one point for each claim and reasoning. In evidence, as 'adequacy' from each of the six experimental results, one point was deducted from a maximum of three points to be scored according to the number of uses of the three inappropriate pieces of evidence for growth conditions. For 'sufficiency', the number of the three inappropriate pieces of evidence for germination conditions was scored on a 3-point scale. The judgements were made by two independent persons, and the agreement rate was 96.9%.

Table 3. The rubric for scoring the free statements.

Element	Score	Adequacy
Claim	1	There are the following claims.
		Masako is wrong.
	0	There is no claim to the above.
Evidence	3	Not a single piece of inappropriate evidence was used, such as
(Adequacy)		(In result 2), maize A grew more.
		(In result 4), green beans C grew more.
		(In result 6) Loofah A was replanted in a field with fertilizer.
	2	One inadequte piece of evidence has been adopted as described above.
	1	Two inadequte piece of evidence has been adopted as described above.
	0	Three inadequte piece of evidence has been adopted as described above.
Evidence	3	The following three pieces of evidence are all correct.
(sufficiency)		(In result 1), both beans A and beans B germinated.
		(In result 3) both maize C and maize D germinated.
		(In result 5), the seeds of kidney bean E contained a lot of starch, but the cotyledons after germination did not contain any starch.
	2	Two of the above pieces of evidence have been adopted.
	1	One of the above pieces of evidence have been adopted.
	0	Not one of the above evidence has been adopted.
Reasoning	1	The following reasons can be given
		Germination needs only water, air and the right temperature (no fertilizer).
	0	There is no reasoning for the above.

RESULTS

Table 4 presents the distribution of scores for the argument construction task. Based on the McNemar test for claim and reasoning and Wilcoxon's signed rank sum test for evidence, the constructs for which the improvement in the distribution of scores between pre- and post-test were found to be significant and shown in bold. In the case of 'claim', most of the pre-service teachers obtained full marks in both the pre- and the post-tests. Although there was no significant improvement in the adequacy of the evidence, about 3/4 of the pre-service teachers scored full marks in both the pre- and post-tests, and there was also a significant improvement in the sufficiency of the evidence ($p<.05$ $Z=-2.539$). Around half of the pre-service teachers had correct answers for ‘reasoning’.

Table 4. The distribution of scores for the argument construction task.

	Pre-test				Post-test				
Score	3	2	1	0	3	2	1	0	
Claim	--	--	13	3	--	--	14	2	
Evidence (Adequacy)	11	1	4	0	12	2	2	0	
Evidence (sufficiency)	**0**	**6**	**2**	**8**	**3**	**9**	**2**	**2**	*
Reasoning	--	--	6	10	--	--	7	9	

DISCUSSION AND CONCLUSIONS

As a result of the analysis of the programme’s argument construction task, the pre-service teachers were able to construct complex arguments about the post-test evidence by selecting several experimental results as evidence leading to the claim, instead of using the experimental results that did not lead to their own claim. This could be attributed to the effect of the programme activities wherein the pre-service teachers themselves examine the evidence, construct the arguments, and assess the learners' arguments.

However, although there was a significant improvement in the sufficiency of evidence, only 3 of the 16 pre-service teachers were able to correctly select all the experimental results that led to their claim. In order to strengthen a claim, there should be more awareness regarding the need to select all possible evidence, not just those with more than one piece of evidence to support it. Increasing this awareness in the selection of evidence is necessary to improve the programme.

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IMPACT OF INITIAL TRAINING ON CONCEPTIONS ABOUT "MEASUREMENT" AND "ATTRIBUTE" OF PRE-SERVICE PRIMARY SCHOOL TEACHERS

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The teaching of the "attribute" and "measurement" concepts at primary school in France is an interdisciplinary issue shared by mathematics and physics teaching. In a previous study presented at ESERA 2019, we confirmed that at the end of their initial training Pre-Service Teachers (PSTs) related the attribute concept to something vague and the measurement concept to something precise. They generally believed that several values are needed to define a measurement value. They noticed that error sources are necessary to be taken into account to enhance the measurement process and obtain better measurement values. In this second study, we investigate the impact of the initial training these trainees received a test similar to the one use in the previous study. The PSTs' responses are analysed at the beginning of the training in order to compare them with previous results obtained at the end of a similar training. Additionally, a specific pedagogical situation dedicated to the concepts involved in this study has been conceived. We look at the evolution of the understanding of the trainees who have taken this specific session. The results indicate a very small effect of the initial training on the trainees' understanding of the attribute and measurement concepts. Beside the specific situation appears to have only a slight effect on their understanding of data collection.

Keywords: Initial Teacher Education (Pre-service), Measurement, Primary School

ATTRIBUTE[12] AND MEASUREMENT IN LITERATURE

The 14th conference of the ESERA spotlighted the uncertainty of the world and moreover this issue in science education from different perspectives. Yet uncertainty is a main issue of the metrology, which is the dedicated field studying measurement for science and technologies. This concept is defined in a guide establishing rules for evaluating and expressing uncertainty in measurement (JCGM, 2008). Although the access to the concepts of uncertainty and error in a measurement issue needs to fully understand the concept of measurement and thus the one of attribute. The main goal of a measurement is to quantify interactions and relationships between objects and phenomena to build mathermatical models. The International Vocabulary of Meausrement (JCGM, 2012) defines Attribute (Quantity) as "Property of a phenomenon, body, or substance, where the property has a magnitude that can be expressed as a number and a reference" (p.2) and Measurement as a "Process of experimentally obtaining one or more quantity values that can reasonably be attributed to a quantity" (p.16). Teaching those concepts

[12] The concept of "grandeur" in French could be translated in English as quantity, magnitude or attribute. The choice to use the term "attribute" is consistent with many English language standards and with research on mathematics education as described by Passelaigue and Munier (2015).

at primary school should enable pupils to get access and to observe the reality of the world but also to introduce that the validity of those observations are limited.

Literature in mathematics and physics education raises the question of the status of attribute and measurement in primary teaching. Since 2015, French curriculum of mathematics spotlights both concepts. It focuses particularly on the building of the number (MEN, 2015). Brousseau (2002) explains that teaching the attribute concept at primary level is valuable as it is linked to fundamental knowledge of mathematics. Then Chesnais and Munier (2015) set out that the practical concepts of measurement and the uncertainties are often set aside during the teaching of mathematics. Those two notions are mostly linked with the experimental sciences education. They appear in the curriculum at the end of primary school for pupils of ten years old. Chesnais and Munier (2015) explain that a differential treatment of the reality between physics and mathematics still exists at primary school. Yet, teachers at primary school in France are shortlisted by a national competitive exam. Then they become teacher trainees attending a Master 2 in which they spend half time in class and half time at a training centre (INSPE[13]). Majority of them did not have a previous specific science or mathematic education at university before this training. Then we can imagine that the teaching of both concepts could be difficult task to them.

In a previous study, presented in the ESERA 19 conference, we wondered how Pre-Service Teachers (PSTs) of primary school understood attribute and measurement concepts by the end of the training year 2017-2018. We first confirmed previous results obtained by Passelaigue and Munier (2015) that French PSTs have a lack of understanding of those concepts at the end of their initial training. They often described the concept of attribute as “something vague, ill defined, not very precise” (p.332). Trainees also explained that “an attribute is only an approximate quality” (p.332) until it is measured. This interpretation is deviated from the nature of the concepts they would have to teach. Second, we studied the way they reasoned about collecting data linked to a measurement. We obtained that they mostly had ideas of statistical processes (average calculus) and seemed to look for error sources to deal with variations in the data collected. Thus, we wonder if this lack of understanding is due to very strong misconceptions which already exist before the training or if this one changes their way of understanding both of those concepts. Thus, we think it is important to learn more about the effects of the initial training on those concepts by comparing trainees’ understanding at the beginning of the training and its end. In addition, we wonder if a specific teaching linked to experimental sciences situations focusing on both concepts could help trainees to develop their understanding. Thus, we conceived such a training session and we looked which could be its effects on PSTs’ understanding.

METHODOLOGY

Data collection procedure

The training received by PSTs in the INSPE is focused on the teaching aspects of their future job. Most of them had a non-scientific education before their training. Thus, we assume the

[13] Institut National Supérieur du Professorat et de l’Education

group of trainees of the year 2017-2018 and the one involved in this study (year 2019-2020), have similar competences since they pass the same competitive exam before accessing to this initial training. Moreover, we assume the training given in a same site is similar from one year to another. Thus, our methodology deals with two comparisons: A) the comparison of different PSTs' views at the beginning of the training and its end; and B) the comparison of similar PSTs' understanding having a specific training in an experimental sciences education course. This methodology is represented in the figure 1.

Consequently, we use for the comparison A the results obtained with 60 PSTs during the previous study in June 2018 at the end of the training year. We compare them to new results obtained with 89 PSTs (4 groups) at the beginning of the year 2019-2020 (in October and November).

Concerning the comparison B, 61 PSTs (3 groups on 4) of the 89 previous ones attended the specific training situation in the form of a 3 hours course. They dealt first with the place of the concepts of measurement and attribute in curriculum and the definition of specific vocabulary. Later PSTs had to manage two situations of estimation and measurement: the mass determination of a small earth globe with modelling dough sticks and a Roberval scale, and the width determination of the classroom with paper stripes. Finally, PSTs watched a video of an in-practice science session in classroom dealing with the measurement of the temperature of melting ice[14]. This specific training situation targets issues such as : the introduction of specific vocabulary link to "attribute" and "measurement", the concept and the procedure of estimation, the implementation of measuring procedure for several attributes, the data processing, the notion of errors and uncertainties, and the statistical treatment and probabilistic aspects. 3 to 4 months later (March or April, depending the group), a similar questionnaire was filled by 40 PSTs. 34 of them filled the one at beginning of the training year.[15]

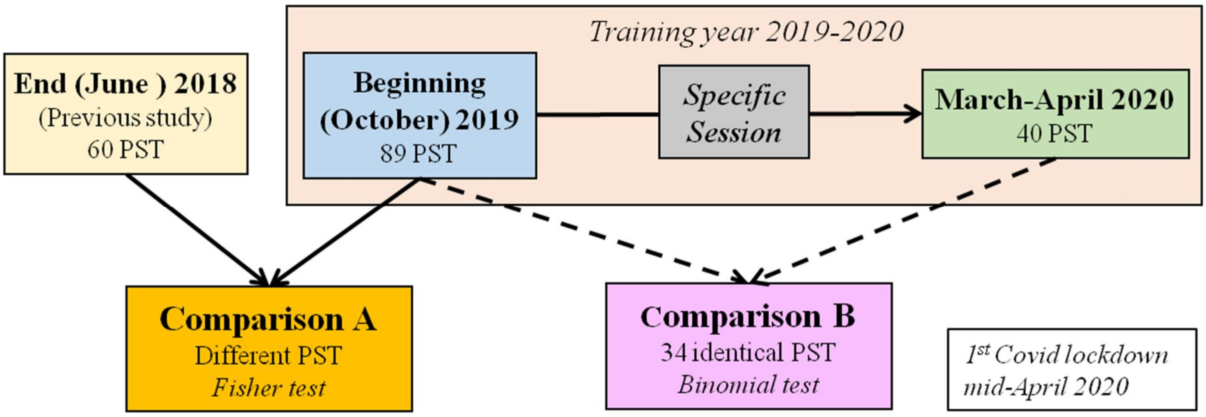

Figure 1. Data collection procedure.

Questionnaire

To assess the understanding of those concepts by the trainees in each of the situations, they complete a similar questionnaire. This questionnaire is based on the one given on the previous

[14] https://www.reseau-canope.fr/bsd/sequence.aspx?bloc=197043

[15] One group (25 PST) filled the questionnaire during a training course, when the 15 others filled it on-line due to the COVID lockdown situation. This explains the weak rate of answers for the last sample.

study (in June 2018, Maisch, 2019). This paper-and-pencil form is composed of two parts based on two surveys. In one hand, we used the test designed by Passelaigue and Munier (2015). Trainees have to define the attribute and the measurement terms and next to make a stand about a list of words referring to those concepts[16]: length, volume, comparison, equivalence, estimation, instrument, gram, decimetre, unit, standard, uncertainty, precision, and number. They also have to provide a justification for each word in order to explain their choice. In the second survey, we passed a three questions test defined by Buffler et al. (2001) to obtain student's idea about the way to think of a data collection. Three fictional characters are discussing about the way to consider the distance covered by a ball dropped from a table (figure 2). Three situations are described: the ball is dropped once, two times, and 5 times. The height of the ball dropped is the same but distances of impacts on the ground change. In the two first situations, each character suggests either to keep the value obtained as a result, or to collect a new value, or to collect several new values. In the last situation, the trainees had to decide which result for the distance they could give. Thus, they could choose one or several values of the list or they could do a calculation. In each situation, the trainees had to justify their choices.

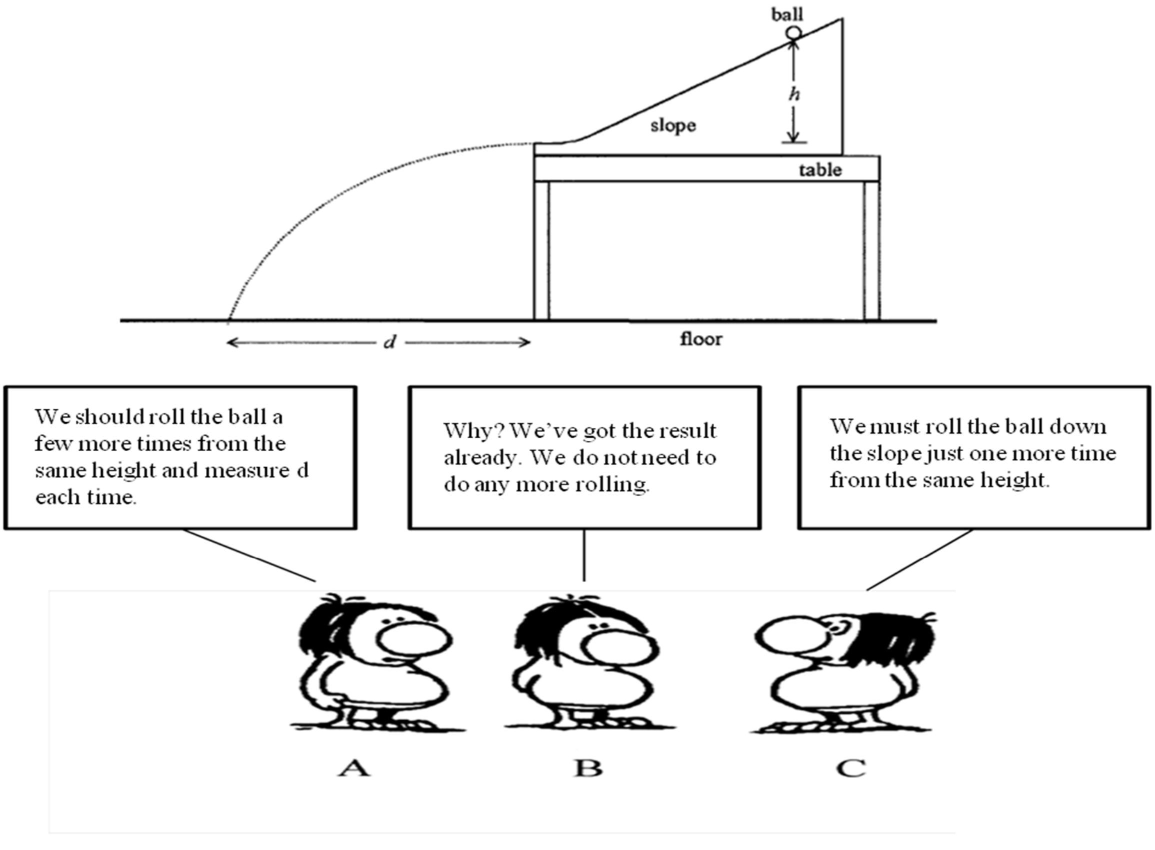

Figure 2. Situation and example of debate (Q1) in the data collecting test (Buffler et al., 2001).

Analysis framework

Regarding the analysis of the questionnaire, we look first at the way PSTs defined both concept following categories obtained in the previous studies (Maisch, 2019). Second, we look at the validity of their ranking linked to the definition they gave. To this end, we use a categorization

[16] They have to choose if each word is more linked to the attribute or to the measurement concept.

under the form of a table defined by Passelaigue and Munier (2015) and implemented with results of our previous study. Regarding the measurement survey with the data collecting part, we classify PSTs' answers in items depending on issues such as the iterations of the data, the variations, the estimation, the errors, the precision, the average, the spread and the uncertainties. Those items are also classified as valid or non-valid regarding to expert definitions obtained in the International Vocabulary of Metrology (JCGM, 2012).

Our first goal is to know if the general training given at INSPE helps PSTs to change their views about the concepts of measurement and attribute and with related concepts. Secondly, we look if a specific training session in a science education context could help them to improve such changes. This means the necessity to compare their results to the questionnaires at different times of the training year. In order to determine the effect of those situations, we use statistical analysis. Regarding the comparison A, we use a Fisher test to compare the answers as PSTs tested are different for each questionnaire. Whereas for the comparison B, PSTs are similar, thus we can use a binomial test to look at possible links between their answers.

RESULTS AND DISCUSSION

Comparison A

In the comparison A situation, we compare the distribution (in percentage) of trainees' answers of the last study obtained at the end of their training to the answers of trainees at the beginning of it. First, we observe in figure 3 and 4 that both sets of PSTs defined "Attribute" and "Measurement" in a similar way without focusing on a valid answer (framed in green in figures). This result is corroborated by statistical results obtain with fisher tests.

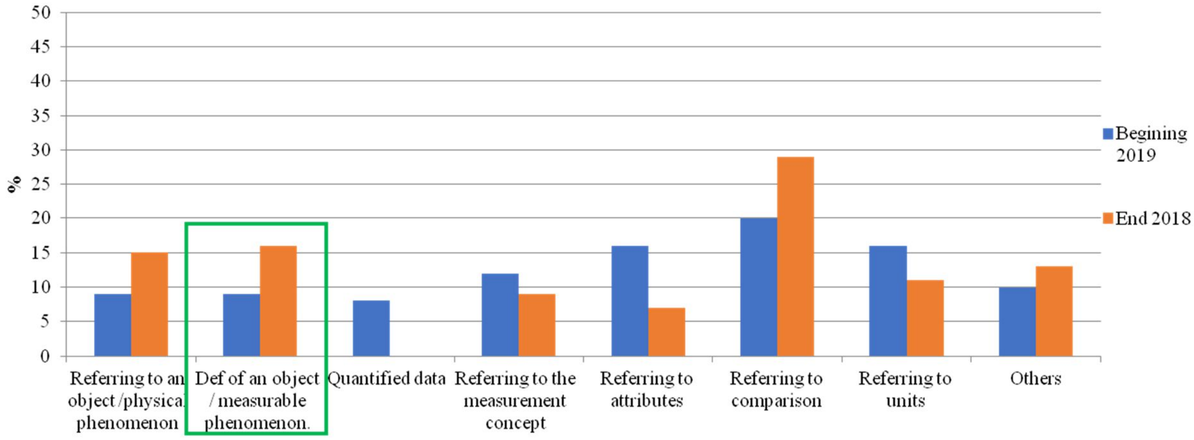

Figure 3. Definition of Attribute beginning 2019-end 2018.

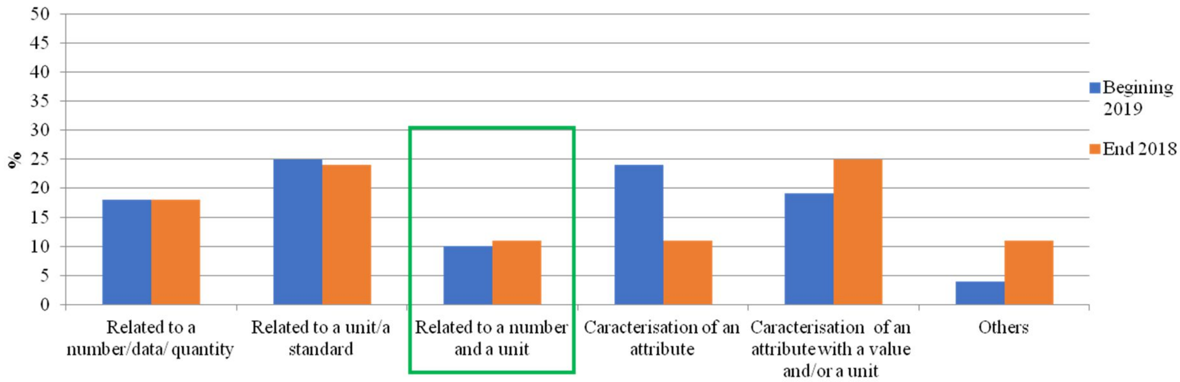

Figure 4. Definition of Measurement beginning 2019-end 2018.

A similar statement can be made on the validity of their classification of the list of words but with slight differences (figure 5). Indeed, Fisher tests show significant differences for the notions of Lentgh (p = 0.0009) and Volume (p = 0,0038) (circled in red in figure 5). Trainees use more unclassified answers (/) at the end of the training than at the begining but do not seem to use more valid answers. But this statement is limited to both notions. Concerning the other notions, the validity of their justifications follows a similar trend in both cases.

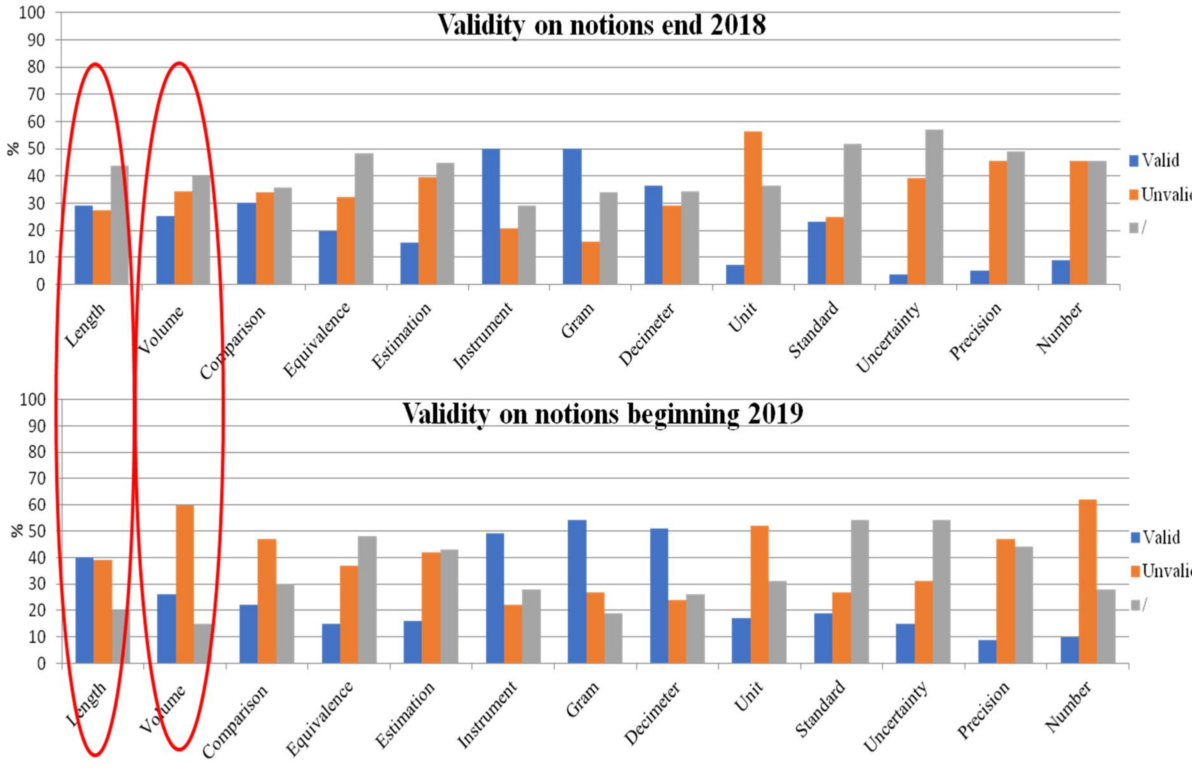

Figure 5. Comparison of validity on notions beginning 2019-end 2018.

Concerning the way to deal with a data set (measurement survey) (figure 6), the trainees used different reasoning to answer to first and second question as showed Fisher test (circled in red, Q1, p = 0,0034; Q2, p = 0,0036). Those results seem to show a change from valid answers to unclassified ones (/). Moreover, PSTs seem to use more valid answers when they have to treat several data.

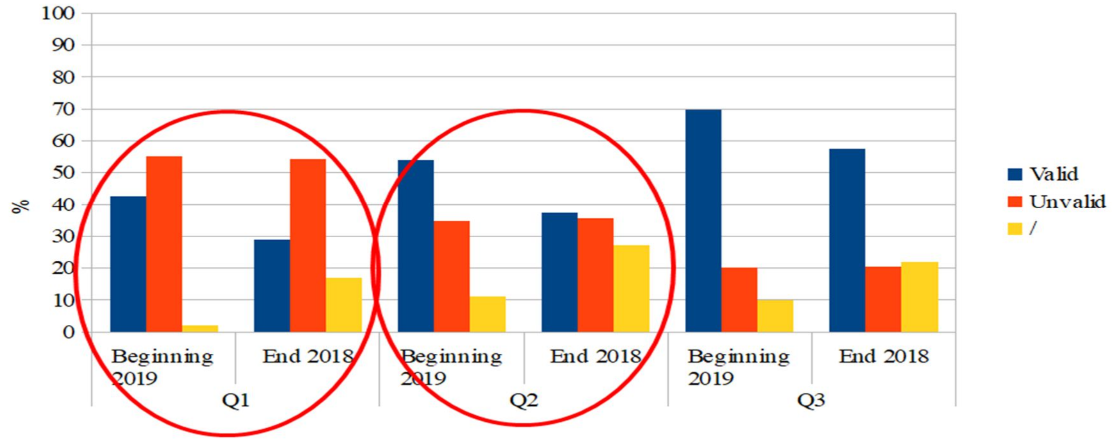

Figure 6. Validity on measurement survey beginning 2019-end 2018.

Comparison B

In comparison B, we search for impacts of the specific session on PSTs' reasoning. Thus, we compare their answers at the beginning of the training year and few months after the specific session. Their ways to define the attribute and measurement concepts (figures 7 and 8) do not show statistical significant differences. But trainees seem to use a better definition of attribute linked to the expert point of view after the specific session.

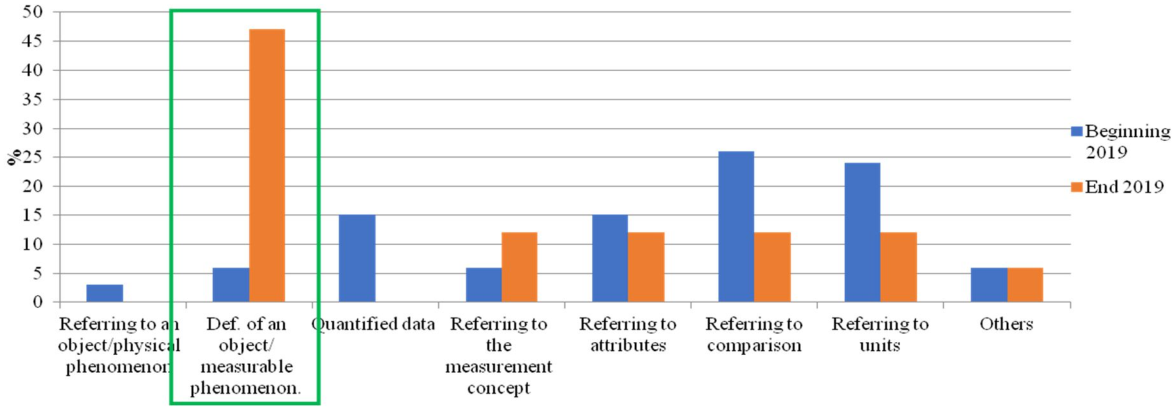

Figure 7. Definition of Attribute beginning 2019-end 2020.

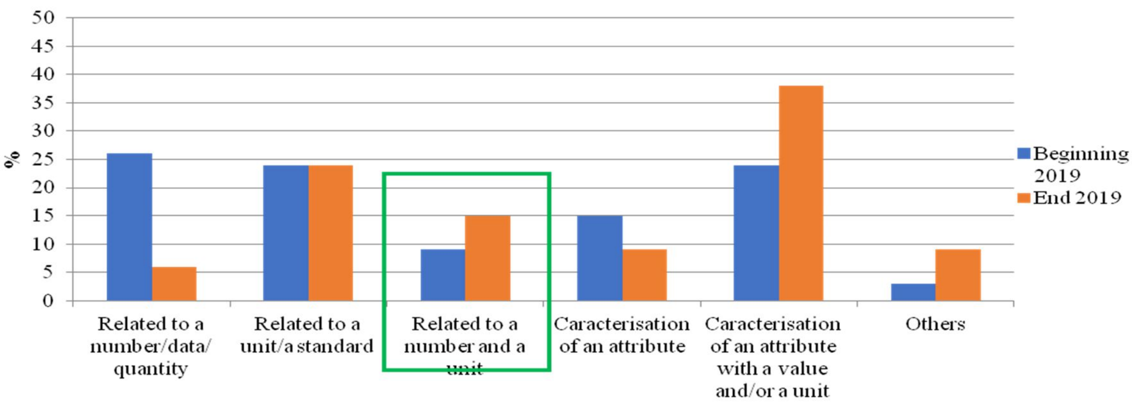

Figure 8. Definition of Measurement beginning 2019-end 2020.

When they have to rank the vocabulary linked to both concepts (figure 9), once again no statistical significant differences appear. We can notice that PSTs seem more inclined giving answers which could be classified after taken the specific course. But those answers seem more recognised as invalid than valid.

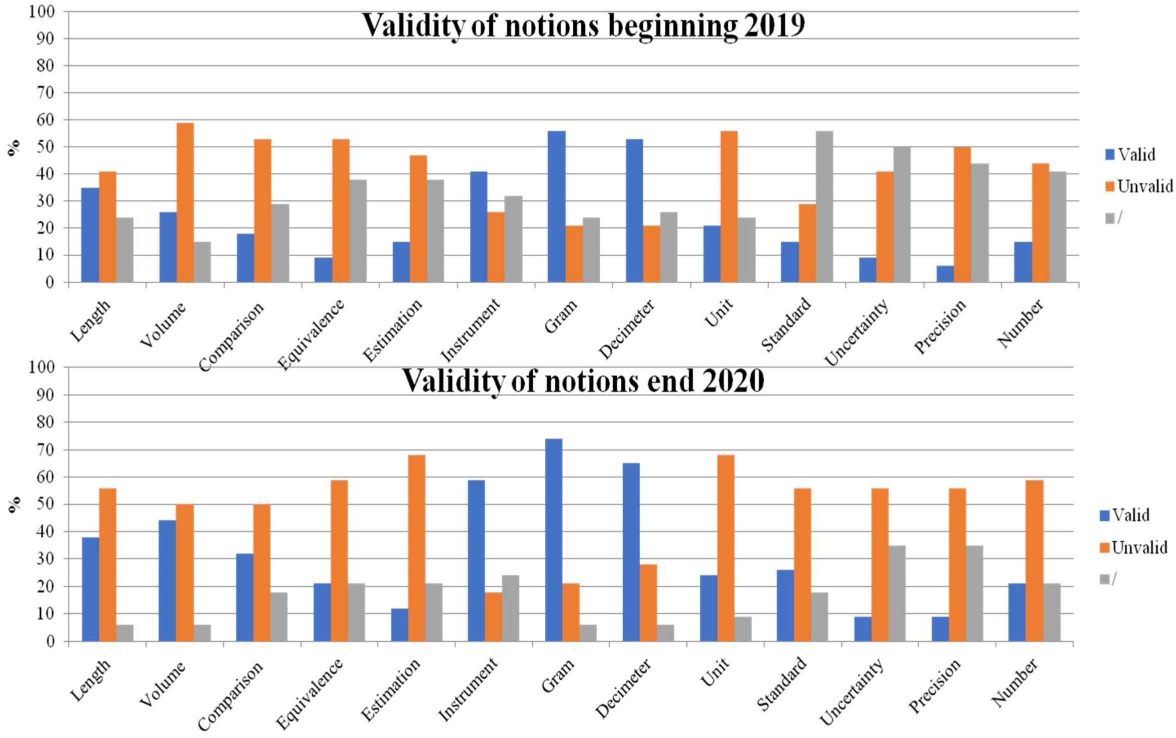

Figure 9. Comparison of validity on notions beginning 2019-end 2020.

Finally, regarding the measurement survey (figure 10), there is a significant difference only on their answers to the first question (circled in red, Q1, p = 0,0001). This result put forward a change from invalid reasoning to valid ones when they answer to this question. For the two other questions, only slight changes seem to occur improving valid reasoning without to be significant.

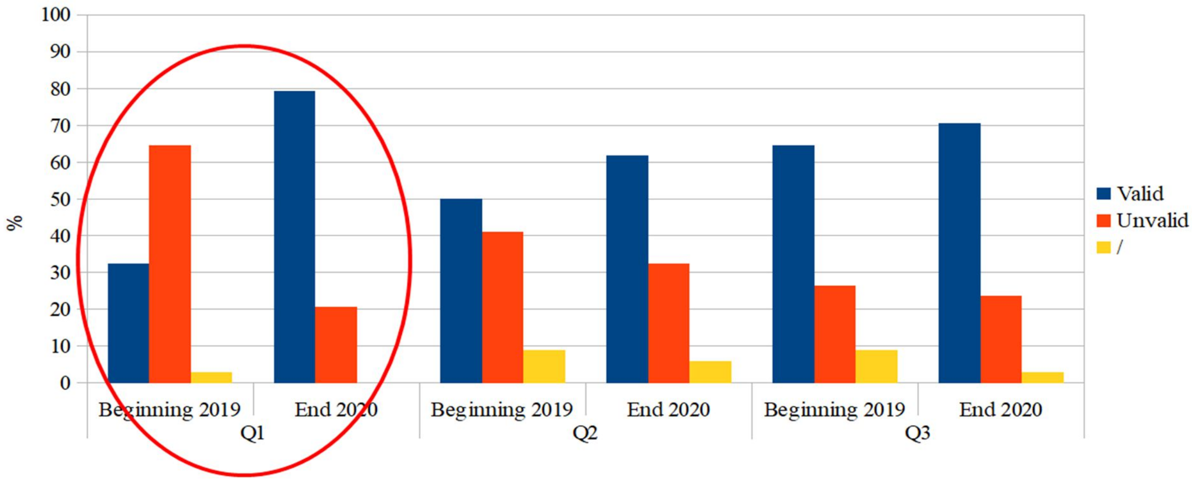

Figure 10. Validity on measurement survey beginning 2019-end 2020.

DISCUSSION

Comparison A

This comparison shows almost no change in the PSTs' understanding of the concepts of attibute and measurement and only a change in their view of the notions of length and volume linked to the concept of attribute. We can suggest those changes are due to specificities of mathematical education training focused on those two attributes with geometrical and units' issues (which could be also linked to the attribute of area, as explained by Clements and Stephan, 2004). The measurement survey shows also changes in their way to reason about collecting data. These changes seems to show more unclassified answers when the number of valid one is reducing. This result does not fit with what we could wait. This means that the INSPE education do not improve their understanding and even seem to obscure its.

Finally, results obtained in the previous study (and fitting with previous results of Passelaigue and Munier, 2015) show a consistency with what trainees think about the measurement and attribute issues before training. This confirms that INSPE training in science and mathematics education is ineffective to help students to better understand both concepts and other issues related to.

Comparison B

We lead a specific session about measurement and attributes concepts in science education training in order to help PSTs to improve their understanding. Results obtained about their understanding of the concepts and notions do not show statistically any significant improvement. However, they seem to shift toward better understanding of the concept of attribute and to use less unclassified definition of the notions. Results obtained on their way to reason about data collecting show a significant improvement when they have to answer to the first question, namely when they have to decide to collect several data. The trend in the following questions seems to be different from results obtained with comparison A. Eventually, we could say the specific session seems to have slight effects and especially on their way to collect data. The low impact of this situation may be explained by its shortness in time. It can be linked to the Brousseau's explanation that the attribute concept is "taught through an early and extended natural and scholar process" (2001, p.2).

CONCLUSION

Finally, it seems relevant to confront the trainees to the concepts of measurement and attribute all along their initial training, and not only with specific sessions. This training has to be an interdisciplinary goal, involving instructors of experimental sciences education and mathematics education. Thus, they have to lead trainees to provide a meaning to the different concepts whether to build the concept of number or for geometry in mathematics education, or to measure physical objects and to deal with errors or uncertainties in experimental science education.

Future analysis of trainees' practices in classroom will provide an understanding of the choices they make in the design and the implementation of teaching situations involving the concepts of measurement and attribute in mathematics and physics.

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DIGITAL MEDIA IN PRE-SERVICE TEACHER EDUCATION – A QUESTION OF IMPLEMENTATION

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STEM education has, due to its technology-related topics, many potentials for a multifaced use of digital media. Integrating these tools into the classroom requires (pre-service) teachers to develop additional knowledge about the technologies themselves and their purposeful implementation in practice. In contrast to approaches that treat ICT separately, digital media were integrated systematically into the existing study program at the Leuphana University Lüneburg (Germany) by linking fundamental science education topics explicitly with the purposeful application of digital media in practice. The designed course has a (significantly) positive influence on pre-service teachers' behavioural intentions (TPB; Ajzen, 1991) and professional knowledge (TPACK; Koehler et al., 2014). Additionally, content analysis of lesson plans showed that after attending the course, pre-service teachers are able to design multimedia enriched learning situations, which go beyond the mere substitution of 'classical' media (SAMR; Puentedura, 2006).

Keywords: Science Education, Teaching Innovations, ICT Enhanced Teaching and Learning

INTRODUCTION

The digital transformation has proceeded rapidly during the last decades not only in daily life but also in school. Especially science education has due to its technology-related topics many potentials for a multifaceted use of ICT. Digital media are not only tools for teaching and learning but can be used to e.g., avoid dangerous experiments, or to visualize abstract relations – potentials that can be supportive especially in diverse classrooms to allow for participation of all students (Stinken-Rösner & Abels, 2021). In order to prepare preservice teachers to design learning activities and environments, which support individual learning processes with digital media, up-to-date pre-service teacher education programs are necessary which foster pre-service teachers' professional knowledge (in particular TPACK; Koehler et al., 2014), behavioural intentions (according to TPB; Ajzen, 1991), and to illustrate subject-specific usefulness.

METHOD

Following the transformative view of TPACK (Mishra & Koehler, 2006; Angeli & Valanides, 2009; Jang & Chen, 2010; Jin, 2019; Schmid, Brianza & Petko, 2020, Stinken-Rösner, 2021b) digital media were implemented systematically in the pre-service science teacher education program at the Leuphana University Lüneburg by linking fundamental science education topics (e.g. scientific language, Nature of Science, experiments, etc.) explicitly with digital media and its usage opportunities in science education. Accompanying research was carried out to evaluate the impact of the course on pre-service teachers' professional knowledge, behavioural intentions, and their ability to plan learning activities with digital media in science classes.

Course Design

The university course is embedded in the second year of the Bachelor's program and consists of a lecture and a complementary seminar of two hours per week each. Pre-service teachers for primary science and secondary biology and/or chemistry education attend the course.

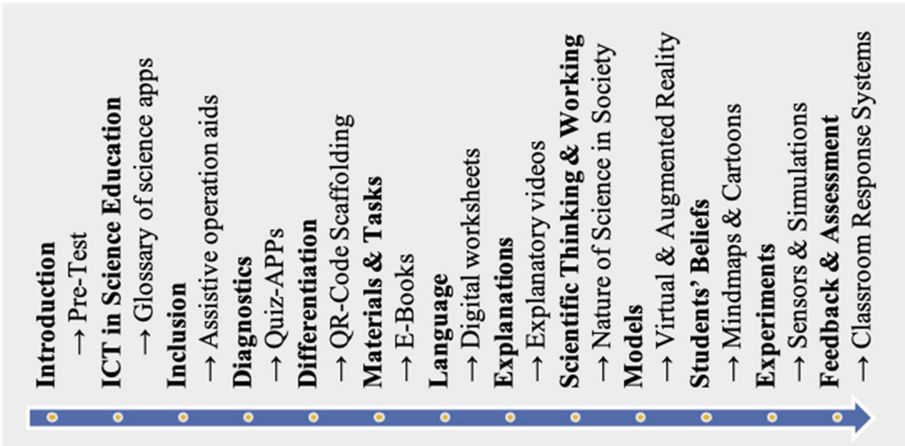

Figure 1. Course design: Each week, a fundamental science education topic is linked explicitly with possible digital media applications.

Each week (altogether 13), a fundamental science education topic is supplemented by implementation possibilities of digital media in class related to the respective topic (see Figure 1).

Research Design and Instruments

The aim of the course is to implement digital media systematically into the science education program at the Leuphana University Lüneburg to increase pre-service teachers' professional knowledge and their behavioural intentions towards the use of digital media in science education at school. This leads to the following questions:

(i) How do pre-service teachers' professional knowledge and their behavioural intentions develop during the course?
(ii) How pronounced are technology exploitations in pre-service teachers' lesson plans in terms of quantity and quality after attending the course?

The accompanying research follows a mixed-methods approach. At two measuring points (pre/post) pre-service teachers' behavioural intentions in terms of attitudes, perceived constraints, self-efficacy, and motivational orientation, as well as their professional knowledge (TPACK and sub-dimensions), are captured on a 5-point Likert scale by self-reports. Therefore, already established test instruments by Chai et al. (2013) and Vogelsang et al. (2019) were adopted. Corresponding scale reliabilities in terms of Cronbach's alpha are acceptable to good ($\alpha > 0.7$) for all scales (Stinken-Rösner, 2021a; 2021b). Further evidence of reliability is given by confirmatory factor analysis (CFA). In CFA results, the model fit indices are acceptable (RMSEA = 0.066) or slightly less than the good fit values (CFI = 0.889, TLI = 0.875) (Stinken-Rösner, in preparation).

Additionally, a (stepwise) linear regression analysis was performed to compare the integrative and transformative views of TPACK (Stinken-Rösner, 2021b). In accordance with previous studies, two of the three hybrids of first-order proved to be positive predictors for TPACK, mainly PCK and TPK (Angeli & Valanides, 2009; Jang & Chen, 2010; Jin, 2019; Schmid et al., 2020). These results strengthen the transformative view of TPACK and thus the chosen course design.

Lesson plans are analysed by qualitative content analysis in terms of quantity and quality of technology exploration (Backfisch et al., 2020). The number and frequency of digital media which are described in the lesson plans as well as the quality of their use based on conceptualizations by Puentedura (2006) were assessed on four hierarchical dimensions: substitution, augmentation, modification, and redefinition (SAMR-Model).

Participants

The sample contains 58 pre-service teachers (9 male and 49 female) who attended the course. 26 (1 male, 25 female) of them participated voluntarily in the questionnaire survey at both measuring points. The participants are on average 21.8 (SD = 2.8) years old, the majority of them has none to little teaching experience. 16 participants study science for primary, eight biology, and three chemistry for secondary education. Note that one participant studies both biology and chemistry. There are no significant differences for any of the scales in relation to the sample characteristics of gender, age, subject, and teaching experience before participating in the course (Stinken-Rösner, 2021a). Lesson plans of all 58 course participants could be analysed.

RESULTS

The results are presented in two parts according to the research questions.

Behavioural Intentions and Professional Knowledge

While the course generally seems to have a positive influence on pre-service teachers' behavioural intentions, significant differences between pre- and post-test only occur in their reported self-efficacy ($t(25) = -4.492$, $p < .001$), as shown in Figure 2.

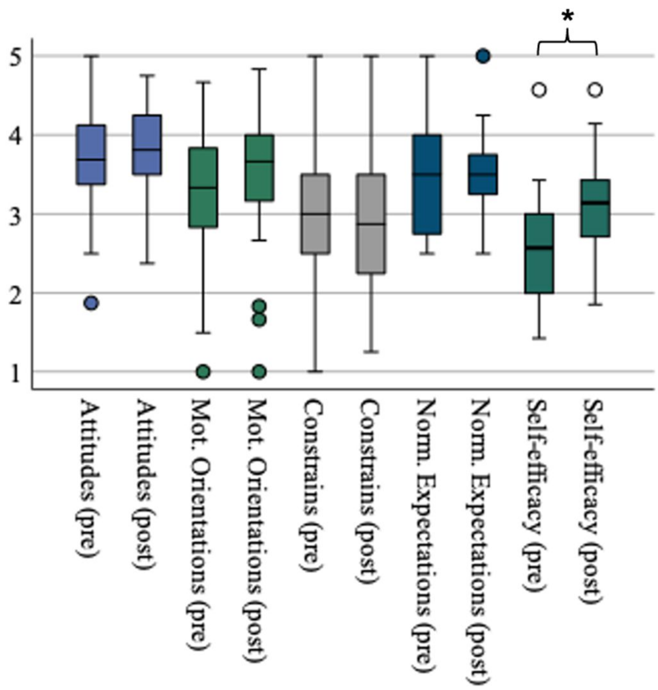

Figure 2. Box-plots of behavioural intentions before and after attending the course. Significant differences are marked with an asterisk.

With regard to pre-service teachers' professional knowledge a (highly) significant increase could be proven for TK ($t(25) = -2.125$, $p = .044$), CK ($t(25) = -2.507$, $p = .019$), PCK ($t(25) = -3.469$, $p = .002$), TCK ($t(25) = -2.416$, $p = .023$), and TPACK ($t(24) = -2.268$, $p = .033$), as shown in Figure 3.

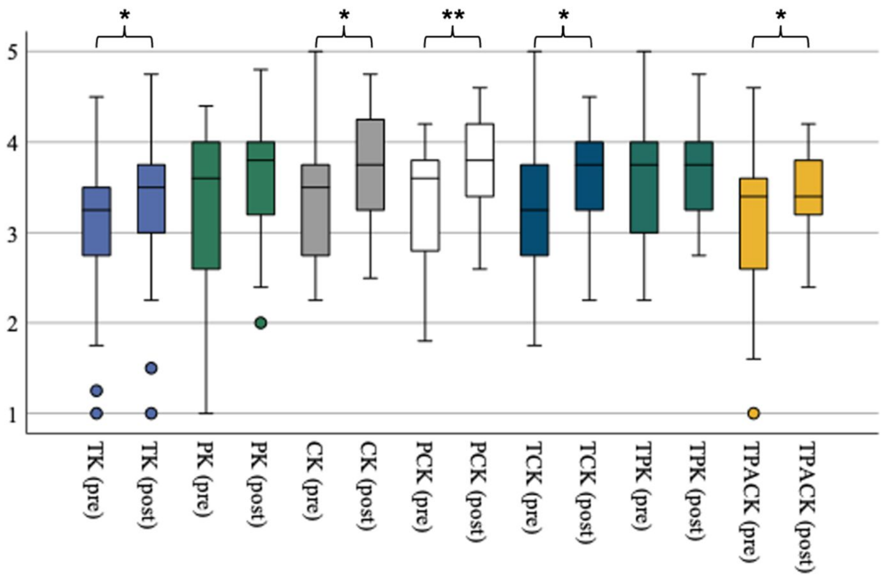

Figure 3. Box-plots of professional knowledge before and after attending the course. Significant differences are marked with an asterisk.

Quantity and Quality of Technology Exploitation

Overall pre-service teachers described the use of 75 different digital media applications in their lesson plans. They mainly included science learning apps, online available explanatory videos, video creation applications, and interactive presentation hardware such as smartboards. The quality of pre-service teachers' technology exploitation ranges from augmentation (45 %) over modification (40 %) to redefinition (13 %) classified according to Puentedura's SAMR-Model (2006). Therefore, digital media are used by pre-service teachers as a direct substitute with functional improvement (augmentation) or to allow for significant task redesign (modification/redefinition).

DISCUSSION

The designed course has a (significantly) positive influence on pre-service teachers' behavioural intentions and professional knowledge regarding the use of digital media in science education. Participants highlighted the practical approach of the course, which combines fundamental science education topics with digital media applications for teaching and learning science. After attending the course, pre-service teachers are able to design first multimedia enriched learning situations that go beyond the mere substitution of 'classical' media, as evident from lesson plans. Whereby ICT is used for functional improvement (augmentation) and/or the redesign of the teaching and learning activities (modification/redefinition). However, the gathered data reflects pre-service teachers' self-perceptions and theoretical lessons, an objective analysis concerning their actions in classroom practice can only be done by lesson observations.

CONCLUSION AND OUTLOOK

The results show that the chosen course design – integration of digital media approaches alongside science education topics – can be assessed as positive in retrospect. Digital media should not be taught additionally, but systematically be integrated into existing study programs. By doing so, pre-service teachers learn how to implement digital media applications purpose-oriented in science education. Thus, the presented course design can serve as a successful example for curriculum designers to redesign courses at their universities in a similar way.

However, the gathered data reflects pre-service teachers' self-perceptions and theoretical lessons, an objective analysis concerning their actions in practice will be investigated in the upcoming semester. Pre-service teachers will design and teach digital media enhanced science lessons in groups of three to four. Related lesson plans are analysed by qualitative content analysis in terms of quantity and quality of technology exploitation (Backfisch et al., 2020). The quality is rated based on conceptualizations by Puentedura (2006) for the level of technology integration (SAMR: Substitution, Augmentation, Modification, Redefinition) and by Chi and Wylie (2014) for the cognitive engagement of students (ICAP: Interactive, Constructive, Active, Passive). In addition, the development of pre-service teachers' behavioural intentions and professional knowledge will be recorded a third time at the end of the upcoming semester. In this way, it is possible to gain a more detailed understanding of the relationship between knowledge on and in action, behavioural intentions, and how their development can be supported by study programmes.

ACKNOWLEDGEMENTS

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PRE-SERVICE SCIENCE TEACHERS' BELIEFS ON DIGITAL TECHNOLOGY– BEFORE AND DURING THE COVID-19-PANDEMIC

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The COVID-19-pandemic influenced the digitisation in Higher Education all over the world enormously. The summer semester of 2020 was the first complete digital semester in the history of German Universities. In this transformation process, it is essential to examine students' beliefs regarding digital technologies in higher education for successfully implementing online teaching and learning with digital technology. This study explores pre-service science teachers' beliefs regarding current mostly used digital technologies. On the one side, the research focuses on the pre-service teachers' beliefs about their learning with digital technologies. On the other side, the study investigates the pre-service teachers' beliefs about their future teaching with digital technologies in school. Besides, the interest for further education and suitable formats are evaluated as well. 146 science pre-service teachers used the quantitative Digital Technologies Survey. The study distinguishes between pre-service science teachers from the winter semester 2019/2020 before the COVID-19-pandemic and those from the digital semester of summer 2020. The results show that overall pre-service science teachers' beliefs regarding digital technology in learning and teaching are on a moderate level. However, differences in the evaluation of own learning and future teaching with digital technology were identified. The pre-service science teachers who participated in the digital semester rate digital technology slightly higher than those who participated in the semester before the COVID-19-pandemic. Highly significant differences were seen only in the intensively used technology of the digital semester. Results will be discussed concerning the digital prerequisites of participants and modifications concerning teacher training.

Keywords: ICT Enhanced Teaching and Learning, Higher Education, Technology in Education and Training

THEORETICAL BACKGROUND

Since March 2020, the COVID-19-pandemic has resulted in enormous teaching and learning changes in general and in higher education in particular. With the enforced modifications, most tertiary education in Germany needed to turn to digital in the summer semester of 2020, starting in April 2020. This change was challenging, while before the COVID-19-pandemic, higher education's digitisation has been realised only inadequately and selectively in Germany (Dittler & Kreidl, 2018).

Before the COVID-19-Pandemic, educational policies in Germany demands learning with digital technology in schools and higher education (KMK, 2017, 2019). Thus, teachers and pre-service teachers need to use digital technology in their (future) teaching. In order to do so, teachers are supposed to have general media knowledge and digital literacy in their individual subjects. In addition, they should have competencies in media didactics, media ethics, media education, and media-related school development (e.g., KMK, 2017 for Germany).

To reach a successful implementation of new methods and media, students` and teachers` beliefs need to be taken seriously in the process (Czerniak & Lumpe, 1996). In line with

Bandura (1986), personal beliefs are the best indicator of why a person behaves, acts, and makes decisions in a particular way. Studies argue that teachers' or pre-service teachers' beliefs strongly affect their behaviours in the classroom (Nespor, 1987; Pajares, 1992) and influence their teaching and learning strategies (Markic & Eilks 2012; Hewson & Kerby, 1993; Pajares, 1992). These beliefs consist of various internal variables, are very broad and multidimensional, and influence all interactions between teachers and students in educational contexts (Koballa, Graves, Coleman, & Kemp, 2000; Lent, Brown, & Hackett, 2002). (Pre-service) teachers' beliefs are based on their experience as learners in class (Keys, 2007; Richardson, 2003) and change over time during further education and personal and professional development (Prestridge, 2017). However, studies have shown that teachers' beliefs are relatively constant and cannot be easily changed (Prestridge, 2017). Thus, beliefs are one crucial factor that positively influences teachers' motivation to integrate digital media in their classes (Ertmer & Ottenbreit-Leftwich, 2010). Therefore, it is essential to examine pre-service teachers' beliefs regarding digital technologies in higher education.

RESEARCH QUESTION

In research (e.g., Admiraal et al., 2017; Hatlevik, 2017), studies have been conducted on specific technologies or general beliefs of pre-service teachers, but few have compared the adoption of various digital technologies by pre-service teachers. Noticing this lack, the present study focuses on pre-service teachers' beliefs towards various digital technologies in higher education. A distinction in the evaluation is made between learning during studies and future teaching in class. Second, the interest in further training and suitable formats of courses are evaluated. Thirdly, due to the COVID-19-pandemic, lecturers and students needed to work with digital technology in summer 2020 more intensively and exclusively. Thus, the differences in beliefs of pre-service teachers comparing both semesters were evaluated. In summary, three main research questions are raised for the evaluation:

RQ1 How do pre-service science teachers evaluate digital technology concerning their (a) own learning and (b) future teaching in school?

RQ2 For which digital technologies do pre-service science teachers wish to receive further information and education during their studies? How should this training be structured?

RQ3 Are there any differences in pre-service science teachers` beliefs on digital technology in the digital semester and the semester before COVID-19? If yes, how are these differences characterised?

METHOD AND SAMPLE

For answering the named research questions, the authors adapted the quantitative *Digital Technologies Survey* by Martin, Polly, Shanna, & Wang (2020). The adaptation, analogue to Martin et al. (2020), built on the existing readiness framework (Rollnick, Mason, & Butler, 2010). A framework with three components was created: (i) importance, (ii) helpfulness, and (iii) competence. These components are considered essential in the evaluation of beliefs regarding current digital technologies. It is distinguished between pre-service science teachers' learning in their studies and future teaching with digital technologies. Questions on the desired type of further education on digital technology in science teaching are added. As in the original questionnaire, a 4-point Likert scale on five different categories and in relation to different digital technologies is used. This sums up to 86 items. In the next section, digital technologies and categories are listed and explained.

Digital technologies

Collaboration Tools, Learning Management System, Online Meeting Tools, Online repositories for lesson plans or activities, Social Media, Classroom Response Systems, Supplemental Video, Creation tools, Video creation/editing, Podcasts, Interactive Whiteboard, Instructional Games and Simulation, Adaptive Technology, Mobile Apps.

Categories and questionnaire scales

- *Importance*: Asked about the importance of the above-named digital technologies for participants' own learning and future teaching – not important (1), somewhat important (2), moderately important (3), very important (4).
- *Helpfulness***:** Asked about the helpfulness of the above-named digital technologies for participants' own learning and future teaching – not helpful (1), somewhat helpful (2), moderately helpful (3), very helpful (4).
- *Competence***:** Asked about the participants' self-assessed competence in learning and teaching with the named digital technologies – not competent (1), somewhat competent (2), moderately competent (3), very competent (4).
- *Interest in receiving training*: Rating of participants' interest in receiving information and training about the named digital technologies – not interested (1), somewhat interested (2), moderately interested (3), very interested (4).
- *Formats of professional development support***:** Rating of participants favors regarding various formats of professional development – not desirable (1), somewhat desirable (2), moderately desirable (3), very desirable (4). The questionnaire uses current training formats, like professional development workshops/training, instructional videos, or other documentation (manual), web resources or tutorials, product demonstrations, faculty/peer mentoring, and one-on-one consultation with an instructional technologist.

Altogether, 146 pre-service science teachers completed the quantitative questionnaire. They were aged 19 - 53 (M = 23.06). 84.9 % were female, which is typical for the study program of primary science teachers in Germany. The study distinguishes between two groups: (i) 70 pre-service science teachers from the winter semester 2019/2020 before the COVID-19-pandemic (pre-semester) and (ii) 76 pre-service science teachers from the digital summer semester 2020 during the COVID-19-pandemic. Demographics show substantially more attendance at online courses for the second group.

RESULTS

RQ1: Evaluation concerning pre-service teachers' learning and future teaching

Table 1. Results for importance, helpfulness, competence, and interest.

	Importance		Helpfulness		Competence		Interest
	Learning	future Teaching	Learning	future Teaching	Learning	future Teaching	
M	2.49	2.65	2.32	2.63	2.45	2.51	3.02
SD	0.49	0.48	0.46	0.50	0.44	0.50	0.50

Overall, the participants rate digital technology for their learning little to moderately important with a value of $M_{\text{Importance-Learning}} = 2.49$ (see Table 1). The participants rate learning management systems, online repositories for lesson plans or activities, supplementary videos, and collaboration tools as moderately important for their own learning. Video creation/editing, podcasts, and adaptive technology are not very important. For their future teaching, the pre-service science teachers rate digital technology overall also little to moderately important, with a value of $M_{\text{Importance-Teaching}} = 2.65$. For their future teaching, creation tools (publishing online content, digital storytelling, websites), online repositories, digital games and simulations, supplementary videos were rated important. Social media and podcasts were rated not very important. Thus, the participants evaluate digital technology as slightly more important for their future teaching as for their own learning. Some unique digital technologies (like learning management systems or online-meeting-tools) are rated more important for their learning. In contrast, the rest of the named technologies (like an interactive whiteboard, collaborative tools, or digital games) are rated more important for the own future teaching by all the participants.

Considering the helpfulness of digital media for their own learning and future teaching, the participants rate digital technology for their learning little to moderately helpful with a value of $M_{\text{Helpfulness-Learning}} = 2.32$. Concerning their learning at the university, some similarities to the rating of importance can be seen. Learning management systems, supplemental videos, collaboration tools, and online repositories for lesson plans or activities are at a high level of helpfulness. On the other hand, video creation/editing, podcasts, and adaptive technology were not helpful in their learning. For their future teaching, the pre-service science teachers rate digital technology overall also little to moderately helpful with a value of $M_{\text{Helpfulness-Teaching}} = 2.63$. Here, the participants rated the helpfulness of digital media in their future teaching similarly to the rating in the category importance: creation tools, supplementary videos, online repositories, and instructional games and simulations were rated as moderately helpful in their teaching. Social media and podcasts were rated as less helpful. Thus, the participants evaluate digital technology as slightly more helpful for their future teaching as for their own learning. Some unique digital technology (like learning-management-systems, collaboration tools, and online-meeting-tools) are rated more helpful for own learning.

The category competence shows a different picture. Here, the participants were asked to rate their self-assessed competence in using digital technology for learning and teaching. The self-accessed pre-service science teachers' competence in using digital technology for learning and future teaching is rated little to moderately confident in learning and future teaching with values around 2.50. In contrast to the categories of importance and helpfulness, there are only minor differences in the self-assessed competence in learning and teaching with these media. Students feel moderately competent in using learning management systems, supplementary videos, social media, and collaborative tools. They rate their competence in video creation/editing and adaptive technology between not competent and somewhat competent. For the remaining different media, they feel somewhat competent.

RQ2: Interest and Support

In the category of interest in training, participants were asked to rate their interest in receiving training in the respective digital technology. The results show that the participants are moderately interested in digital technology training with a value of $M_{Interest} = 3.02$. Participants are more than somewhat interested in all digital media with no score below $M_{Interest} = 2.0$. They rate creation tools, instructional games and simulations, and adaptive technology as moderately to very desirable. The other media are also moderately interesting for them, with values around $M_{Interest} = 2.90$. Social media and podcasts were rated as not very interesting.

In the category formats of support, participants were asked to rate preferred training formats in learning digital technologies for learning and teaching. All of the named training formats seem moderately desirable for the participants with an average $M_{Formats} = 3.02$. Continuing professional development workshops or training, instructional videos or other documentation, web resources or tutorials, and product demonstrations were rated the highest. Personal guidance from an instructional technologist was rated lowest.

RQ3: Differences between before and during the Covid-19 pandemic

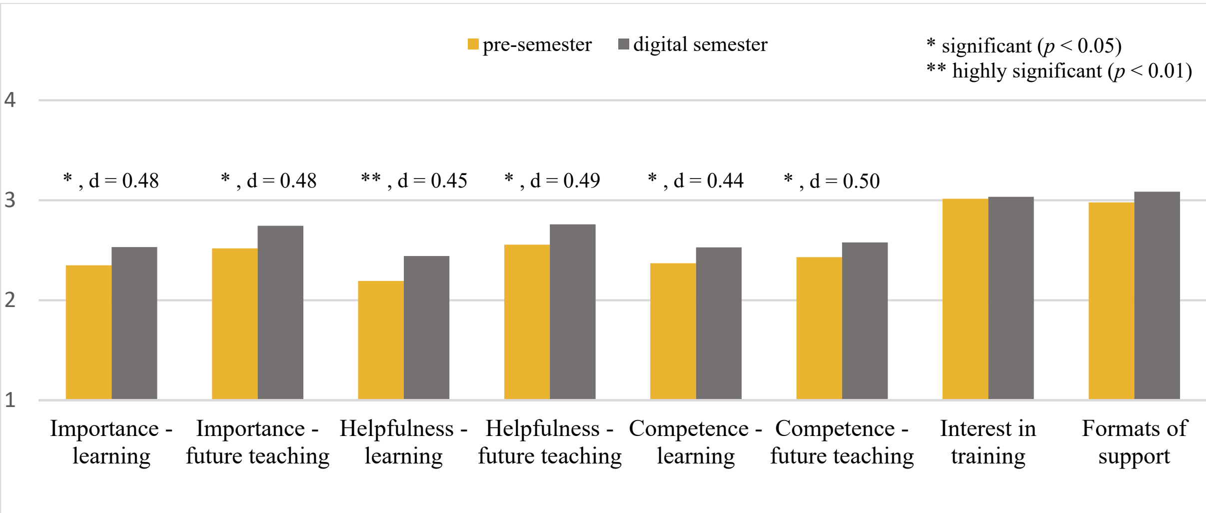

Figure 1. Students' beliefs in the digital semester and the semester before COVID-19.

Overall, the pre-service science teachers participating in the digital semester rated the named technologies in importance, helpfulness, and competence slightly higher than the pre-service science teachers in the semester before the pandemic (see figure 1). This difference is statistically significant with medium effect sizes. Regarding the students' rating of interest in training and support formats, both groups rate these on a similar level.

The scores of the unique digital technologies show that only a few were rated significantly more important and helpful. Interactive whiteboards ($\Delta M_{\text{Importance}} = 0.42$, $p = .008$, $d = 0.44$; $\Delta M_{\text{Helpfulness}} = 0.41$, $p = .008$, $d = 0.25$) and online meeting tools ($\Delta M_{\text{Importance}} = 1.85$, $p < .001$, $d = 1.56$; $\Delta M_{\text{Helpfulness}} = 2.09$, $p < .001$, $d = 1.01$) were significantly more important and helpful for learning in higher education for pre-service teachers in the digital semester. Regarding the pre-service teachers' future teaching, the biggest differences were stated at online-meeting tools ($\Delta M_{\text{Imporance}} = 1.02$, $p < .001$, $d = 0.95$; $\Delta M_{\text{Helpfulness}} = 1.24$, $p < .001$, $d = 1.12$) and learning-management-systems ($\Delta M_{\text{Importance}} = 0.46$, $p = .008$, $d = 0.44$; ($\Delta M_{\text{Helpfulness}} = 0.49$, $p = .003$, $d = 0.49$). Regarding the self-assessed competence to learn and teach with digital technology, pre-service science teachers participating in the study during the first online semester in Sommer 2020 rate significantly higher compared to those of the pre-semester. Again, this is based on a highly significant different evaluation of only one learning technology, the online meeting tools ($\Delta M_{\text{Importance}} = 1.62$, $p < .001$, $d = 1.34$; $\Delta M_{\text{Helpfulness}} = 1.42$, $p < .001$, $d = 1.37$).

Interest in training was rated by both groups similar, but pre-service science teachers from the digital semester rated their interest in online-meeting-tools significantly higher ($\Delta M_{\text{Interest}} = 0.36$, $p < .001$, $d = 0.72$). Regarding the desired formats webinars ($\Delta M_{\text{Formats}} = 0.53$, $p = .001$, $d = 0.54$), online help-desk or support ($\Delta M_{\text{Formats}} = 0.30$, $p < .031$, $d = 0.36$) and product demonstrations ($\Delta M = 0.28$, $p = .05$, $d = 0.32$) were rated significantly more desirable by pre-service science teachers in the digital semester.

DISCUSSION

Based on this study's results, pre-service science teachers' beliefs regarding digital technology in learning and teaching are on an average level. Only a few of the various digital technology was rated on a high level. The slight differences between learning and future teaching evaluation can be explained by the lack of usage of digital technology in higher education until the pandemic but also less till no usage of digital technology in secondary education for the participants. When there is no use of digital technology by lecturers in higher education, the reflection about the importance and helpfulness of these is missing and thus, not seen. Is seems as if the evaluation of participants' learning reflects their education. Nevertheless, they can imagine that some digital technology could be important or helpful in their future teaching. Starting from the innovation in teaching based on digital media, the question should be raised if pre-service teachers in this study, who have traditional beliefs regarding their future teaching (which means limited usage of digital media), would successfully follow the innovation and integrate digital media in their teaching.

There is a significant difference in pre-service teachers' beliefs between pre- and online-semester. Due to the study design, we cannot detect a change in the participants' beliefs. However, demographics show remarkable similarities between both groups. Based on the lack of other reasons and indications, we assume that the detected differences in beliefs can be justified mainly with the digital semester. This influence is supported by the result that the only technologies that the pre-service science teachers used intensively during the digital semester, like learning-management-systems and online-meeting-tools, are rated significantly higher.

Thus, it is inferred that the difference in pre-service teachers' beliefs between pre- and online-semester is based on their digital semester experience.

Further, only selective technologies seem more important and helpful in learning and future teaching for the pre-service teachers. The same applies to their self-assessed competence in learning and teaching with this technology. The beliefs regarding the other technologies do not differ between the two groups. In conclusion, the digital semester influences pre-service teachers' beliefs regarding single digital technology but does not influence their general beliefs regarding learning and teaching with digital technology. This confirms already known research results, that beliefs are relatively constant and cannot be easily changed (Prestridge, 2017), and that long-term learning processes are recommended (Huberman, 1993; Reusser & Tremp, 2008).

Starting from the results of the present study, for the teacher training, this implicates that it could be insufficient to teach only exemplary digital technology and hope that (pre-service) teachers will transform the gained experience to other teaching aspects with digital technology. Therefore, a systematic approach in teacher training could be promising in order to fulfil the demands of the educational policy.

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HOW TO TEACH SCIENCE DIGITALLY!? DIKOLAN – A FRAMEWORK FOR PRE-SERVICE TEACHER EDUCATION

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Introducing prospective science teachers systematically to subject-specific competencies for the integration of digital elements into future teaching needs a suitable curriculum. According to the analysis presented in this paper, the competency frameworks published so far lack the subject-specificity that is required for successful integration of digital media and technologies into science education. Therefore, by deducing seven central digital competency areas that are compatible with skills needed for planning and running science lessons we developed a framework of digital competencies for teaching in science education (DiKoLAN - Digitale Kompetenzen für das Lehramt der Naturwissenschaften, transl. Digital Competencies for Teaching in Science Education). A detailed description of DiKoLAN and the underlying concepts was published together with presentations of 23 established teaching projects related to DiKoLAN (see https://dikolan.de*). DiKoLAN enables teacher educators to coordinate training objectives according to both cross-curricular and subject-specific learning objectives formulated specifically for science teaching subjects. The sum of all contained competency expectations describes the advisable basic level of competence that all science teachers should have reached at the end of the university training phase. In this paper, we present and discuss our concept of DiKoLAN, as a structured approach to systematically integrate digital media into teacher education. Moreover, as DiKoLAN is structured by using the TPACK model, it is compatible with existing models and therefore integrable into existing course structures.*

Keywords: ICT Enhanced Teaching and Learning, Initial Teacher Education (Pre service), Technology in Education and Training

INTRODUCTION

The COVID-19 pandemic was not the first time that the importance of digital media for the future viability of a society was recognised. As early as the 1990s, industrialised countries began attempting to use digital media in education and to describe the skills needed. These efforts have gained momentum in recent years, leading to the development of numerous corresponding educational frameworks. But so far, none of these frameworks are specific to teaching in science subjects, although research has shown that addressing content-specific teaching with digital media is of major importance for promoting teachers' technology acceptance and the ambition to implement digital tools in teaching (Vogelsang et al., 2019; Mayer & Girwidz, 2019). To tackle this problem, the teacher training (pre- and in-service) must be adapted and restructured to the new challenges due to advancing digitalisation. To successfully implement digital competencies in university teacher education, training needs to be subject-specific. Therefore, subject-specific digital competencies must be identified, formulated, structured, and categorised in a system that is suitable for curricular allocation and coordination. This is a central prerequisite for a consistent integration of these competencies into courses of science education and pedagogy. Hence, a collaboration of nine researchers from Germany, Austria, and Switzerland in the field of science education addresses the following open questions:

1. Which digital competencies are addressed in already published competence frameworks?
2. What digital competencies do science teachers need beyond general pedagogical digital competencies?
3. How can these competencies be defined, structured, and graded in a meaningful way?

METHODS

In order to answer the listed questions, a literature review was conducted first. This resulted in an overview of the current frameworks and standards in teacher education (for more details, see Kotzebue et al., 2021). One of the most influential frameworks in the international arena is the UNESCO's ICT Competency Framework for Teachers (ICT-CFT), which set an international standard at a very early stage in describing the facets of competency required for ICT teaching (UNESCO ICT-CFT, 2011). However, this framework is not so much a specific, formulated set of skills, but rather a guiding principle that helps to design digital educational concepts that are compatible with respective national goals. ICT-CFT was developed for teachers at primary and secondary level and describes desirable ICT teaching activities in consideration of six aspects (ICT, ICT in education, curriculum and assessment, pedagogy, organisation and administration, as well as teacher professional learning) and three levels (technology literacy, knowledge deepening, knowledge creation) (UNESCO ICT-CFT, 2011, p. 3). Numerous national and international frameworks used the ICT-CFT as guidance for the development of their own frameworks, such as the ICT-enhanced Teacher Standards for Africa (ICTeTSA, 2012) or the ICT Competency Framework for Teachers in Guyana (Moore, Butcher & Hoosen, 2016). In addition to the ICT-CFT, there are other frameworks that have a decisive influence on regional and national curricula. Some of these can be seen as precursors of the ICT-CFT, such as the ISTE Standards for Educators in the Anglo-American region (Crompton, 2017), or as influenced by them, such as the European Framework for the Digital Competence of Educators (DigCompEdu, Redecker, 2017). Like the ICT-CFT, they serve a similar basic function in their regions in describing general guidelines and standards for teacher education and addressing skills of teachers themselves. For the European region, DigCompEdu (Redecker, 2017) is one of the most relevant frameworks to strengthen 21st century skills (Trilling & Fadel, 2009) and thereby promote the digital transformation of the European Union.

DigCompEdu describes in five competency areas a total of 18 non-subject-specific competencies as a prerequisite for teachers to open up potentials of digital technologies in teaching-learning processes (Redecker, 2017). The development of pupils' digital competence is covered by a sixth also non-subject-specific competence area which covers a total of five competencies. For DigCompEdu, corresponding self-assessment tools are available in three variants, addressing teachers at school, at university, or in adult education (Ghomi & Redecker, 2019). Based on this structure DigCompEdu influences the development of curricula in many European countries, e.g., national frameworks in Spain (Common Digital Competence Framework for Teachers-CDCFT; INTEF, 2017) and in Norway (Professional Digital Competence Framework for Teachers; Kelentric, Helland & Arstorp, 2017). Due to the broad level of application, DigCompEDU, like other overarching frameworks, focuses more on pedagogical aspects of teachers' professional development in the context of digitalisation (Caena & Redecker, 2019; Redecker, 2017). However, subject-specific competencies that teachers need in order to implement the content requirements of the national curricula and thus to be able to apply the professional added value of digital media are missing. Therefore, the national guidelines for the integration of ICT in education as well as their specification and implementation were also analysed (Kotzebue et al., 2021; Meier et al., 2021). As an example, for this, in Germany *The Standing Conference of the Ministers of Education and Cultural Affairs* published a strategy for education in the digital world (KMK, 2016), which formulates interdisciplinary digital competencies that all pupils have to acquire until the end of compulsory education - *Kompetenzen in der digitalen Welt* (*transl.* Competencies in the Digital World). The summarised guidelines and specifications compilation represents one of the central documents for the digitalisation of schools and teaching in Germany. Competencies in the Digital World comprise a total of six overarching areas of competency pupils are supposed to develop (1. searching, processing and storing, 2. communicating and cooperating, 3. producing and presenting, 4. protecting and acting safely, 5. problem solving and acting, 6. analysing and reflecting) which are divided into 21 areas of competence and are described by a total of 61 competencies. Similar to the specifications of UNESCO and DigCompEDU, no subject-specific competencies are described here, but rather a multidisciplinary canon that pupils need for a sustainable participation in society. It is up to the federal states and ultimately the teachers to integrate these competencies into the curricula or syllabus of the individual school subjects and ultimately to address them with suitable teaching concepts. In addition, there is a lack of information on how these essential competencies for students are acquired by teachers during their pre- or in-service phase, or what they need to be able to teach these competencies. Our review of the literature revealed that none of the existing frameworks address digital competencies that future teachers need, especially for teaching the natural sciences (Kotzebue et al., 2021).

But how can competencies be meaningfully defined, structured, and graded in teacher education? One result of our analysis showed that the TPACK framework (Koehler et al., 2013) is very prominent in teacher education. TPACK describes central knowledge areas that a teacher needs for successful teaching (pedagogical knowledge, PK, content knowledge, CK, and technological knowledge, TK) as well as their intersections (Fig. 1). They form domains that can be assigned to individual components of teacher education and in their connection enable successful teaching.

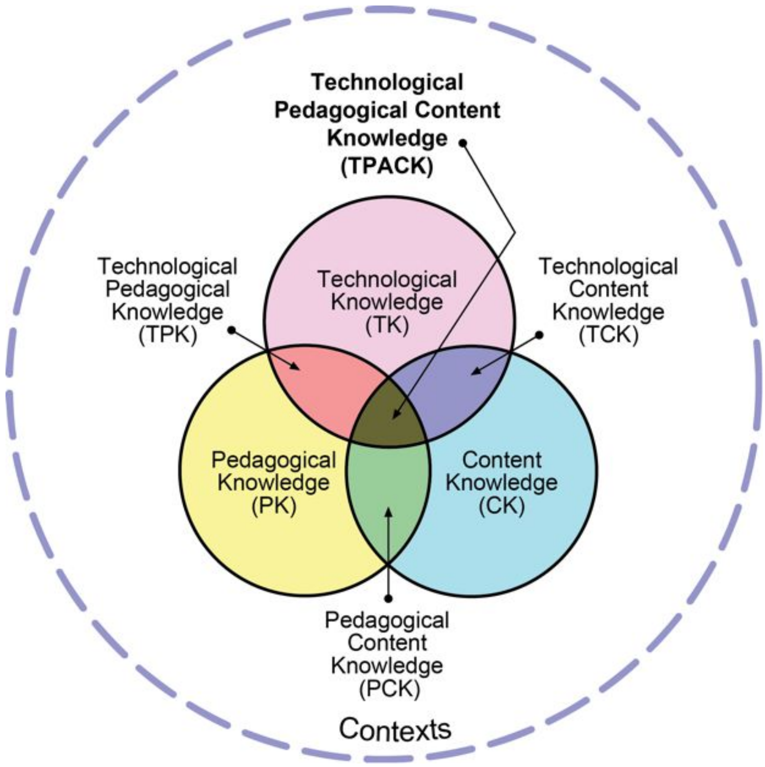

Figure 1. The TPACK framework (http://tpack.org).

Taking the educational perspective of biology, chemistry, and physics into account, it is important to reflect scientific methods used in the respective professional fields. The literature often formulates and delineates general interdisciplinary practises (e.g., search for information, and communication) or subject-specific working methods (e.g., measurement, data acquisition, logging, drawing, modeling and mathematics; Gott et al., 1999). Moreover, to adequately represent the natural sciences, teacher education needs to discuss the use of digital technology as part of scientific practices (Evagorou et al., 2015). Hence, the TPACK model is a compatible approach to also structure digital competencies with reference to manageable fields of activity or application areas of teaching as well as to elements of the science method as a central component (Thyssen et al., 2020). Since the TPACK model is widely accepted in teacher education and covers technological and content knowledge as well as pedagogical knowledge, it is an excellent blueprint for the internal structuring of individual competency areas, even if only TK and the intersections formed with it need to be taken into account for a description of digital competencies. In addition, aspects of digitality were considered according to the DPaCK model (Huwer et al., 2019).

RESULTS

As a result of the literature review as well as the structuring approach of the TPACK model, a working group of nine researchers from nine universities developed a new framework for digital competencies for pre-service teachers in the natural sciences: the structured and graded framework "Digital Competencies for Teaching in Science Education (DiKoLAN)" (Becker et al., 2020; Kotzebue et al., 2021). DiKoLAN describes seven areas of competencies (see Fig. 2).

Figure 2. The DiKoLAN framework (Digital Competencies for Teaching in Science Education) (https://dikolan.de/en/).

Thereby, the structuring of the competency areas follows an overarching structure (Kotzebue et al., 2021). Four competency areas in the upper row in Fig. 2 (*Documentation*, *Presentation*, *Communication/Collaboration*, as well as *Information Search and Evaluation*) are more general and interdisciplinary but still covering subject-specific contexts of teaching the natural sciences and subject-specific content and elements related to scientific research. The three additional subject-specific areas in the lower row (*Data Acquisition*, *Data Processing*, as well as *Simulation and Modelling*) are closely linked to subject-specific ways of working methods in the natural sciences and their didactics (Thyssen et al., 2020).

Professional knowledge included in the individual areas of competency is further differentiated based on the didactic function and the targeted areas of application: Teaching (TPACK), Methods/Digitality (TPK), Content-specific Context (TCK), and Special Tools (TK). Thus, the inner structure of DiKoLAN follows the technology-related competence areas described in the TPACK model (Koehler et al., 2013). Furthermore, DiKoLAN classifies the competency expectations on three levels (*Name*, *Describe*, and *Use/Apply*). In addition, the framework also considers the *Legal Framework* and *Technical Core Competencies*.

DISCUSSION

Relation to Relevant Frameworks Published by Governmental Institutions

DiKoLAN with its overarching structure is based on already existing frameworks and expands them in the sense of subject-specificity for the natural sciences. Figure 3 illustrates the relations between DigCompEdu (Redecker, 2017), the Competencies in the Digital World (KMK, 2016) and DiKoLAN.

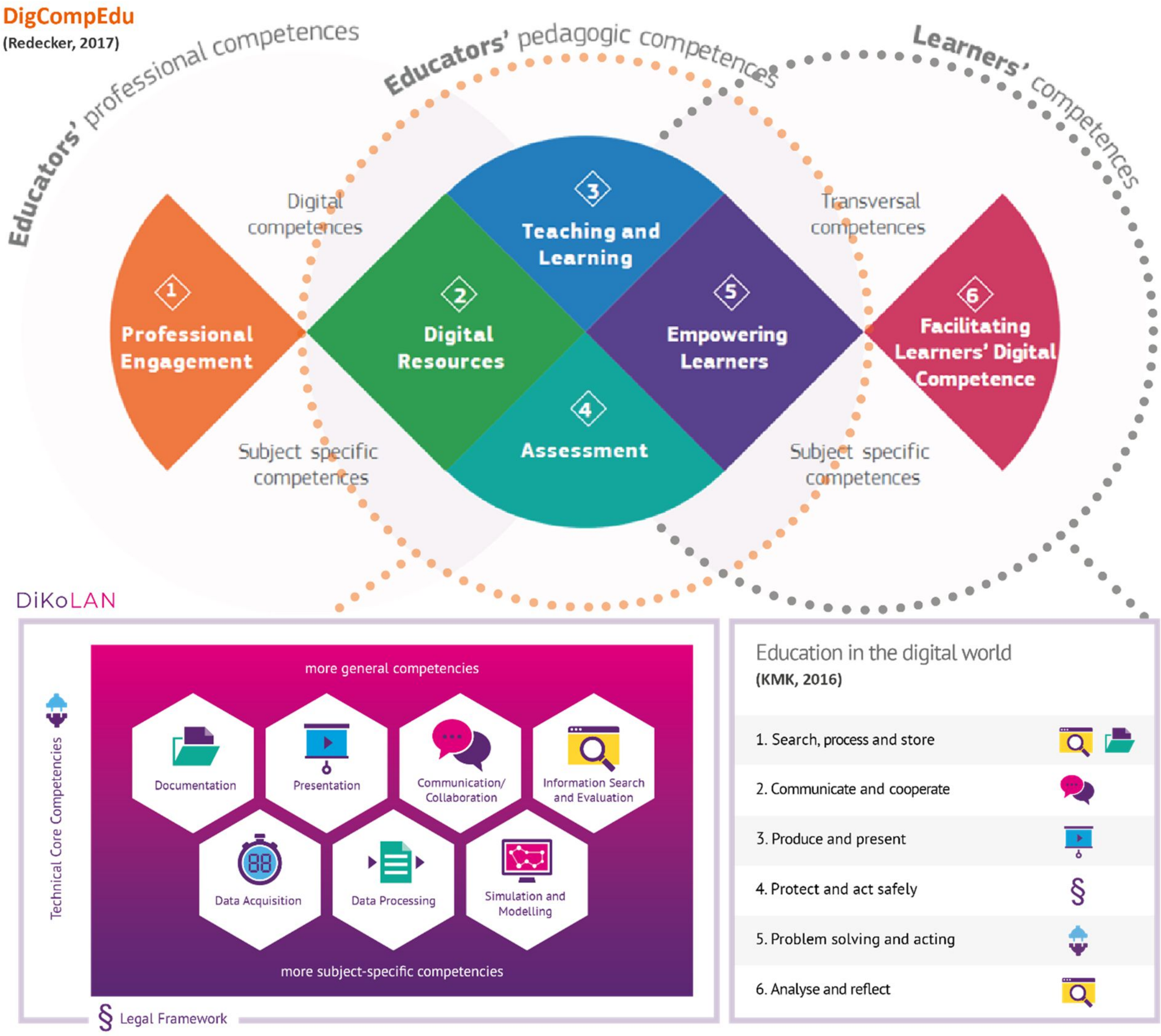

Figure 3. The DiKoLAN framework and its relation to DigCompEdu (Redecker, 2017) and the Strategy "Bildung in der digitalen Welt [Education in the Digital World]" (KMK, 2016) (transl. from Thyssen et al., 2020).

In DigCompEdu, general pedagogical and didactic competencies of teachers are taken into account with the competence areas 1 to 5. Aside from this, DigCompEdu also mentions subject-specific elements but does not further explicate them. Therefore, DiKoLAN specifies essential elements of these competency areas for the natural science subjects. Based on these competencies, the competencies of learners addressed in DigCompEdu area 6 can then be fostered in teaching, according to the Competencies in the Digital World, starting from the corresponding competencies of teachers. In this way, the subject-specific elements mentioned only marginally in DigCompEdu, but not explained in detail are specified by DiKoLAN for science teaching.

Reference to empirical findings

Eickelmann et al. (2017) analysed the use of ICT in school and identified relevant indicators for the use of digital technology in teaching and learning five typical applications: 1. working with word processing programmes, 2. designing presentations, 3. using applications for data collection and processing, 4. working with spreadsheet programmes and 5. working with simulation, experimentation, or modelling programmes. Eickelmann et al. (2017) also mention pedagogically or didactically relevant teaching activities (visualisation, research, and individual support as well as communication and cooperation) as important albeit not subject-specific indicators for teaching and learning with ICT. Figure 4 illustrates which competencies are needed on the part of teachers to support students' learning activities with ICT according to Eickelmann et al. (2017).

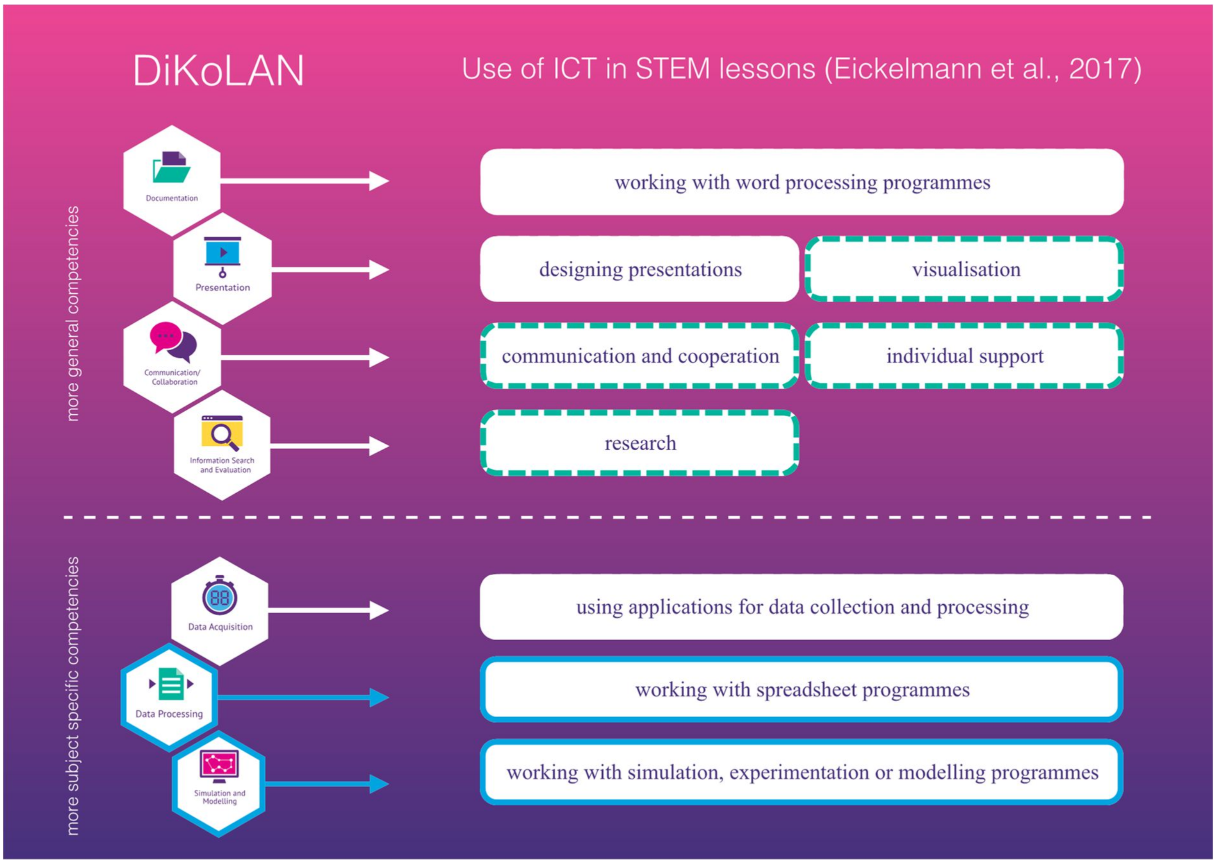

Figure 4. The DiKoLAN competency areas (left side) in assignment with the use of ICT in STEM lessons (right side): typical applications (no outline) and pedagogical functions (dashed outline). For the blue framed applications, a significantly higher use in STEM lessons was found by Eickelmann et al. (2017). Hence, the blue framed competency areas are specific to STEM teaching.

DiKoLAN covers all of the indicators for ICT use in the classroom empirically validated by Eickelmann et al. (2017). In addition, Eickelmann et al. (2017) showed that in STEM lessons compared to other subjects' digital technologies are used significantly more often to process data and students are significantly more often encouraged to use simulation, experimentation and modelling programs. Thus, the meaningfulness of the differentiation of the competency areas into more subject-specific and more general competency areas is also empirically supported. Although there is no significant difference in the frequency of use of data acquisition in the classroom, this does not mean that these competency areas do not require a subject-specific professional knowledge. Since, based on the theoretical derivations already mentioned, firstly, fundamentally different technologies are used generically in the area of data acquisition for teaching in the natural sciences than in other subjects, and secondly, DiKoLAN also pursues the didactic goal of emphasising the special importance of data acquisition in the natural sciences and science teaching, it remains justified to assign data acquisition to the more subject-specific competency areas.

CONCLUSION

The *DiKoLAN* framework provides for the first time a detailed overview of subject-specific digital competencies that prospective natural sciences teachers should acquire at the university level. Planning and implementing lessons, in which digital tools support or even enable the teaching-learning process, involves a variety of competencies. In the development of DiKoLAN, considerations of different frameworks and models have been incorporated (DigCompEDU, TPACK etc.) (Kotzebue et al., 2021). The inner structuring of DiKoLAN according to the TPACK model is coherent to the organisational structure of university teacher education. Hence, DiKoLAN can be used as a support tool in the design of university teacher training courses and for coordinating training objectives, both interdisciplinary and subject-specific, coupled with the development of corresponding curricula (Thoms et al., 2021). Additionally, DiKoLAN proved to be compatible with the interdisciplinary specifications of the *European Framework for the Digital Competence of Educators* (DigCompEdu) as well as the *Competencies in the Digital World* (KMK). However, DiKoLAN is subject to constant change due to the rapid progression in the field of digitalisation. Thus, if necessary, new competency areas can be added to the honeycomb structure as well as new competency expectations can be added within a competency area and existing ones can be changed or deleted. Therefore, the framework is subject to future research and development.

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TRANSFORMATION OF PRE-SERVICE SECONDARY SCIENCE TEACHERS' BELIEFS ABOUT GOOD LESSONS AND IDEAS OF PLANNING

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The concept of pedagogical content knowledge (PCK) is recognized as of great importance. However, there is little consensus on what PCK entails. This study explores the transformation of pre-service science teachers' beliefs about good lessons and lesson planning in Japan. Data were collected using a descriptive survey questionnaire. The findings revealed four main points: First, pre-service science teachers in Japan believe that it is important to explore how teachers can effectively teach science and how they can help their students understand the contents of science lessons. Both pre-service science teachers' beliefs about lessons and lesson planning were strongly affected by the ministry's curriculum guideline. This led to the belief that good lessons are lessons that make students think about their learning contents. Second, the skills needed to teach science are systematically integrated into the most complex community, which shows "the learning of science related to the ministry's curriculum guideline" through classes in the university. Third, the transformation of their beliefs about lessons affects the transformation of the lesson planning process.

Keywords: Initial Teacher Education (Pre service), Pedagogical Content Knowledge, Secondary School

INTRODUCTION

The concept of pedagogical content knowledge (PCK), which was introduced by Shulman (1986), is recognized as one of the most important components of teachers' professional knowledge. PCK has been influential in research on teacher education. However, there is still little consensus on what PCK is (Stender, Brückmann & Neumann, 2017). In the model of teacher professional knowledge and skill (TPK&S), PCK is defined as both a knowledge base used in planning for and the delivery of topic-specific instruction in a very specific classroom context and a skill that is used to facilitate teaching (Gess-Newsome, 2015). Personal PCK is the knowledge of, reasoning behind, and planning for teaching a particular topic in a particular way, for a particular purpose, and to particular students to facilitate enhanced student outcomes (Gess-Newsome, 2015). Teachers' beliefs, motivation, and self-regulation have a moderating effect on the influence of topic-specific professional knowledge (TSPK). Although TSPK influences personal PCK, this influence is amplified or filtered as a teacher develops personal PCK over time (Stender, Brückmann & Neumann, 2017). Teachers' beliefs influence the manner in which they prepare their lesson plans.

RESEARCH OBJECTIVES AND RESEARCH QUESTIONS

This study aims to examine the transformation of pre-service science teachers' beliefs about lessons and preparing lesson plans in Japan. To achieve this, it uses a descriptive survey questionnaire.

The research questions are as follows:

1. What kind of transformation of pre-service secondary science teachers' beliefs about good lessons was recognized after taking classes about lessons planning?
2. What transformation about their ideas on good lesson planning was recognized?

METHODS

This study involved 31 third year pre-service science teachers studying in the Faculty of Education at the same university in Japan. The pre-service teachers took two subjects: 12 classes for Methodology of Science Education Ⅲ and 12 classes for Methodology of Science Education Ⅳ. In both classes, they learned how teachers should prepare lesson plans for secondary science lessons. Descriptive survey questionnaires were administered to the participants through an online survey platform. The questionnaires were administered during the first day of classes in May (pre-description) and during the final day of classes in August (post-description), 2020. The questionnaire had two open-ended questions questions—Q1and Q2. Both the questionnaire and the answers were written in Japanese.

Q1: What do you think makes up a good science lesson is like?

Q2: How can one teach good secondary science lessons?

To answer the research questions, an analysis was conducted using Higuchi's (2004) KH Coder, an open source program for quantitative analysis. This Coder's quantitative text analysis is defined quantitatively, and it involves arranging or analysing text-based datasets using computer applications to understand the quality of the original text material (Higuchi, 2014).

RESULT

Volume of description

Terms that are used in the ministry's curriculum guideline in Japan were regarded as one compound word, such as "perspectives and thoughts," "observation; experiment," "things; phenomenon," and "problem-solving."

Numbers of words in each of the descriptions studied are listed in Table 1.

Table 1. Number of words in each of description.

Number	Beliefs about good lessons		Ideas of good lesson planning	
	pre-description	post-description	pre-description	post-description
word	23209 (9349)	26355 (10601)	28927 (11733)	32357 (13059)
word types	1649 (1337)	1616 (1304)	1899 (1573)	1868 (1531)

Note: Numbers in parentheses indicate the number of words in the analysis.

Word Frequency

Table 2 shows top 30 words of each word frequencies in each of descriptions. The original words are Japanese in descriptions.

Co-occurrence network analysis

Co-occurrence network analysis helps identify the relationships between words in a text. This study used nouns, verbs, and adjectives from the reviews and created a co-occurrence network with highly co-occurring words to facilitate the understanding of a more complete image of the

.

21	aim (52)	result (56)	setting (68)	prediction (67)
22	think[b] (50)	inquiry (56)	comment (62)	think[b] (66)
23	knowledge (50)	self (55)	important (58)	time (66)
24	problem (48)	discussion (53)	self (55)	self (66)
25	MEXT (48)	observation; experiment(50)	knowledge (54)	comment (63)
26	competency[c] (46)	introduction (49)	important (50)	science lesson (63)
27	self (45)	learning (43)	prediction (50)	important (61)
28	discussion (44)	important (43)	learn (48)	school science (60)
29	competency[d] (44)	express (43)	observation (46)	have (58)

30	learning (43)	proactive (42)	question (46)	interest (53)

destination. Additionally, the network illustrates more important edges using a minimum spanning tree [Higuchi, 2014].

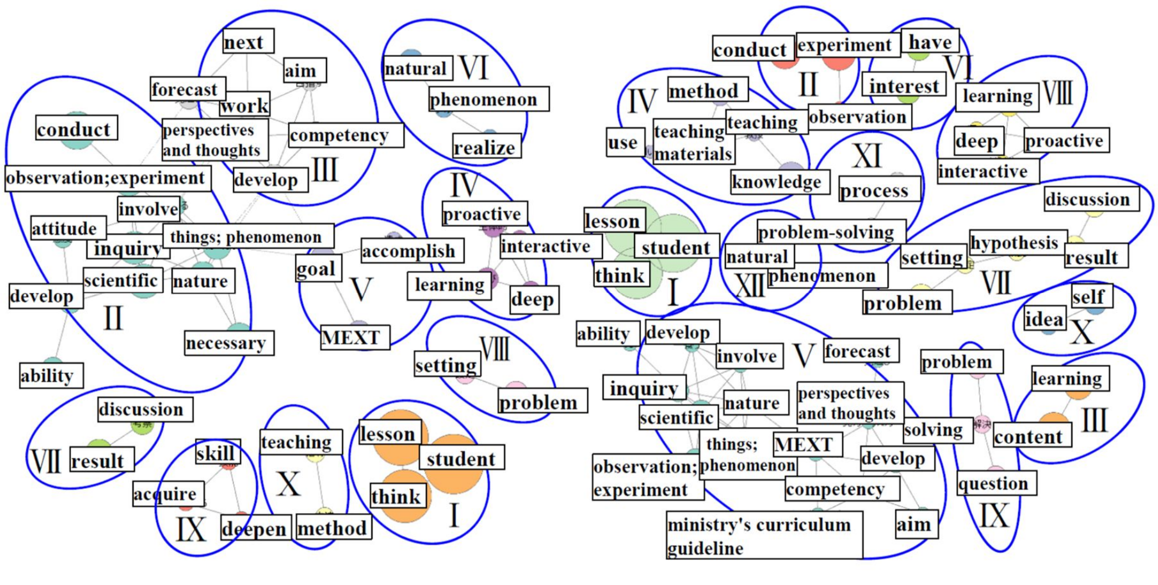
Co-occurrence network analysis of beliefs about good lessons in description

Figure l (a) illustrates the word co-occurrence network in pre-service science teachers' beliefs about good lessons in the pre-descriptions, which consists of 10 communities.

Community (I) shows "how lessons should be," including "student," "lesson," and "think," which are strongly interconnected. For example,

"I think that good lessons trigger student's thinking process (like discussions)" (Student 14).

Community (II), the most complex community, shows "learning of science related to the ministry's curriculum guidelines," such as "scientific," "observation; experiment," and "things; phenomenon." Community (III) shows the main content of the ministry's curriculum guidelines, which takes into account "competency" and "perspectives and thoughts." For example,



(a) pre-descriptions **(b) post-descriptions**

Figure 1. The word co-occurrence network in pre-service science teachers' beliefs about good lessons

Note: MEXT is short for 'the Ministry of Education, Culture, Sports, Science and Technology' in Japan.

"By having a relationship with things and phenomenon in the nature, working perspectives and thoughts, and observing or conducting experiments, students are able to develop competency to enquire about things and phenomenon scientifically (MEXT, 2018)"(Student 1).

Community (Ⅳ) illustrates the "proactive, interactive, and deep learning" required by the ministry's curriculum guidelines. For example,

"Students are required to acquire competency through 'proactive, interactive, and deep learning' activities outlined in the ministry's curriculum guidelines" (Student 16).

Community (Ⅴ) shows "the aim of the ministry's curriculum guidelines." For example,

"The competency to inquiry about things and phenomenon in nature scientifically should be nurtured through students' proactive activity (MEXT, 2018)" (Student 31).

Community (Ⅵ) illustrates "the recognition of natural events," including "nature," "events," and "recognize." Community (Ⅶ) highlights "the results and discussion," while community (Ⅷ) shows "problem and setting." Out of these three communities (i.e., communities (Ⅵ), (Ⅶ), and (Ⅷ)), "the processes of learning, such as recognition of things and phenomenon in nature, setting of problem, setting of hypotheses, verification planning, conducting of the observation and experiment, handling of results, discussion and reasoning, and expression and communication are presented" (Student 12).

Community (Ⅸ) shows "getting the skills" such as "get" and "skill." For example,

"Regular lessons in which students are interested need to be developed to facilitate the understanding of things and phenomenon in nature and to acquire skills of the observation and experiment" (Student 25).

Community (Ⅹ) shows "the teaching methods." For example,

"Teachers are required to understand the contents of units and determine which teaching method is best suited for specific units" (Student 4).

Figure 1 (b) shows the word co-occurrence network in pre-service science teachers' beliefs about good lessons in the post-descriptions, which consist of 12 communities.

Community (Ⅰ) shows "how lessons should be," including "student," "lesson," and "think," which are interconnected. For example,

"If teachers are already aware of what their students know and what they don't know, they should not create lessons that allow students to make their own conclusions" (Student 5).

Community (Ⅱ) shows "the experiment and observation." For example,

"The skills to enquire scientifically include being able to analyse and discuss the results and draw a conclusion by carrying out activities such as making observations and conducting experiment with an aim of achieving particular objectives" (Student 20).

Community (Ⅲ) shows "the learning contents." For example,

"Good science lessons are ones that allow students to easily understand the contents of lessons in which they are interceded in and with which they can relate other events" (Student 3).

Community (Ⅳ) shows “the knowledge of teaching,” including “teaching,” “resources,” and “methods.” For example,

“The three sets of mixed teacher knowledge are ‘teacher knowledge concerning subject matter’, ‘teacher knowledge concerning pedagogy’, and ‘teacher knowledge concerning students’” (Student 4).

Community (Ⅴ) shows “proactive, interactive, and deep learning,” which is a prerequisite provided for by the ministry’s curriculum guidelines. For example,

“Students are required to acquire competency through ‘proactive, interactive, and deep learning’ activities, as outlined in the ministry’s curriculum guidelines” (Student 16).

Community (Ⅵ) shows “the interest.” For example,

“I think that ideal lessons are the ones that draw students’ interest to the contents of the lessons, with questions emerging naturally and, in addition to that, students can take lessons proactively with a perspective that they can answer the questions” (Student 7).

Community (Ⅶ) shows “the process of problem-solving,” which includes the “problem,” “hypothesis,” “results,” and “discussion.” For example,

“The process of inquiry means ‘setting of the problem’, ‘hypothesis’, ‘observation and experiment’, ‘result’, and ‘discussion.’” (Student 8).

Community (Ⅷ) shows “proactive, interactive, and deep learning,” which are a prerequisite of the ministry’s curriculum guidelines. For example,

“Students are required to acquire competency through ‘proactive, interactive, and deep learning’ in the ministry’s curriculum guidelines” (Student 16).

Community (Ⅸ) illustrates “problem-solving,” which includes “question,” “problem,” and “solving.” For example,

″Science lessons are developed along the process of problem-solving; i.e., recognition of things and phenomenon in nature, setting of problem, setting of hypotheses, verification planning, conducting of the observation and experiment, handling of results, discussion and reasoning, and expression and communication (MEXT, 2018). Teachers are required to guide students to solve problems adaptively by following this process” (Student 12).

Community (Ⅹ) shows “lessons that allow students to think.” For example,

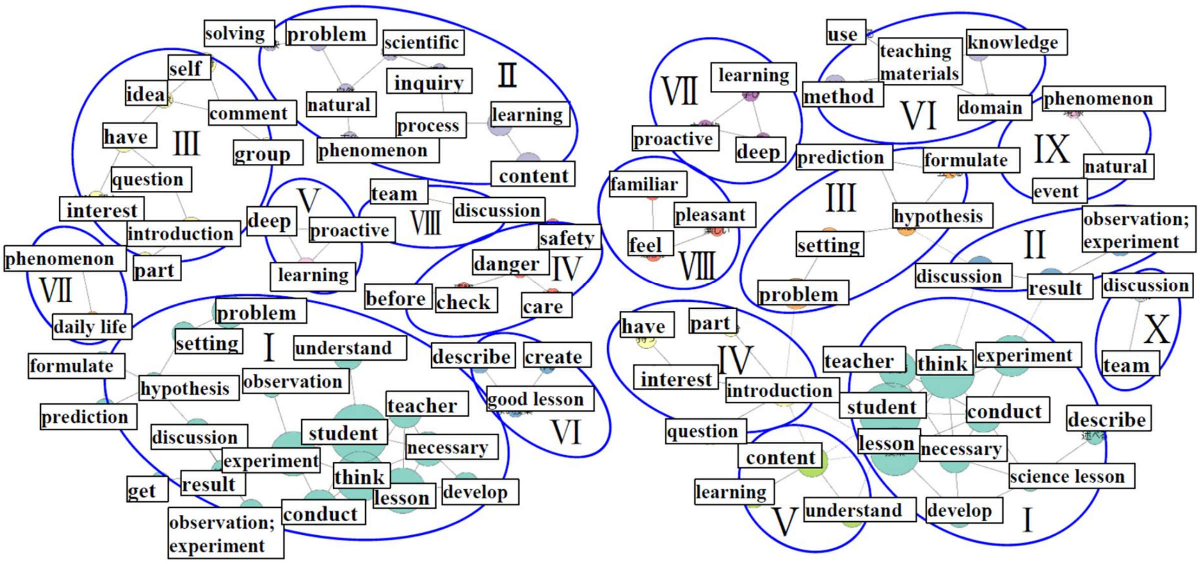
“I think that good lessons are ones that allow students to air out their opinions and deepen their knowledge through discussions with their peers” (Student 20).

Community (Ⅺ) shows another “process of problem-solving.” Community (Ⅻ) shows “the phenomenon in nature.” For example, for these two communities, "Science lessons are developed along the process of problem-solving; i.e., recognition of things and phenomenon in nature, setting of a problem, setting of hypotheses, verification planning, conducting observations and experiments, handling the results, engaging in discussions and reasoning activities, and allowing expression and communication (MEXT, 2018)" (Student 4).

Co-occurrence network analysis of ideas of good lessons planning in descriptions

Figure2 (a) illustrates the word co-occurrence network in pre-service science teachers' ideas of good lesson planning in pre-descriptions, which consist of eight communities.

Community (Ⅰ), the most complex community, shows "how lessons should be," including "student," "lesson," and "think," which are interconnected and associated with the process of



(a) pre-descriptions **(b) post-descriptions**

Figure2 . The word co-occurrence network in pre-service science teachers' ideas of good lessons

problem-solving, such as "problem," "hypothesis," "results," and "discussion." For example,

"Students can understand the contents of lessons and discuss and think about the experiment methods they can employ" (Student 21).

Further, "students can collect the results, discuss them, talk about them, and compare their opinions (Student 31).

Community (Ⅱ) shows "the learning content of science lessons" such as "content," "learning," "inquiry," "nature," and "science." For example,

"It is important for students to think about things related to real problems in society as this deepens their understanding about nature and sharpens their scientific inquiry skills" (Student 25).

Community (Ⅲ) shows "the track of science lessons," which includes "introduction," "questions," "ideas," and "comments." For example,

"In the introduction, teachers draw students' interest to certain things by asking questions related to familiar parts of the objects in question" (Student 16).

Community (Ⅳ) shows "the safety in experiment," which includes "safety," "danger," and "beware." For example,

"Teachers should check what is dangerous, conduct experiments to facilitate preparation, describe the impeding danger, and conduct exercises to promote consciousness and ensure safety in a lesson plan" (Student 26).

Community (Ⅴ) illustrates the "proactive, interactive, and deep learning" required by the ministry's curriculum guidelines. For example,

"Students are required to achieve 'proactive, interactive, and deep learning' to develop their competency in relation to the contents of a unit and time to teach in the ministry's curriculum guideline (MEXT, 2018)" (Student 6).

Community (Ⅵ) shows "the good lessons." For example,

"It is important that a teacher devises way of teaching and creating good lessons" (Student 19).

Community (Ⅶ) shows "the phenomenon in daily life." For example,

"Teachers should clarify a domain using lessons that are related to the kind of phenomenon that students interact with in their daily lives" (Student 1).

Community (Ⅷ) shows "group discussions." For example,

"It is good that students interact with members of their group and share their views on the most appropriate answer to a specific question" (Student 31).

Figure 2 (b) shows the word co-occurrence network in pre-service science teachers' ideas of good lesson planning in the post-descriptions that consist unities.

Community (Ⅰ), the most complex community, shows "how lessons should be," and it includes "students," "think," "lessons," "experiments," "conduct," and "teachers," which are strongly interconnected. For example,

"I think that students need enough time to make observations and this about the experiments" (Student 1).

Community (Ⅱ) illustrates "the results and discussions in inquiry." Community (Ⅲ) shows "the problem and hypothesis in inquiry." For example, out of these two communities (i.e., Community (Ⅱ) and (Ⅲ)), "MEXT (2018) presents a specific process that involves introduction, setting of problem, setting of hypotheses, verification planning, conducting observations and experiments, handling the results, discussions and reasoning, and expression and communication" (Student 20).

Community (Ⅳ) shows "the introduction," which includes "question" and "interest." For example,

"Setting the problem in the introduction phase allows the students to identify the problem by themselves, and this leads to proactive learning because the problem arises from the students' questions" (Student 16).

Community (Ⅴ) shows "the understanding of learning content in science lessons." For example,

"I think that lessons that incorporate a lot of observations and experiments are effective in facilitating students' understanding of learning content" (Student 25).

Community (Ⅵ) shows "the resources," which include "resources," "methods," and "knowledge." For example,

"There are four types of mixed teacher knowledge: 'teacher knowledge concerning subject matter and pedagogy,' 'teacher knowledge concerning subject matter and pedagogy,' 'teacher knowledge concerning pedagogy and students,' and 'teacher knowledge concerning subject matter, pedagogy, and students'" (Student 26).

Community (Ⅶ) highlights the "proactive, interactive, and deep learning" required by the ministry's curriculum guidelines. For example,

"Lessons whose quality is improved by realizing 'proactive, interactive, and deep learning' are ideal" (Student 1).

Community (Ⅷ) illustrates the feeling, which includes "interesting" and "relevant." For example,

"I think students feel that it is interesting to use resources related to things and phenomenon in nature because they are more familiar with them and hence easily imaginable" (Student 20).

Community (Ⅸ) shows "the things, phenomenon in nature." For example,

"According to MEXT (2018), the process is developed in science lessons as follows: introduction, setting of problem, setting of hypotheses, verification planning, conducting observations and experiments, handling results, discussions and reasoning, and expression and communication" (Student 3).

Community (Ⅹ) shows "group discussions." For example,

"When students predict the answer to a specific question, they should be allowed to discuss their predictions in a group" (Student 31).

DISCUSSION

Transformation of pre-service science teachers' beliefs about good lessons

The common characteristics of the communities in both Figure l(a) and Figure1(b) were analysed quantitatively. Community (Ⅰ) in both Figure 1(a) and Figure l(b) illustrate how lessons should be and the terms used are strongly interconnected. The word "think" implies that the participants think of how teachers should teach science and that they think that it is important to make students think about the learning contents in science lessons. Community (Ⅳ) in Figure l(a) and Community (Ⅷ) in Figure l(b) illustrate the "proactive, interactive, and deep learning" required by the ministry's curriculum guidelines. This implies that the participants recognize the ministry's prerequisites as the key components of teaching. Community (Ⅵ) in Figure l(a) and Community (Ⅻ) in Figure l(b) show the unique phenomenon in nature. This implies that the participants recognize that students learn the phenomenon in nature through science lessons.

The unique characteristics illustrated by the communities in both Figure l(a) and Figure l(b) were analysed quantitatively. Communities (Ⅱ), (Ⅲ), and (Ⅴ) in Figure l(a) were found to be weakly connected. These three communities show that the learning of science has to be related to the ministry's curriculum guidelines. These three communities are integrated into one community—Community (Ⅴ) in Figure l(b). Communities (Ⅶ) and (Ⅷ) in Figure l(a) are separated to illustrate the process of problem-solving. These two communities are integrated into one community—Community (Ⅶ) in Figure l(b). This implies that the participants recognize problem-solving as a set of the process. Taken together, these findings reveal that the knowledge needed to teach science is integrated systematically through two lessons: Methodology of Science Education Ⅲ and Ⅳ. Communities similar to Communities (Ⅺ) and (Ⅻ) in Figure l(b) were not found in Figure l(a); however, these two communities were found in Figure l(b). This means that the participants recognize these two communities as of utmost importance.

Transformation of pre-service science teachers' ideas about good lessons

The common characteristics of the communities in Figure 2(a) and Figure 2(b) were analysed quantitatively. Both Community (Ⅰ) in both Figure 2(a) and Figure 2(b) show "how lessons should be," and these words are strongly connected. The word "think" means that the participants think of how teachers can effectively teach science and that they think it is important to allow students to think about the learning content of science lessons. Community (Ⅴ) in Figure 2(a) and Community (Ⅶ) in Figure 2(b), which are found in beliefs about good lessons in Community (Ⅳ) in Figure 1(a) and Community (Ⅷ) in Figure 1(b), illustrate the "proactive, interactive, and deep learning" required by the ministry's curriculum guidelines. This implies that the participants recognize that it is important for the teaching techniques adopted to adhere to the ministry's curriculum guidelines and plan their lessons accordingly. Community (Ⅷ) in Figure 2(a) and Community (Ⅹ) in Figure 2(b) illustrate the importance of "group discussions." This implies that the participants recognize the importance of discussions in creating good lessons.

The unique characteristics exhibited by the communities in both of Figure 2 (a) and Figure 2(b) were analysed quantitatively. Community (Ⅰ) in Figure 2(a) was divided into two communities, which are similar to Communities (Ⅰ), (Ⅱ), and (Ⅲ) in Figure 2(b). Community (Ⅰ) relates to Communities (Ⅱ) and (Ⅲ), which are annularly connected to Communities (Ⅳ) and (Ⅴ). This implies that the participants considered ways through which they can teach the lessons effectively in relation to each of the communities; i.e., Communities (Ⅰ), (Ⅱ), (Ⅲ), (Ⅳ), and (Ⅴ) in Figure 2(b). These communities, which are similar to Communities (Ⅵ) and (Ⅷ) in Figure 2(b), are not found in Figure 2(a). This implies that the participants recognize that these two communities, which are related to resources and the feelings of "interesting" and "relevant," form part of the important elements in teaching science. This suggests that their idea of lessons is transformed closely through two classes; Methodology of Science Education Ⅲ and Ⅳ.

CONCLUSION

Pre-service science teachers in Japan believe that it is important to transform how science is taught in schools and ensure that students are allowed the opportunity to reflect on the learning content of science lessons. This leads to the teachers' beliefs that good lessons are the ones that make students think about the learning content in science lessons. In addition, both pre-service science teachers' beliefs about lessons and lesson planning are affected strongly by the ministry's curriculum guidelines, which emphasize the need for "proactive, interactive, and deep learning."

The skills needed to teach school science are integrated systematically into the most complex community, which illustrates how "the learning of science is related to the ministry's curriculum guidelines." This is affected through two lessons offered by the university, which guide teachers on how to plan secondary science lessons, including making lesson plans. Taken together, the transformation of the participants' beliefs about science lessons affects the transformation of their lesson planning techniques.

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ANALYSIS OF THE CURRICULAR EMPHASIS PREFERENCES OF PRESERVICE SCIENCE TEACHERS IN CHILE AND SPAIN

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In context-based science education, the concept of curricular emphasis exhibits a particular interest to teachers, as it helps to identify what they consider science education to be. Therefore, in this work, we present a quantitative study on the curricular emphasis preferences from two educational context, Chile and Spain. Using a Likert-type questionnaire as a research instrument, we comparatively analyze the choices of 40 pre-service science teachers from Physics and Chemistry, identifying similarities and differences between both countries. The results show a clear preference for the emphasis on Science, Technology and Society, even though the contrasts of the two educational systems and the profile of the pre-service teachers.

Keywords: context-based learning, initial teacher education (pre-service), inquiry-based teaching

INTRODUCTION

A common trend that has been registered in recent years in science education consists of adopting a context-based approach (Pilot & Bulte, 2006), to promote students' interest in science, providing coherence and necessary cohesion to the contents addressed in the curricula.

In this sense, its combination with the practice of inquiry, in which students adopt a positive attitude towards science, participating actively linked to the educational transposition of scientific research and more independent in the learning process. Therefore, it is associated with a change in the perspective of teaching, applying the context as a starting point for the development of scientific ideas, and not the other way around, as is usual in more traditional methodologies (Bennett et al., 2007; Lupión-Cobos et al., 2017).

However, this conceptual change requires the inclusion of new teaching strategies and approaches related to the development of both personal and professional skills, which allow students to acquire an adequate understanding of the Science, Technology and Society relationships (STS), which applies to everyday situations and contributes to their personal development and active integration in society, as scientifically and technologically literate citizens (Boerwinkel et al., 2017; European Commission, 2014).

In this educational framework, teachers not only require a solid knowledge of the content, but they also need to be involved in the design and practice of the teaching process, which is associated with numerous responsibilities (Slavit et al., 2016). From their guiding role, they are expected to help their students develop critical thinking, problem-solving, and decision-making or use ICT tools, thus enhancing responsible citizenship skills.

Thus, teachers' sense-making processes are involved in a social setting of teachers' understanding and perceptions of new aspects related to teaching innovative curricula compared to teaching conventional curricula (Spillane et al., 2002).

It is important to identify the teachers' points of departure on their attitudes towards the introduction of a context-based approach (Coenders et al., 2010) since their beliefs and their evolution are different depending on personal factors in which teachers face to do it (Avraamidou, 2014).In addition, the challenges of features of the schools where the teachers work, the structures of their science departments, and the institutional policies in the workplace (Pedretti, et al., 2008; Avraamidou, 2014).

In fact, new strategies are being studied for adequate professional development in teaching context-based science curricula, as an exemplar of curriculum innovations in which teachers are confronted with new pedagogy and new content simultaneously. Dolfing et al. (2020) have analysed the strategies to support teachers' professional development regarding from the perspective of teachers' sense-making relate to teachers' accommodation of the new aspects in content and pedagogy of teaching context-based science curricula guiding the design of activities. They described the framework in three new aspects: setting a context in class, performing a new teaching role, and teaching new content.

Professional competences for context-based education: the importance of the curricular emphasis

These changes in teacher cognition and practice directly affect teachers' professional competence to apply these didactic approaches, with an inherent complexity associated with the difficulty of transferring real problems to the classroom and a whole series of limitations that condition it (de Putter-Smits, 2012). For example, teachers have difficulties in selecting and prioritizing content, and that the use of contexts should not be reduced only as a motivating introduction, an anecdote between lectures or a final mention of the technological application of what has been taught (Marchán-Carvajal & Sanmartí, 2015a; Moraga-Toledo & Palomera-Rojas, 2022).

Therefore, from pre-service teaching, it is essential to address the development of the teaching skills and competencies necessary to face context- and inquiry-based science teaching successfully. In this sense, it is important to train initial teacher trainees to develop, implement and evaluate the results of their own proposals as it is a good way to provide them with practical experience of these approaches and to transfer the knowledge to the classroom (Lupión-Cobos, et al., 2017). Distinguishing mainly among "use of context", "regulation" and "emphasis". Although the first two can be associated with the familiarity with which the teacher adopts the context, and their ability to regulate student learning through specific activities, respectively, the "emphasis" presents greater complexity, referring to the messages and objectives that provide an answer to the why of learning (Roberts, 1982). And as also inquiry is inherently linked to context, and context-based teaching requires extra-situational knowledge of the context and not just declarative knowledge of science (Jaana et al, 2019)

Given the relevance of the preferences about the curricular emphasis for the inquiry and context-based science education and considering the diversity on its application regarding distinct curricular systems, this study aims to compare pre-service teachers' initial perceptions in Chile and Spain on the matter.

METHODOLOGY

Participants in this study were 40 pre-service science teachers (PSST) from the Chilean Physics Pedagogy Degree (25) and the Spanish Master's degree in Secondary Teacher Education (15). For data collection, we used the questionnaire developed by de Putter-Smits (2012), which consists of an extension of van Driel et al. (2005). The five-points Likert-type questionnaire (1: totally disagree; 2: disagree; 3: neither agree nor disagree; 4: agree, and 5: completely agree), was translated into Spanish from its English version, has a total of 54 questions (38 about science education in general, and another 16 specific to Physics and Chemistry), and includes three curricular emphasis: fundamental science (FS), science, technology and society (STS) and knowledge development in science (KDS). While FC considers that theoretical notions and scientific knowledge should be taught first, since they provide a basis for understanding the natural world and are necessary for students' future education, STS implies the relevant role of communication and decision-making in matters involving scientific issues. Finally, KDS, related to the nature of science, connects with the idea that students should learn how scientific knowledge develops in socio-cultural contexts, understanding science as a constant development system.

Table 1 classifies according to the three curricular emphases, the 38 items on science teaching in general and table 2 classifies according to the three curricular emphases, the 16 items specific to Physics and Chemistry.

Table 1. Classification of the 38 items about science education in general.

	Fundamental Science (FS, n=12)	**Science, Technology and Society (STS, n=8)**	**Knowledge Development in Science (KDS, n=9)**
Items	1, 6, 7, 13, 18, 21, 23, 29, 30, 32, 35, 37.	3, 5, 9, 15, 17, 20, 22, 25, 26, 28, 31, 34, 38.	4, 8, 11, 12, 14, 16, 19, 24, 27, 33, 36.

Table 2. Classification of the 16 items specifics for Physics and Chemistry.

Fundamental Science (FS, n=5)		**Science, Technology and Society (STS, n=0)**	**Knowledge Development in Science (KDS, n=3)**
Items for Physics	40, 42, 43, 44, 46.	---------	39, 41, 45
Items for Chemistry	40, 42, 43, 44, 46.	---------	39, 41, 45

For both countries, we collected the data prior to implementing an inquiry and context-based teaching proposal, located at an equivalent learning moment (6th semester in Chile and 2nd quarter in Spain). Given that within the 54 initial questions de Putter-Smits (2012) identifies the items with the highest correlation, we calculated the frequency distribution, mean scores and standard deviation for the set of items associated with the different emphasis.

RESULTS

We present the main findings concerning each of the curricular emphasis and educational contexts. Regarding STS items (I1-I12) results, we observe a similarity in the preferences (figure 1). The value means for the Spanish PSST in this emphasis is 4.04, which is lower than the Chilean PSST (4.34), expressing a marked predilection for the use of Science-Technology and Society contexts for the last ones. Thus the Spanish students scored considerably lower in items I2, I10 and I11, related to the importance given to the discussion of current social topics in the science subject, to whether the exit qualifications should be based on an analysis of social situations where science plays an important part, or to the preference on the use of societal context to show what the importance of science is, respectively.

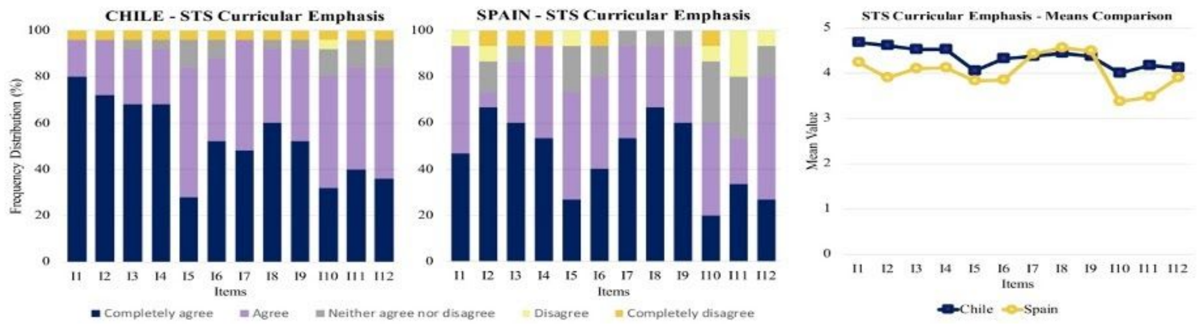

Figure 1. Frequency distribution (Chile and Spain) and means comparison for the STS curricular emphasis.

About the KDS curricular emphasis items (I13-I19/I20) (figure 2), although the total means value still differs a little (4.25 for Chile and 3.89 for Spain), the profile depicted by both Chilean and Spanish PSST is even closer. There are just two considerably differences concerning I13 (about the important task of science education to acquire insight into the socio-historic development of scientific knowledge) and I19 (about the relevance of treating the historical background of radioactivity). Hence, for both items, Spanish PSST scored lower than Chilean. Here we would also like to remark that the absence of Chilean data for I20 is due to the specificity of this item for Chemistry PSST, and therefore, only Spanish students scored it.

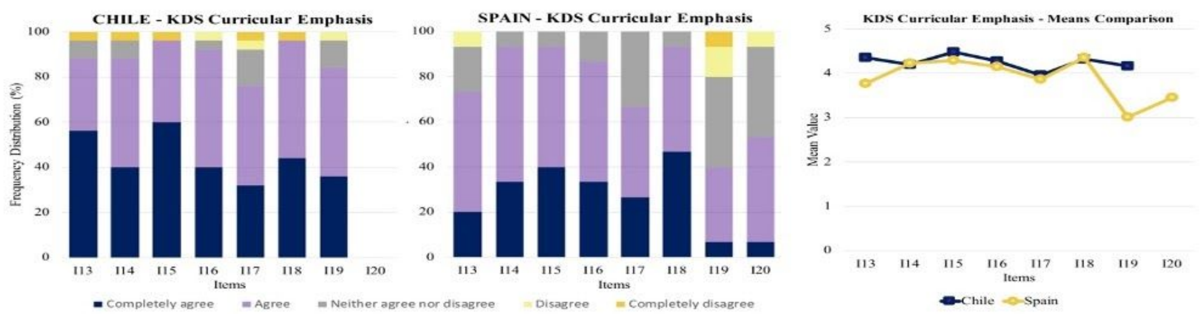

Figure 2. Frequency distribution (Chile and Spain) and means comparison for the KDS curricular emphasis.

Finally, although the results on the FS curricular emphasis items (I21-I28/I29) (figure 3) are practically identical for both countries, and so are the total mean values (2.85 for Chile and 2.87 for Spain). We want to highlight the scores on I24, related to whether students should acquire basic scientific skills before working on applications. For FS emphasis, this item obtained the highest scores both in Chile and Spain, even though all the others did not score greater than 3.5. As it happens before, the absence of Chilean data for I28 is due to the specificity of this item for Chemistry PSST, and therefore, only Spanish students scored it.

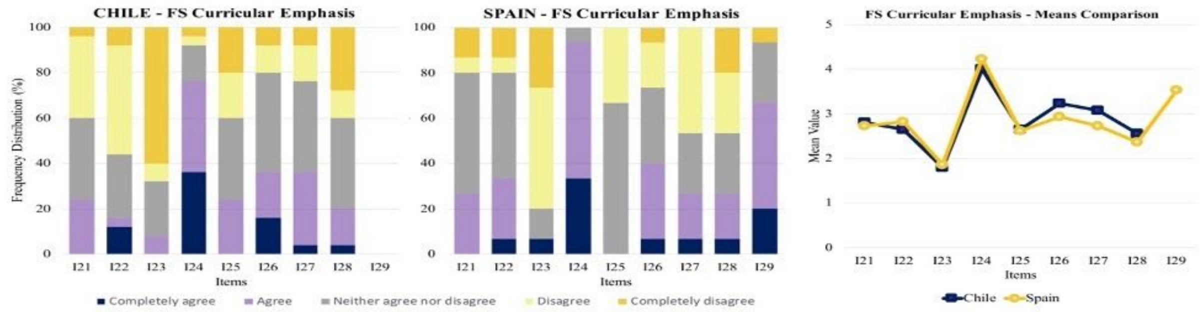

Figure 3. Frequency distribution (Chile and Spain) and means comparison for the FS curricular emphasis.

CONCLUSIONS

Since international studies usually highlight the disparities between educational systems, even more considering the differences when approaching inquiry and context-based science education, we gratefully have established a small-scale comparison about Chilean and Spanish PSST's curricular emphasis preferences. For both, we observe an apparent positive inclination towards the use of STS and KDS emphasis, a trend that, according to van Driel et al. (2005), would represent an approach to more active teaching strategies. This tendency is more marked for Chilean PSST, mainly due to the curricular structure and duration of the Physics Pedagogy degree and the Chemistry Pedagogy degree, as well as to the differences in the scientific background with respect to the Spanish ones. Although these finding may not be generalisable and apply to a small number of participants, the satisfying results obtained encourage us to continue promoting this type of didactic approaches, highlighting the relevance of teaching in context and providing tools for its proper implementation within the two countries.

ACKNOWLEGMENTS

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PRIORITY MATTERS TO BE RESEARCHED ACCORDING TO TRAINEE PRIMARY EDUCATION TEACHERS

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It is important to train scientifically literate citizens. In this, formal education plays a relevant role. In the present work, a questionnaire was administered which was prepared ad hoc for a convenience sample comprised of 367 primary education teachers undergoing initial training, from 5 Spanish universities. The questionnaire sought to detect how teachers are able to identify science in society and what matters are considered most priority. The results of the analysis show that Health and the Environment, but not others, are the subjects consider most important by future primary teachers. The awareness of scientific issues forgotten needs to be included among the teacher education course activities. The analysis according to sex, age and academic year variables have shown statistically significant differences regarding the sex variable. Comparative analysis with the results of questionnaires addressed to the population at large, both European and Spanish, have found some differences in order of priority of scientific issues.

Keywords: Initial Teacher Training, Scientific Literacy, Socio scientific Issues

INTRODUCTION

The scientific literacy of all citizens is increasingly necessary in today's world (Aikenhead, 2006; Ezquerra and Magaña, 2017) in the face of the evident crisis of confidence in science as indicated rise of anti-vaccine movements, terraplanists, Climate Change deniers or advocates of homeopathy… (Achterberg et al., 2017; Saltelli and Funtowicz, 2017). The pursuit of scientific literacy for participatory democracy is a goal claimed within the movement socio-scientific issues (ISS) and advocated in science education reforms internationally, which is necessarily linked to the development of critical thinking or the ability to search for and evaluate information (Acar, Turkmen y Roychoudhury, 2010; Sadler, Romine and Topçu, 2016). That concern mobilises institutions in different countries who seek to know the situation of the population and its evolution (DeBoer, 2011; DeBoer, 2014; Roberts & Bybee, 2014; Cortassa, 2016) in order to improve the scientific training of their citizens. This diagnosis in Spain has been carried out through surveys by the Spanish Foundation for Science and Technology (FECYT according to the acronym in Spanish) every 2 years from 2002 and at European level through the Eurobarometer study on Public Perceptions of Science (Directorate-General for Communication, 2014).

Due to the important role formal education has in scientific training of citizens, different countries have enshrined in their legislation the intention to train their population scientifically. In the case of Spain, it is included in the current educational law (LOMCE, 2013): "Preparation for the exercise of citizenship and for active participation in economic, social and cultural life, with a critical and responsible attitude and with the ability to adapt to the changing situations of the knowledge society". However, legislating is not enough, more research efforts are needed both to document the potentialities or constraints of scientific literacy and citizenship education through science curricula and to evaluate what training and viewpoint teachers have. Especially relevant is improving of teachers training of the first stages of education. More so since, research has showed the public domain of science of the trainee Primary Education teachers affects the kind of thinking they develop, and their teaching plans (Spiliotopoulou and Papantoniou, 2011). For this it would be necessary to consider factors and skills such as decision making, problem solving, identification of science in the environment, sustainable development, etc. (Hodson, 2003). Nevertheless, scare work has been carried out on this group to detect its capacity to identify science in society and its transfer to the classroom. Prior studies show that Primary Education teachers in initial training do not show differences compared with other citizens of the same age (Fuertes-Prieto et al., 2020). Moreover, they have difficulties in adequately including science in the learning process (Ezquerra, Rodríguez & Hamed, 2014; Rivero et al., 2017).

Due to all this, it is of interest to diagnose capacity to identify the presence of science in society among this group of teachers. Therefore, the aim of this work was to analyse what subjects are considered important to be researched by science in a sample of students of the Degree in Primary Education.

METHOD

Participants

A convenience sample was drawn, it was composed for 367 students of Primary Education Degree, belonging to five Spanish universities (Granada University, Valladolid University, Complutense University of Madrid, Castilla-La Mancha University and CEU Cardenal Spinola, Sevilla). Most of the participants of the group (72,75%) were women. This is a similar percentage to that of the Spanish active teaching staff. As expected, the majority were young people between 19 and 24 years old. None of the students were in their first year.

Coding of data procedure

The method used to carry out this work is described below. In order to achieve the objectives, the research has had three stages (Figure 1). The first was putting into circulation the next question: *"please tell us which topics you consider to be the most important for science to investigate. If you can, please tell us up to five topics"*. The question was on-line administered in the context of a science education course during the first semester of academic year 2019-2020.

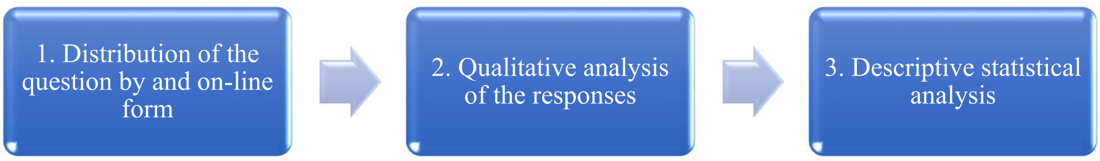

Figure 1. Stage of research.

Once the responses were received, next stage was to implement a qualitative analysis of the responses (content analysed by adopting an emergent coding approach) to detect the recurring themes. Initially, three coders independently inspected the answers what were encoded and assigned to categories. Next, emergent categories identified by the independent coders were compared and differences were reconciled, resulting in a common list. In the different refining phases until to find the consensus, the research team grouped the categories to generate a system of macro-categories. These major categories are comparable to those already used in similar studies such as the FECYT surveys administered to citizens in Spain and Eurobarometer in Europe. Thus, expressions such as "Alzheimer" or "Rare diseases" were encoded in the emergent category "Diseases" that, along with other emergent categories such as "Treatments" or "Vaccines", configured the macro-category "Health". Subsequently, a descriptive statistical analysis was carried out of the citations to allow the relative frequency of each macro-category to be obtained in the set of responses.

RESULTS AND DISCUSSION

The overall results obtained are shown in Table 1. It gives a brief description of the macro categories detected in alphabetical order and their relative frequencies. According to our sample, the topics that Spanish trainee teachers consider a priority to be investigated by science could be grouped into seven macro categories.

Table 1. Short description of the macro- categories and their relative frequencies (RF).

MACRO-CATEGORIES	DESCRIPTION	RF
Basic and applied science	Groups the mention of basic scientific disciplines and their applications in society.	11.1%
Education	Compiles aspects related to scientific literacy and teaching.	5.9%
Environment	Records codes that refer to climate change, energy sources, pollution, conservation of the environment, etc.	21.1%
Food	Records content related to types of food, nutritional characteristics and properties, diets, etc.	3,2%
Health	Covers references to diseases, medical treatments, medicines, etc.	37.8%
Pseudo-science	Compiles mentions of non-scientific practices.	0.3%
Society	Covers items linked to wellbeing, consumption, culture, sports, the economy, politics, and population.	9%
Technology	Covers codes related to telecommunications, means of transport, robotics, and new materials.	11.4%

The data indicate that students show interest in two topics: Health (37.8%) and Environment (21.1%); while Technology (11.4%) and Basic and Applied Science (11.1%) occupy the third and fourth place, respectively. The themes Society (9%), Education (5.9%) and Food (3.2%) are presented as a lower priority. It is important to point out that responses were also gathered on practices that are not considered scientific, for example "Astrology". These affirmations are grouped in an eighth category, Pseudoscience (0.3%). Although it could be considered as anecdotal for, they amount to a low percentage, in our opinion it is a type of declaration that should not arise among future teachers. Their presence among preservice teachers should be a source of reflection, since these may be part of the hidden curriculum that they will transmit to their students (Fuertes-Prieto et al., 2020).

In order to obtain greater detail of the distribution of priorities that future Primary Teachers have, the relation between the macro-categories established and three distinctive variables was studied: sex, age and academic year. We point out that there are no statistically significant differences for the age and academic year variables. Nevertheless, our data shows, with significant differences ($p<0.05$) that women are more likely than men to mention Health (39,66% vs. 33,09%), Environment (23,11% vs. 16,18%), Education (6,99% vs. 3,31%) and Food (3,28% vs. 2,94%). However, men prioritize topics related to Basic and Applied Sciences (16,54% vs. 8,99%), Technology (15,81% vs. 9,70%), Society (11,76% vs. 7,99%), and Pseudoscience (0,37% vs. 0,29%) (see Figure 2). These results differ from the findings of Revuelta and Corchero (2016) who identify women as one of the social groups that most believe in pseudoscience.

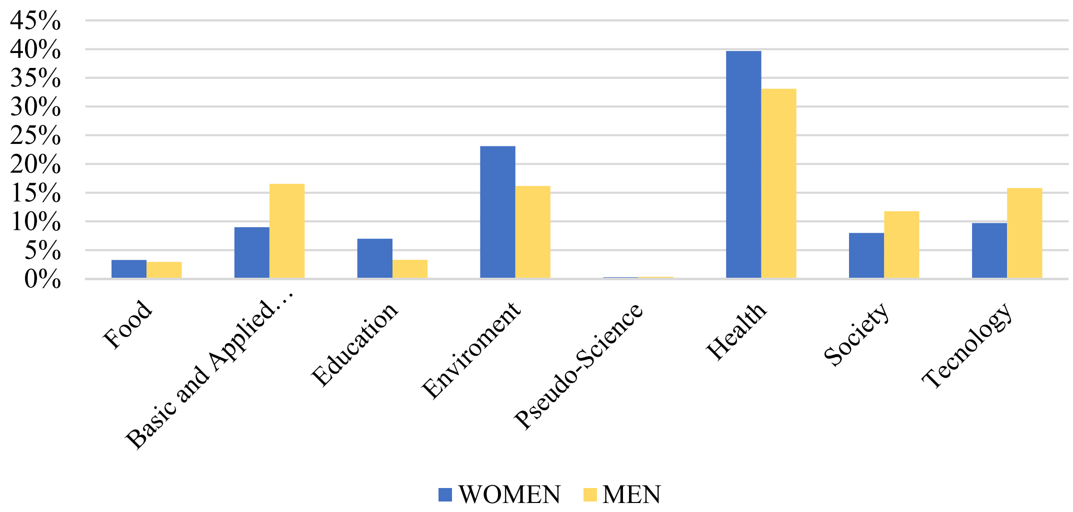

Figure 2. Comparative study between sex variables.

Comparative study between teacher-students and citizens

Although the question was not exactly the same, a comparative study has been carried out for the discussion in this study between our data and the results (1) of the Eurobarometer (2014) and (2) the Social Perception of Science Survey (FECYT, 2019) among Spanish citizens. The preliminary study carried out compares the position that each subject occupies according to the importance the different samples are assigned. Figure 3 shows the results obtained in this study, Figure 4 shows the results of the social perception of science in Spain and Figure 5 shows the results for European citizenship.

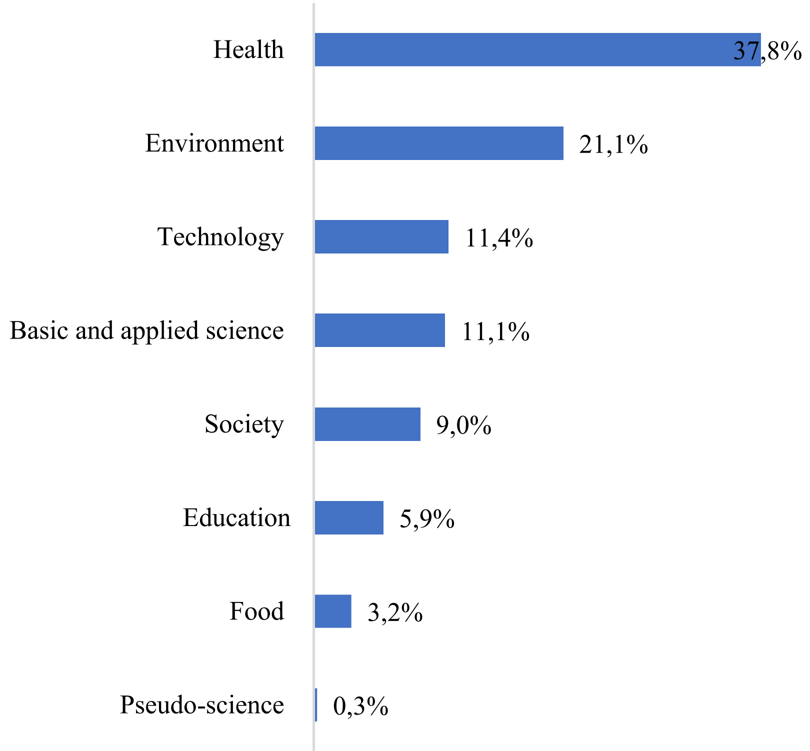

Figure 3. Results of teachers training obtained in this research.

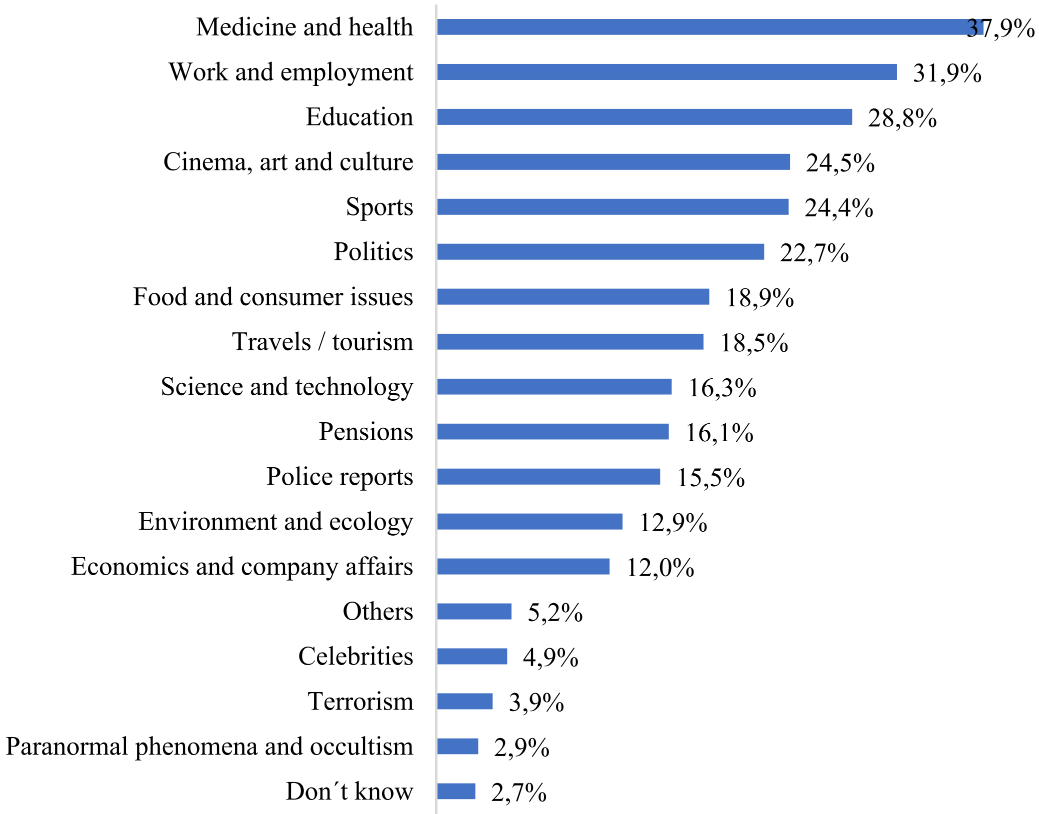

Figure 4. Results of Social perception of science and technology survey (Spanish Foundation for Science and Technology -FECYT-). Source: FECYT (2019). Percepción social de la ciencia y la tecnología 2018.

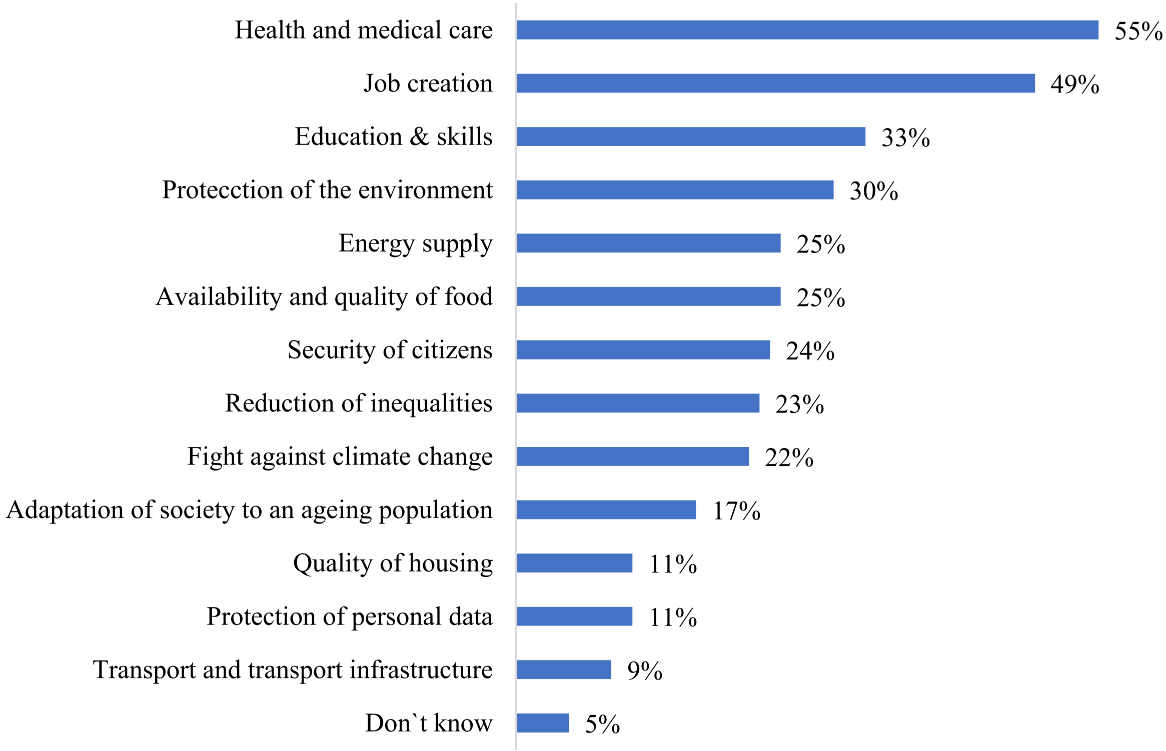

Figure 5. Result of Eurobarometer. Source: Directorate-General for Communication (Coord.) (2014). Special Eurobarometer 419.

Health is in a high position, regarding the European population (55%), the Spanish citizens (37,9 %), and the trainee Primary Education teachers (37,8 %). But if the Environment macro-category is considered to include protection of the environment, climate change and sources of energy as it is in the present research, the European population put this macro-category above Health (the sum of percentages is 77%). However, that is not the case for Spanish citizens. In regard of Environment, the Spanish general population consider in a lower position (12,9 %) than the university students of this research (21,1 %), and the European population.

About Education, Spaniards (28,8 %) match European citizens (33 %) when, in both cases, they grant greater importance to that matter than the sample in our study (5,9 %), which are preservice teachers. It is surprising that future teachers place Education in such a low position compared with other matters and that this order is less ambitious than that gathered from citizens at large, especially for the Spanish citizens.

We found concerning the emergence of pseudo-sciences (0,3%) among the answers to our study but the relative frequency in the sample is low than that from Spanish citizens (2,9%). The emergence of uncritical pseudo-scientific proposals in our society has been a matter of concern for years but has recently become more pronounced in Spain (Cano-Orón 2019; Cortiñas-Rovira et al. 2015; Fuertes-Prieto et al., 2020). These results confirm the need to improve the training of future teachers in this aspect, since it would affect in the citizens of the future.

CONCLUSIONS AND LIMITS OF THE STUDY

Findings showed that, according to our sample, Spanish student-teachers priority issues to be investigate by science could be group in seven macro-categories. Health and Environment were the main. Considering the responses provided in each of the identified macro categories, it can be seen how future teachers value the role of science in society through a utilitarian approach to science to achieve individual or collective good. Results showed no significant difference between students' age or academic year. Statistically significant differences were found in sex.

What the students mention as the more important matters to be researched differs from the Spanish and European population. Their awareness of scientific issues of daily life needs further development and evidence suggests that there is a need for more specific guidance to be included in the teacher education course activities. This study has allowed us to identify a wide range on which to work on Science in Society in the classroom. In this way, an education that responds to the needs of students would be achieved, improving their quality of life and promoting educational inclusion.

This preliminary study requires more deep analysis and that cannot be covered in the limited length of this text. Our research group infer the relationship between the priority issues than science must research for the trainee Primary Education teachers and the Nature of Science conception. This inference comes from the low position for social issues, especially Education, and is now in process of study.

Lastly, it is necessary to point out that the results shown here reflect a pre Covid-19 vision, that would foreseeably change if the data gathering had taken place late.

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TEACHER, TEACHING AND SCHOOL FROM THE PERSPECTIVE OF PRE-SERVICE CLASSROOM TEACHERS

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Pre-service teachers' views, expectations and the factors that affect their choice of profession affect their career success. Starting from this point of view, this research aims to investigate the thoughts of the pre-service classroom teachers on teaching profession, school, and expectations from the faculty of education. The phenomenology design was conducted with the participation of the 18 pre-service classroom teachers. Data were collected through the open-ended interview form. Data were analyzed with content analysis. According to the results, most of the participants stated that teacher is a guide, informant and compassionate, and they thought the professional duties and responsibilities, and raising individuals with universal values are the most important duties of the teacher. The participants' reasons for choosing the teaching profession were mostly internal factors. Most of the participants stated that schools are anywhere where learning takes place, and that school should provide students with knowledge, and universal values. The findings revealed that the expectation that most of the participants had when starting education faculty was to become equipped with professional knowledge and skills. Lastly, only seven participants stated that their expectations were met by the faculty.

Keywords: Pre-service classroom teachers, perspective, expectation

INTRODUCTION

Teaching is a profession that has a long history, from being a preferred career with high social status to being regarded as a career selected by individuals, based on the extent that teaching is judged to be useful (Moosa, 2020). It is known that pre-service teachers' views on the concept of teacher, their expectations from teaching and the factors that affect their choice of profession affect their career success (Tataroğlu, Özgen, & Alkan, 2011). For this reason, it is very important to determine the opinions, expectations and preferences of pre-service teachers.

It was found that pre-service teachers generally describe teaching as a profession that requires responsibility and sacrifice (Ozbek, Kahyaoglu, & Ozgen, 2007; Watt & Richardson, 2008). In the studies, it was determined that pre-service teachers had expectations from the program and teaching staff such as to become equipped with professional knowledge and skills, none rote learning, to take applied courses, and learning through discussion (Cakir & Akkaya, 2017; Tataroglu et al., 2011). Various studies were conducted on the reasons for pre-service teachers to choose teaching programs (Cakir & Akkaya, 2017; Ekinci, 2017; Tataroglu et al., 2011; Watt & Richardson, 2008; Yurdakal, 2019). In these studies, it was determined that many internal and external factors such as the fact that teaching is a respected profession, getting insufficient score in the university exam, enjoying the teaching, and loving children were effective under the profession choices of pre-service teachers.

Above mentioned studies conducted with pre-service teachers are generally quantitative. In this context, there is a need for qualitative studies in which the opinions, reasons for career choice, and expectations of pre-service teachers about the teaching profession are investigated comprehensively. Moreover, no study investigating the perceptions of pre-service classroom teachers on school was found in the literature. Within this context, this qualitative research aims to investigate the thoughts of the pre-service classroom teachers on teaching profession, school, their choice of profession, and expectations from the faculty of education.

METHOD

Research Design

Phenomenological design was used in the research. In phenomenological studies, the researcher focuses on a phenomenon, collect data through in-depth interviews and interpret the participants' perceptions (Fraenkel, Wallen, & Hyun, 2012). The present research was carried out with phenomenological design since it was aimed to investigate, understand and explain pre-service teachers' experiences related to teacher, teaching and school.

Participants

The participants of the study consisted of 18 fourth-year pre-service classroom teachers studying in a university in Central Anatolia, Turkey during the spring semester of the 2019-2020 academic year. Participants were determined by criterion-based sampling. The main criteria are that participants have teaching practice experience and are willing to participate in the research.

Data Collection Tool

In phenomenological research, data can be collected through in-depth interviews or interview forms consisting of open-ended questions (Creswell, 2007). In this context, data were collected through an interview form consisting of four open-ended questions:

(i) Who is a teacher? What are the most important duties and responsibilities of the teacher?

(ii) Why did you choose to be a teacher?

(iii) Where is the school? What should the school contribute to a student?

(iv) What were your expectations when starting the education faculty? Have they been met?

Before the open-ended written interview form was applied to the participants, two field experts were informed about whether these questions were suitable for the purpose of the study. Then, in the classroom environment, data were collected.

Data Analysis

Content analysis, which is used to formulate themes and categories in order to organize and make sense out of large amounts of descriptive information (Fraenkel et al., 2012), was used in the research. The collected data were analysed separately by two researchers, and the agreement level between them was checked for consistency. While analysing the data, the codes were firstly determined, and similar codes were taken together to create the categories.

As a result of the analyses, the average percentage of the agreement between experts regarding the codes were measured as 0.90. The percentage value above 70% is considered reliable (Miles & Huberman, 1994).

RESULTS

Pre-service Teachers' Views on Teacher

The pre-service classroom teachers stated the characteristics of the teacher as guide, informant, compassionate, role model, the one who enlightens the mind, warm-hearted and patient, respectively (Table 1).

Table 1. Pre-service teachers' thoughts on who teacher is.

Categories	f
Guide	8
informant	7
compassionate	6
role model	5
enlightens the mind	4
warm-hearted	3
patient	2

Majority of the participants thought that the most important duties and responsibilities of the teacher were professional duties and responsibilities, and raising individuals with universal/ human values (Table 2). In addition, the participants mentioned the responsibilities such as raising students with national values, preparing them for the future, dealing with their problems, guiding them, and following the latest developments.

Table 2. Pre-service teachers' thoughts on duties and responsibilities of the teacher.

Categories	f
Professional duties and responsibilities	11
Raising individuals with universal/ human values	11
Raising individuals with national values	7
Preparing individuals for the future	6
Dealing with students' problems	4
Guiding the student	3
Following the latest developments	2

Pre-service Teachers' Views on the Reasons for Choosing the Teaching Profession

In the study, pre-service teachers' reasons for choosing the teaching profession were grouped under two themes (external and internal factors) and 10 categories. As it is seen in Table 3, internal factors outnumbered external factors, and number of participants emphasizing internal factors is also higher.

Table 3. Pre-service teachers' reasons to choose the teaching profession.

Theme	Categories	f	Sample answer
Internal factors	Enjoying teaching	14	*"I chose this profession because I love both teaching and children."* [P2]
	Liking of children	10	
	Making the world a better place	7	*"Teaching is the most enjoyable and effective way to change world."* [P10]
	Childhood dream	3	*"Becoming teacher was my childhood dream."* [P9]
	Enjoying self-improvement	2	*"I found this profession suitable for me as I love to improve myself."* [P1]
	Being interested in psychology	1	*"I love to think about psychology and talk about people's problems."* [P11]
External factors	Being inspired by teacher	4	*"One reason to choose teaching is my first grade teacher, whom I love so much. Also it is a respected profession."* [P17]
	Being a respected profession	2	
	Family influence	1	*"I chose this profession with guidance of my uncle who was a teacher."* [P3]
	Inadequate score	1	*"Since my score was inadequate for my dream job I chose this job."* [P3]

Pre-service Teachers' Views on School

As it is seen in Table 4, most of the pre-service classroom teachers stated that schools are anywhere where learning takes place. Some participants defined school as an institution, while some saw it as a home.

Table 4. Pre-service teachers' thoughts on where the school is.

Categories	f
Any place where learning happens	11
Official institution	5
Home	4
The place where training activities are carried out in a systematic and planned manner	3

Pre-service teachers generally stated that school should provide students with knowledge, and universal values such as honesty, respect, love, fairness (Table 5).

Table 5. Pre-service teachers' thoughts on the school's contributions to the students.

Categories	f
Knowledge	11
Universal/ human values	11
Skills	8
Socialization	6
Discovering interests and talents	6
Experience	3

Pre-service Teachers' Expectations from the Faculty

According to the findings, the expectation that most of the pre-service teachers had when starting education faculty was to become equipped with professional knowledge and skills (Table 6). Moreover, six participants stated that they expected to take applied courses rather than theoretical ones. Seven participants stated that their expectations were met, whereas six participants stated that their expectations were partially met, and four participants stated that their expectations were not met by the faculty.

Table 6. Pre-service teachers' thoughts on expectations from the faculty of education.

Categories	f
Becoming equipped with professional knowledge and skills	11
Taking applied courses rather than theoretical courses	6
Providing ways to exchange ideas	2

DISCUSSION OF FINDINGS AND IMPLICATIONS

The results revealed that most of the pre-service classroom teachers thought teacher was a guide, informant and compassionate. Thinking that behaviourism is centered around transmission of knowledge from the instructor to the students (teacher is the informant) whereas constructivism is focused on the construction of knowledge by the students (teacher is a guide), this finding is interesting. Moreover, majority of the pre-service teachers stated that teacher's most important duties and responsibilities were professional duties and responsibilities, and raising individuals with universal/ human values such as honesty, justice, compassion and tolerance.

According to the findings, pre-service classroom teachers' reasons for choosing the teaching profession were mostly internal factors such as enjoying teaching and liking of children. These findings are in line with many other studies in the literature (e.g., Buldur & Bursal, 2015; Tataroglu et al., 2011). The extrinsically motivated teacher focuses on the benefits of teaching such as salary, lengthy holidays and status. On the other hand, intrinsic values are the highest motive for choosing teaching. The pre-service teachers who are motivated by internal factors tend to be more committed to the teaching profession (Moosa, 2020; Roness, 2011).

Most of the pre-service classroom teachers stated that schools are anywhere where learning takes place. Some participants defined school as an institution, while some saw it as a home. Pre-service teachers generally stated that school should provide students with knowledge, and universal values such as honesty, respect, love, fairness. In parallel with these findings, Dilekçi, Limon and Sezgin Nartgün (2021) investigated pre-service teachers' metaphorical images of school, and found that the most common metaphor was family/home. Additionally, the participants stated that schools are the sources of information.

According to the results, most of the pre-service teachers expected to become equipped with professional knowledge and skills. Some of them also stated that they expected to take applied courses. Similarly, Tataroglu et al. (2011) stated that pre-service mathematics teachers had expectations from the program to become equipped with professional knowledge and skills, to take applied courses, and to learn through discussion. It is remarkable that no pre-service teacher focused on pedagogical knowledge. In their study Frågåt, Henriksen and Tellefsen (2021) investigated first and final-year pre-service science teachers and in-service physics teachers to describe the knowledge and skills needed to be a good teacher. The results of their study revealed first-year pre-service teachers put more emphasis on pedagogical skills and personality traits, whereas final-year pre-service teachers and in-service teachers focused more on teacher content knowledge and skills. However, teacher knowledge comprises more than subject-matter knowledge, thus teacher education should focus on integrating content knowledge and pedagogical knowledge.

This study is limited to the selected participants. In the research, a cross-sectional study was carried out and the fourth-year pre-service teachers were studied. It can be suggested to conduct longitudinal studies designed to cover all grade levels of pre-service teachers from different departments. By this way, the findings of the present study would be validated by incorporating a larger sample size and different grade groups. Within this context, it is suggested to examine the future professional expectations of pre-service teachers by adding new questions to the interview form.

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Part 14 / Strand 14

In-service Science Teacher Education, Continued Professional Development

Editors: *Claudio Fazio & Pedro Reis*

Part 14. In-service Science Teacher Education, Continued Professional Development

In-service science teacher education, teachers as lifelong learners; methods, innovation and reform in professional development; evaluation of professional development practices, reflective practice, teachers as researchers, and action research.

Part 14: IN-SERVICE SCIENCE TEACHER EDUCATION, CONTINUED PROFESSIONAL DEVELOPMENT

Editors: *Claudio Fazio & Pedro Reis*

INTRODUCTION

The area of in-service teacher education and continued professional development of teachers is of growing interest internationally, and it has been given increasing importance in the last years throughout many countries in the world. Clearly, the value and success of any educational system strongly correspond with the quality of its teachers' competencies and practices, and for a long time, Strand 14 of ESERA has been dealing with high-quality research in this science education field.

The present edition of the 2021 ESERA conference proceedings portrays a wide array of research pieces addressing several issues and aspects of science teacher education and continued professional development, mainly from an empirical point of view. Compared to the last ESERA conference proceedings, the number of papers presented in this strand is reduced from 32 to 18. The papers included in the strand come from all over the world. There is a strong European presence, with papers/contributions coming from research institutions in Austria, Belgium, Czech Republic, Germany, Greece, Ireland, Italy, Poland, Portugal, Slovenia and Switzerland. Non-European, international presence and collaboration are also strong, with papers from the U.S.A., South Africa, South America (Brazil and Uruguay), Asia (Singapore), and Oceania (New Zealand). This collection has a clear international character and confirms once more that including research pieces from all over the world is a trend that is gaining momentum in each ESERA edition.

Looking at the contents and approaches of studies, we see that there are mainly empirical studies, and one theoretical study is also present. In addition, studies are related to innovations concerning specific course developments and applications, including investigating the effects and the possibilities of evaluating science teaching. That variety demonstrates well how the complexity of in-service science teacher education and continued professional development is scientifically approached and addressed by the ESERA community.

The theoretical study at the beginning of this chapter investigates and discusses the link between Pedagogical Content Knowledge (PCK) and teaching practice through the lenses of the recently proposed Refined Consensus Model of PCK.

The empirical studies found in this chapter deal with several topics, such as the study of three dimensions of inquiry in physics teacher professional development (in a paper synthetizing the discussion held during a Symposium at the ESERA 2021 Conference), the professionalization processes of teachers in all phases of their careers and their assessment; PCK development in pre- and in-service teachers; visual representations of teaching practices; teaching/learning sequences development and validation. Qualitative, quantitative, and mixed methods are used to analyze the empirical results and draw conclusions and implications for improving in-service teacher education and continued professional development of science teachers.

Looking at the selection of papers presented in Strand 14 and accepted for publication, it is possible to say that the ESERA community continues to show strong support for the improvement of in-service teacher education and continued professional development of science teachers all over the world by means of high-quality research pieces that deal with topics of great interest.

Linking Pedagogical Content Knowledge and Teaching Practice

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Science education researchers have developed a refined understanding of the nature and sources of science teachers' pedagogical content knowledge (PCK), but how to develop applicable and situation-adequate PCK remains unclear. Since (classroom) teaching experiences are acknowledged as a rich source of PCK in science teacher education, this study sought to systematize existing science education research on PCK and practice through the lens of the recently proposed Refined Consensus Model (RCM) of PCK as a means of exploring, and explore in what ways teaching experiences contribute to teachers' PCK development. In this review, selected studies' approaches to their investigation of PCK and teaching practice and selected findings were characterised and synthesised as an overview. We found that studies largely employed a qualitative case-study methodology featuring specific PCK models and tools. Major findings from the researched studies indicated links between PCK and practice were summarised and the potential for further research was identified. The RCM proved to be a meaningful theoretical lens for conceptualizing links between teaching practice and PCK development by virtue of pedagogical reasoning as a de facto mechanism and/or explanation for PCK development in the context of teaching practice.

Keywords: PCK, teaching practice, pedagogical reasoning

INTRODUCTION

While classroom learning can be affected by a variety of factors, Hattie (2003) argues the educational research community should focus on the greatest source of variance that can make a difference to learning in class – the teacher – if findings are to inform more effective learning. Within the broad context of science education, researchers recognise the importance of teachers in supporting student learning with many turning their attention to the pivotal role of school teachers' professional knowledge for quality teaching (e.g., Shulman, 2001; Berliner, 2001; Magnusson et al., 1999). To characterise quality teaching, researchers conceptualised the necessary professional knowledge as the pedagogical content knowledge (PCK) of teachers (Baumert et al., 2010; Sadler et al., 2013). However, some researchers (e.g., Gess-Newsome et al., 2017) point out that while previous studies confirm positive links between PCK and effective teaching, they do not uncover developmental mechanisms related to PCK. A possible barrier to such research is the lack of a testable model for PCK, related to teaching practice, that could facilitate exploration of links between science teachers' PCK and practical teaching experiences.

In the Refined Consensus Model (RCM) of PCK Carlson et al. (2019) conceptualise practical teaching experiences as core to teachers' PCK. By recognising classroom teaching activities are opportunities for this unique form of teacher professional knowledge to be both manifested and generated, because teachers engage in pedagogical reasoning during the teaching cycle (plan-teach-reflect lessons), the RCM stresses the context-specificity and situated nature of PCK.

In this paper, it is our intention to explore links between PCK and practical teaching experiences in the context of science teacher education, notably the role of pedagogical reasoning, by using the RCM of PCK as a conceptual framework.

MODELLING PCK

PCK emerged as a particularly important construct for science teaching because it has the potential to characterise expert teachers' professional knowledge and skills and predict effective teaching (Baumert et al., 2010; Sadler et al., 2013). As a result, PCK has become a central component of many university-based science teacher education programmes (Gess-Newsome et al., 2017). Instruction featuring the nature of students' preconceptions, conceptual difficulties, instructional strategies, assessment, and curriculum was promoted to afford pre-service science teachers with opportunities to begin building relevant PCK for their profession (Park & Oliver, 2008).

However, modelling PCK in teacher education has proven difficult and has a diverse history (Gess-Newsome, 2015). Initially, Shulman (1987) viewed PCK as an amalgam of two forms of knowledge i.e., content knowledge (CK) and pedagogical knowledge (PK). To Shulman, PCK was a distinct and new form of knowledge transformed from CK and PK, and soon others began developing more elaborate conceptual frameworks for PCK (e.g., Grossman, 1990; Magnusson et al., 1999; Park & Oliver, 2008). Unfortunately, rather than clarifying research directions, it is possible that these different schools of thought about the nature (and development) of PCK in science education began hampering progress in the field, and in time led to calls for consensus around the conceptualisation of PCK (Abell, 2008).

In 2016, based on the earlier work of Gess-Newsome et al. (2015), Carlson et al. (2019) repositioned PCK in a new model of teachers' professional knowledge for teaching science. Building on the existing PCK components of earlier models, the Refined Consensus Model (RCM) for teaching science (Carlson et al., 2019) introduces three differentiated realms of PCK that inform understanding of potential sources and/or mechanisms for the development of science teachers' PCK. These realms include collective PCK (cPCK), personal PCK (pPCK), and enacted PCK (ePCK). According to the RCM, cPCK exists within the larger science education communities that researchers and teachers belong to. Pre-service, as well as in-service, teachers become aware of cPCK through their immersion in the wider science education community during university-based teacher education and beyond, where they are exposed to and experience use of various curricular and teaching documents and resources and engage in interactions with other teaching professionals. They begin developing, amongst other forms of knowledge, a unique and personal form of PCK termed pPCK, which over time is increasingly informed by the teachers' experiences of classroom teaching. pPCK becomes a major intellectual resource that enables science teachers to think and perform as a teacher, both on explicit and tacit levels (Alonzo et al., 2019). In its centre, the RCM explains that during the act of teaching an individual teacher uses a process of pedagogical reasoning (involving decision-making) to manifest aspects of his/her pPCK as ePCK during the plan-teach-reflect (teaching) cycle (Alonzo et al., 2019). Therefore, teaching practice becomes a forum for knowledge exchange and PCK development, and pedagogical reasoning is the mechanism by which this exchange and development occurs. The RCM indicates that knowledge exchanges across the two realms can lead to changes in both pPCK and ePCK.

Delving into the central ePCK realm of the RCM, Alonzo et al. (2019) identify two distinct plan-teach-reflect cycles - a macro cycle focused on whole lesson planning, teaching and retrospective reflection; and a micro cycle within the teach phase of the macrocycle that features in-the-moment teaching decisions made during classroom instruction. In the micro cycle, ePCK guides interpretation (noticing and reflecting) of teaching situations that arise during the lesson and planning decisions and actions in response to those moments. Using these cycles, Alonso et al. (2019) argue that ePCK is related to a teacher's planning (ePCKp), teaching (ePCKt), and reflecting (ePCKr).

The RCM anticipates that ePCK is linked to pPCK in complex ways and testable inferences can be drawn about these links. Practical teaching experiences (e.g., during university-based teacher education programs) are important means of individual PCK development (Grossman et al., 2009; Alonzo et al., 2019) since teaching practice requires pedagogical reasoning to enact PCK and reflect upon those experiences (Loughran, 2019). Thus, these interactions between pPCK and ePCK constitute a link between a teacher's teaching experiences and her/his PCK development that is accessible to research. However, there are presently no conclusive overviews on the actual developmental mechanisms between PCK and teaching practice that have been studied in the science education literature (Gess-Newsome et al., 2017; Aydin et al., 2013).

This present study focuses on the interaction of ePCK and pPCK to refine and elucidate our understanding of links between PCK and teaching practice, and to flesh out the anticipated links in the RCM. It carries out a closer inspection of teaching practice and developmental mechanisms by presenting a systematic literature review of studies that investigated, in some form or another, links between PCK and teaching practice.

RESEARCH QUESTIONS

Based on the findings of Chan and Hume (2019), this study explores in greater depth how PCK and teachers' professional practice potentially interact. First, this study summarises two aspects of the reviewed studies to evaluate the representativeness of the review and to give an overview of the dissemination of theoretical PCK models.

(1) What is the research context of the studies (research foci, methods, framework)?

Second, the study addresses two further research questions to identify features of the interplay between science teachers' PCK and teaching practice. RQ 2 remains within the conceptual framework of the RCM, while RQ 3 ventures an exploratory look 'outside' the framework and attempts to relate these findings back to the RCM.

(2) What role did teaching experience (pPCK) and teachers' pedagogical reasoning in the teaching cycle (ePCK) play in promoting PCK development?

(3) What effects of interplay between PCK and teaching practice did researchers discuss and how do they relate to knowledge exchanges between the realms of pPCK and ePCK?

METHOD

To search the field of science teacher education for studies related to PCK and teaching practice, a systematic literature review following the approach taken by Bennett et al. (2007) was conducted. First, keyword searches in research databases (e.g., ERIC, PsychINFO, web of science) were implemented according to the goals of this study, using the search terms 'PCK', 'practice', 'pedagogical reasoning', 'STEM', and the STEM subjects to retrieve an exhaustive list of potentially relevant studies. The identification of suitable articles included peer-reviewed research articles for science teachers' PCK from 1986, when PCK was first conceptualised, to the end of 2018. Using standardised quality criteria, all studies were screened by reading the titles and abstracts.

To analyse the RQs in relation to the theoretical framework of the RCM, all studies were processed in a procedure that involved: (1) Identifying relevant segments in the abstract and full text of the papers. (2) Coding (inductive and/or deductive coding) by a first rater who was well acquainted with the RCM (first author). This rater developed a coding manual comprising categories and definitions for the categories. (3) Recoding subsets of the studies by an independent second rater (third author), which was done on the basis of the developed coding manual. (4) Calculating interrater agreement as a measure of interrater agreement that is corrected for chance (Cohen's κ).

RESULTS

Evaluating Method

The initial search yielded N=881 articles (212 ERIC, 94 PsycInfo, 525 WoS, and 50 peDocs). The abstracts of all these articles were read to identify the included articles, which resulted in a total of N=246 studies for the review. In the screening phase that followed, the remaining articles were read in detail and N=97 studies were selected for inclusion in the final systematic literature review. The interrater agreements for all RQs can be considered substantial or better (Landis & Koch, 1977) (Interrater Reliability: $\kappa_{[RQ1]}$=.95 | $\kappa_{[RQ2]}$=.91 | $\kappa_{[RQ3]}$=. 79).

Framework of studies (RQ1)

The included studies were conducted in multiple countries across six continents. Pre-service teachers, novice teachers and experienced teachers with more than five years of teaching experience were subjects in the selected studies. The majority of the studies used experienced teachers to study PCK in relation to teaching practice (N=42), followed by pre-service teachers (N=14). Amongst grade levels, most data were collected from secondary school teachers (N=55). In 12 studies, both primary and secondary school teachers were examined. Sample sizes of N=1 to N=118 were present in the study selection, but only 4.1% of the studies had a sample size of more than 100 teachers, while 76.3% had less than 10 participants. Most studies involved science teachers (N=30), followed by chemistry (N=27), biology (N=22), mathematics (N=16), physics (N=15), elementary science (N=4), and earth science (N=4) teachers. Space science, engineering, and science and technology were the least studied subject domain in the studies (N=1 each). N=17 studies used one single type of data source, N=21 used two types, N=33 used three types, and N=26 used four or more types of data sources. Predominantly qualitative methods were used.

In line with Chan and Hume (2019), the analysed studies were divided into two groups, one comprising studies that conceptualised PCK using integrative PCK models and the other using transformative models of PCK. The first group (N=9; 9.3%) considered PCK to be an integration of different knowledge categories, while the second group (N=88; 90.7%) conceptualised PCK as an independent and unique knowledge category resulting from a transformation of other knowledge forms. Almost a third (N=30) of the second group who viewed PCK as a transformed knowledge form used the Magnusson et al. (1999) PCK model and its five unique components as a conceptual framework to guide their studies. N=36 studies were identified that did not refer to any PCK conceptualisation, whether integrative or transformative.

Role of personal PCK and enacted PCK in promoting PCK development (RQ2)

In order to summarise interactions regarding past teaching experience and pedagogical reasoning during teaching, we looked in the reviewed studies for evidence of teachers' reasoning related to decision making while planning, teaching, or reflecting on/during actual lessons. We found no study in this review examined teacher's pedagogical reasoning explicitly – those studies that did discuss reasoning referred exclusively to students' reasoning rather than that of teachers. Therefore, therefore the review yielded little information about interactions between pPCK and pedagogical reasoning while teaching.

To investigate links in the literature between PCK development and teaching experiences in greater depth, we used the RCM conceptualisation of the teaching cycle (comprising the macro and micro cycles) as an analytical framework for interpreting how the reviewed studies investigated ePCK. This approach allowed us to account for most concepts in the plan-teach-reflect cycle that were investigated in the reviewed studies and how these concepts were investigated in relation to the macro and/or micro cycles. Most of the studies focused on the entire teaching cycle, although researchers examined the cycle in different ways. N=63 studies refer to at least one part of the macro cycle. In authentic classroom situations, only N=18 studies attempted to draw (or infer) conclusions about teachers' reasoning on the micro level (all on the teach part of the cycle), while N=17 of which appeared to use at least one reference to the macro level. On the micro level, only planning and reflecting were analysed in simulated situations. As a means of exploring in what ways researchers attempted to capture the teaching cycle parts via data gathering approaches, we crossed the teaching cycles with the methods used (from RQ1).

As already identified in RQ1, the majority of the studies uses qualitative methods of data collection. With the exception of lesson planning (N=41) and written reflections (N=22), which capture important dimensions of the teachers' pedagogical reasoning, the studies use methods that attempt to capture the teaching cycle on a macro level (semi-structured interview, that is: N=70; classroom observation: N=48; or reflective stimulated recall interviews: N=13). On a micro level, planning and reflecting were only analysed in simulated situations, whereas teachers' micro ePCKt was examined and analysed in real classroom situations and more frequently than micro ePCKp and ePCKr. At least N=23 of the N=84 studies on macro ePCKr were concerned with drawing conclusions about the micro ePCKt. Appropriate conceptual tools for capturing teachers' pedagogical reasoning during the teaching cycles seem to be Content Representations (CoRes) for macro planning, Pedagogical and Professional-experience Repertoires (PaP-eRs) for reflection during classroom observations or interviews during guided macro reflection. Stimulated Recall Interviews seem to be beneficial to capture parts of the micro teaching cycle.

In summary, all studies showed that more experienced teachers with more developed pPCK performed better in PCK tests and also better during classroom practice (plan-teach-reflect). In addition, methods for measuring PCK and PCK development seem to be well elaborated for small samples. However, in studies investigating PCK development it is mostly explicit learning opportunities (e.g., workshops, interventions, internships) or teachers' experiences that are taken into account, and those concerned with PCK development as a result of pedagogical considerations in the plan-teach-reflect cycle on a micro or macro level are rare.

Interplay of PCK components and practice (RQ3)

Figure 1 displays a summary of the effects of interplay between PCK and teaching practice, as discussed by at least two studies. All concepts (terms) in the research context of PCK and teaching practice were organised into four groups for clarity. (1) PCK components - not specified whether integrative or transformative, (2) PCK levels within the RCM, (3) pedagogical reasoning as it relates to the teaching cycle, and (4) other concepts discussed in studies that are not specifically related to PCK. If implications, in the sense of cause and effect or if-then statements, were discussed in the studies, then these relationships were illustrated in Figure 1 using arrows.

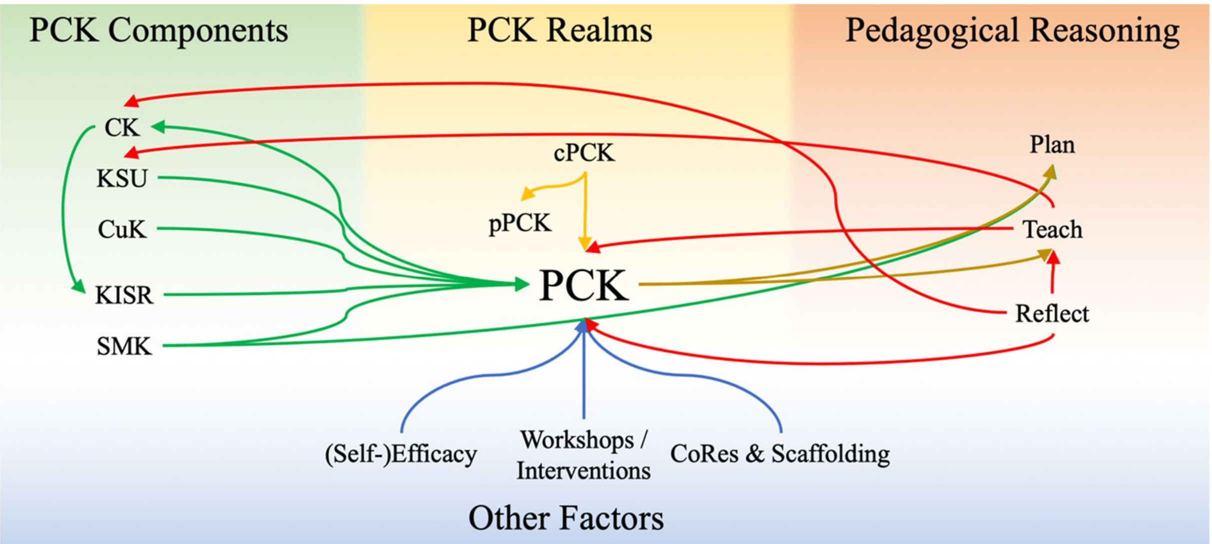

Figure 1. Map of discussed effects in the field of science teachers' PCK and their teaching practice.

In the N=97 studies dealing with PCK and teaching practice, N=11 studies directly identify effects of PCK (components) on teaching practice. Of those studies, N=6 studies (e.g., Demirdöğen et al., 2016) found that PCK (in generic terms) has a positive effect on aspects of teaching practice, while in the other N=5 further studies specific PCK components were found to have positive effects on teaching practice (e.g., Boesdorfer & Lorsbach, 2014). For teaching in a classroom situation, SMK/CK is considered essential by N=2 studies (e.g., Friedrichsen et al., 2009).

Teaching in class is often (N=12 studies) identified as facilitating development of PCK components (e.g., van Driel et al., 2002). A substantial proportion of the studies (N=11, and N=10, respectively) found reflection (e.g., Park & Oliver, 2008) and workshops and interventions (e.g., Nilsson & Vikstrom, 2015) resulted in positive effects on various PCK components. N=22 studies found teachers' interaction with the education community and/or colleagues (cPCK) as another aspect of practice that had positive effects on PCK.

Since a total of 112 positive effects on PCK and PCK development could be identified in 97 studies, it can be summarised that more pronounced or better networking of PCK components by teachers in their practice seem to have a greater impact on science teachers' PCK and its development.

DISCUSSION

This study sought to characterise and synthesise research featuring science teachers' PCK and their teaching practice to advance our understanding of the development of applicable and situation-adequate PCK. We were able to identify that no consistent PCK model is used across the studies even if most used scaffolds (e.g., Magnusson et al.,1999; Park & Oliver, 2008) might be conceptualized with the help of the RCM of PCK. Our findings indicate that existing studies related to PCK and teaching practice used predominantly qualitative methods for analysing the relationships between PCK and teaching practice. Many researchers engage in data triangulation to grasp these complex constructs such as PCK and teaching practice.

We argue the findings from this review suggests the RCM of PCK acknowledges and facilitates research that addresses the networking of PCK components in classroom teaching, since it explicitly links PCK and teaching practice by depicting the teaching cycles (plan-teach-reflect) and pedagogical reasoning at its core as classroom manifestations and/or generators of PCK. Using the RCM as a guide, this study identified that all reviewed studies attended to at least one aspect of the teaching cycle in their research of PCK and teaching practice. In addition, particular means of linking PCK and practice were found using research tools that focus on PCK in the planning, teaching, or reflecting aspects of the cycle. Data collection tools were often used that attempted to elaborate rationales for teachers' actions, resulting in aspects of the teaching cycle being addressed in different ways. It is notable that imbalances exist between studies investigating realistic and simulated teaching situations on the one hand and the micro and macro teaching cycles on the other. Most realistic teaching studies refer to a macro level of the teaching cycle, while the few studies that refer to a micro level typically investigated simulated situations (e.g., in stimulated recall interviews). In summary, these findings show that teachers' past experience and teaching actions (pPCK and ePCK) and pedagogical reasoning do appear to be closely interwoven and interconnected. We argue these findings suggest the interplay of networked PCK components with teachers' practical actions represents teachers' pedagogical reasoning as it manifests in teaching cycles.

The analysis of the discussed effects of interactions between PCK and practice indicates that there is agreement in the literature that pronounced or rich PCK (e.g., teachers who scored highly in PCK measurement) or (networked) PCK components (e.g., teachers who scored highly in CK, PK, and/or KSU performance-tests or showed multiple interacting knowledge bases in interviews) are beneficial for effective teaching practice (based on verifiable evidence from sources such as classroom artefacts, students interviews, or observations). Furthermore, teachers' self-influencing factors (e.g., their interaction with the science education community and/or their pedagogical reasoning) seem to be as effective for PCK and PCK development as external factors (e.g., workshops/ interventions). Based on these findings, it might be worthwhile to investigate science teachers' PCK development from a community of practice (CoP) perspective (as discussed for example by Polizzi et al., 2016) when considering the role of teacher connectedness to their professional community. Analyses regarding RQ3 suggest that the implications of findings from the reviewed studies are multidimensional. Broad implications (like the positive effects of well-developed PCK components on PCK and teaching practice) are more often discussed, while specific or consistent implications are only indirectly considered as part of comprehensive effects.

IMPLICATIONS AND FUTURE DIRECTIONS

The RCM of PCK provides a suitable lens for the investigation of the more concrete relationships that are implied from this investigation of the interplay between PCK and practice. Two groups of influences on PCK arising from teaching practice can be identified: first, teachers' interactions and participation in their teaching community and second, self-influencing factors that are independent of his/her professional community and only affect a single teacher. In sum, many of the reviewed studies argue that PCK is strengthened by teaching practice through (1) one's own planning, teaching, and reflection that is activated and sustained by pedagogical reasoning, and (2) interactions with colleagues and community. It remains to be evaluated which PCK components, if any, are most closely related to classroom performance.

Limitations to our findings arise from the conceptual ambiguity associated with PCK in the literature and teaching practice. Research on teacher beliefs and motivational constructs might present further important insights into effective professional development programs that foster relevant competencies for teachers. To deepen understanding of the relationship between PCK and practice, we recommend that PCK components and realms (as in the RCM) need to be investigated in relation to each other, with due consideration given to amplifiers and filters and the role of pedagogical reasoning in knowledge exchanges with and between realms of PCK. This review also revealed that, as in most PCK and practice research, there is a lack of quantitative research (Wilson et al., 2019), which may provide more evidence of tangible links and estimates of effects size to enhance qualitative links. In addition, established refined methods may allow an examination of PCK development in relation to pedagogical reasoning. Focused and quantitatively verifiable analyses of the interrelationships between the individual components are needed to strengthen understanding, and a unified framework model of PCK (like the RCM) would be very helpful for this.

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THREE DIMENSIONS OF INQUIRY IN PHYSICS EDUCATION

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It is well established that many challenges need to be considered to address student interest and participation in science. While all of the science disciplines face challenges engaging students, it is particularly pronounced in the physics context for a multitude of reasons including shortages of qualified physics teachers, unconscious biases and perceptions of being difficult, to name just a few. Students often consider physics as irrelevant and are not motivated to study at upper secondary or tertiary level. However, physicists view physics as the fundamental discipline for further studies in science and technology and consider physics education as critical to empowering individuals and societies to thrive in our ever-changing complex world. This paper discusses the key findings of the Three Dimensions of Inquiry in Physics Education (3DIPhE) project which involved seven partner organizations and over one hundred in-service teachers of physics from four European countries (Slovenia, Belgium, Ireland and Poland). This paper discusses the key findings from three inquiry levels considered in this project, namely:

- *Inquiry Based Learning approaches to support student learning in physics,*
- *Practitioner inquiry of teachers inquiring into their classroom practices,*
- *Inquiry processes in collaborative professional learning communities of teachers*

Keywords: Inquiry Based Learning, Practitioner Inquiry, Professional Learning Community

INTRODUCTION

The modern world is increasingly dependent on exact, natural and technical sciences, thus there is a growing need to attract people who would associate their future and professional career with the development of these areas of life. One of the eight key areas of competence indicated in EU Key Competences (2018) is to provide basic education in natural and exact sciences. Since these are areas closely related to experience and practical work, special emphasis should be put on developing practical research skills, basing teaching on experiments and specific references to everyday life in motivating and teaching them. The benefits of using innovative learning and teaching approaches to enhance student learning in science are significant – students develop their conceptual understanding alongside developing the key skills and competences they need to live and thrive in our complex society. Such approaches serve to influence student's attitudes towards science and increase their appreciation of the value of science in society. Inquiry based learning (IBL) is an approach to learning and teaching physics that is gaining popularity, as it has proven the efficiency in gaining new knowledge, comprehension as well as retention (Sokolowska, 2018). Despite decades of dissemination of the IBL method, it is still not very representative during the science lessons, because, among others, teachers are not particularly convinced of its effectiveness and feasibility of using it in a school time-and-space regimen. To encourage teachers to implement the IBL method, the 3DIPhE project proposed a new strategy for IBL workshops to support teachers developing their IBL teaching skills and giving teachers a deep insight into the spirit of the method.

There is a widespread consensus that for teacher professional learning to be successful it needs to take place over an extended period of time, needs to be valued by teachers and should focus on the learning needs of their students. The Three Dimensions of Inquiry in Physics Education (3DIPhE, 2017-2020) project adopted a "generalistic" approach. The inquiry learning approach was extended to other dimensions, from students to teachers that formed professional learning communities of teachers (PLCT), and to teachers' coaches also called facilitators. The general framework of the scientific method, from formulation of the problem, designing the inquiry approach, collecting evidence, drawing conclusions, and presenting results was adopted and slightly adapted to practitioner inquiry (PI) of teachers and to practitioner inquiry of coaches. However, while the approach was generalized to different dimensions, the focus remained the IBL in physics education, that was, physics teachers inquired their IBL classes, and coaches focused on IBL in physics and PIs connected to it in PLCTs. Finally, an overarching concept of inquiry was applied in educational design research that inquired the processes across the project. The project 3DIPhE was active from September 2017 until August 2020 and involved seven partners from Slovenia, Belgium, Ireland and Poland who met regularly for more than two years with physics teachers from different schools in PLCTs, co-created many IBL units with them, developed protocols for supporting formulations of inquiry questions, collecting evidence, drawing conclusions, but also to support an open and friendly atmosphere in these PLCTs. The key learning and findings from the 3DIPhE project are shared in an e-book with four volumes (De Lange, 2020; Lovatt, Grimes & McLoughlin, 2020, Peeters, 2020; Sokołowska, 2020). The findings of the 3DIPhE project across three different inquiry levels in physics education are discussed in the following sections, namely:

- Inquiry by students who use the inquiry-based learning (IBL) approach to learning physics.
- Practitioner Inquiry (PI) of teachers inquiring the processes in their classroom.
- Inquiry processes in professional learning communities of teachers (PLCTs)

METHODOLOGY

Given the complex nature of the 3DIPhE project, Educational Design Research (EDR) was selected as the methodology used to inform, structure and elicit learnings across and between all inquiry levels (Lovatt, Grimes & McLoughlin, 2020). EDR, stemming from the 'family' of design research, addresses educational problems in real-world settings. It is a problem-oriented approach that focuses on reflection and cycles in order to achieve the most efficient solution (McKenney and Reeves, 2019). EDR is the act of interacting systematically with the subject of study and taking the learnings from that to improve practice. EDR has two primary goals, developing knowledge and developing solutions. Like other research approaches, it aims to develop scientific knowledge, but it also strives to develop interventions in practice. EDR extends theoretical knowledge through data collection and analysis embedded in the cyclic development of a solution to the problem being tackled. The nature of these solutions can be educational products, processes, programs or policies. While there are several definitions and descriptions of EDR, there is common agreement on the essential aspects, and common features appear in both the descriptions of design research, design-based research and educational design research. Plomp's (2013) description of EDR as "...the systematic study of designing, developing and evaluating educational interventions as solutions for complex problems in educational practice, which also aims at advancing our knowledge about the characteristics of these interventions and the processes of designing and developing them" succinctly describes the key ideas that most descriptions of EDR are based upon.

INQUIRY BASED LEARNING TO ENHANCE PHYSICS EDUCATION

IBL is an active learning method in which students, in order to develop knowledge or find solutions (e.g. to discover trends, measure quantities of objects or quantities related to phenomena, find out the limits etc.), follow a scientific method used by researchers in science studies, reflected in the IBL cycle (Figure 1). IBL emphasizes the students' role in the learning process in which they are encouraged to explore the scientific issues, ask questions, and share ideas. Instead of memorizing facts and rules students discover them by doing. Unlike traditional teaching, inquiry-based learning is student-centred, consequently leading students to gain more and more independence in learning. The teacher's role is to support students in their learning process, and not to reply solely on direct instruction. Redefinition of the teacher's role in the IBL requires a new strategy for teacher education, both pre-service and in-service. Teachers need to gain new skills through active engagement in the IBL process, both as learners and facilitators of the learning. Such a two-side perspective makes the teachers enter into the spirit of the method, makes them aware of subtle details of implementation and enables them to perceive the benefits of this learning approach. In order to encourage teachers to implement the IBL in their daily practice, it is necessary to show them examples of good practice and evidence provided by other practitioners, as well as collected from the literature about the benefits for students' learning outcomes (Sokołowska, 2018), opportunities for development of interest, motivation and positive attitudes towards science careers (e.g. Kanter& Konstantopoulos, 2010), as well as chances to achieve better results by students usually doing poorly in science (e.g. Marx et al., 2004).

During 3DIPhE workshops with in-service teachers the IBL method was introduced first by sharing 'good' IBL examples collected from coaches and other teachers as members of PLCTs. By implementing the examples in their own classes, teachers could practice the IBL method principles, develop their positive attitude towards the IBL and their self-confidence in conducting the IBL cycle (Figure 1) in an accurate manner (Sokołowska, 2020). Following these examples, the teachers could adapt the existing IBL materials to the specific curricula or the needs of their students. However, such a path enabled teachers, in a sense, to come only halfway to developing their sense of ownership in teaching the IBL. To master their competences in the IBL method teachers needed to experience the IBL spirit in a more rigorous, deepened approach to the method. They needed to start to create the IBL material by themselves from scratch. However, they were not left alone in this process, since that might result in many doubts, early-stage discouragement and dropping the demanding IBL method. Such an opportunity of a group work arose in PLCTs, where teachers were supported by other teachers, making the same journey of developing the IBL teaching skills.

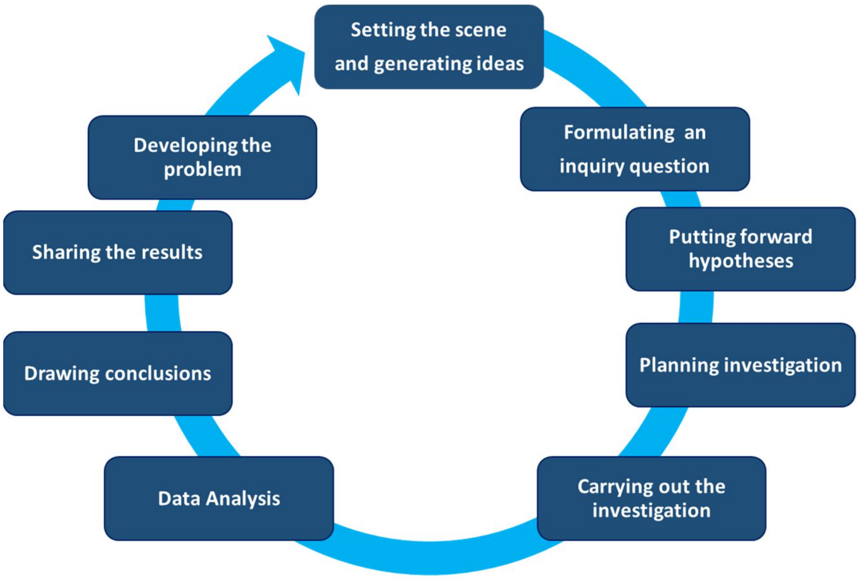

Figure 1. Inquiry Based Learning Cycle (Sokołowska, 2020).

Two approaches to introducing and developing teacher's IBL teaching skills were adopted. The first was intended for teachers with very little or no experience in teaching through IBL. For them the introduction to the IBL method was necessary, based on a sequence of intensive activities in exploring existing IBL materials. During a few workshop meetings teachers took on the roles of students and experience the IBL activities, following the material introduced by the coach. Subsequently, some teachers started the second sequence of workshops in an advanced format. Preferably, teachers started their pilot implementations of the IBL method in their classes somewhere between the first, introductory part of the course and the second, advanced part. In such a way they gained experience from two perspectives, which was beneficial for their development when they started workshops at the advanced level. Teachers already experienced in the IBL method might deepen their practice by participating from the beginning in the advanced part.

During the advanced sequence of workshops teachers took part in two types of activities. They continued their experience of the ready-to-use IBL learning units during the workshops when they again took on the roles of students. At the same time, during each meeting they also participated in workshops, in which they practiced one IBL teaching skill at a time ((1) Brainstorming, (2) Formulating a research question, (3) Design of the learning unit plan, (4) Design of IBL assessment tools), playing alternately the roles of teachers - unit designers and the roles of students. During the last meeting of each sequence of the course on developing the IBL teaching skills, PLCT members were also asked to reflect individually on their IBL practice in their own classes. For that the Self-reflection Tool for Teachers, designed in the Fibonacci project (Carulla, 2012) was used.

PRACTITIONER INQUIRY IN PHYSICS TEACHER EDUCATION

Teachers are continuously faced with many challenges that impact their teaching. However, finding out systematically what works in one's professional practice is often not regarded as part of a teacher's role. Teachers must be facilitated and encouraged to develop an inquiry stance about their own teaching practice. Their inquiry is about their profession, their practice, their daily work with students. This inquiry leads to a lot of learning for teachers and is referred to as 'practitioner inquiry'. Practitioner Inquiry (PI) is a form of professional learning defined as the systematic intentional study by teachers on their own practice (Cochran-Smith, 1993). The teachers (practitioners) engage in systematic reflection and act for change by asking questions ("wonderings"), gathering data to explore their inquiries, analysing the data, making evidence-informed changes in their practice, and sharing their learnings with others (Dana and Yendol-Hoppey, 2014).

During the 3DIPhE project the partners recognized several 'stages' during a PI cycle, as illustrated in Figure 2 (De Lange, 2020). However, it is important to consider this inquiry cycle not as a linear process but more as an ongoing process that must be used in a flexible way depending on teachers' needs. Conducting a PI can be done by an individual teacher. However, there is a lot of evidence that the process of improving of students' learning has the most impact if it is carried out as part of a collaboration.

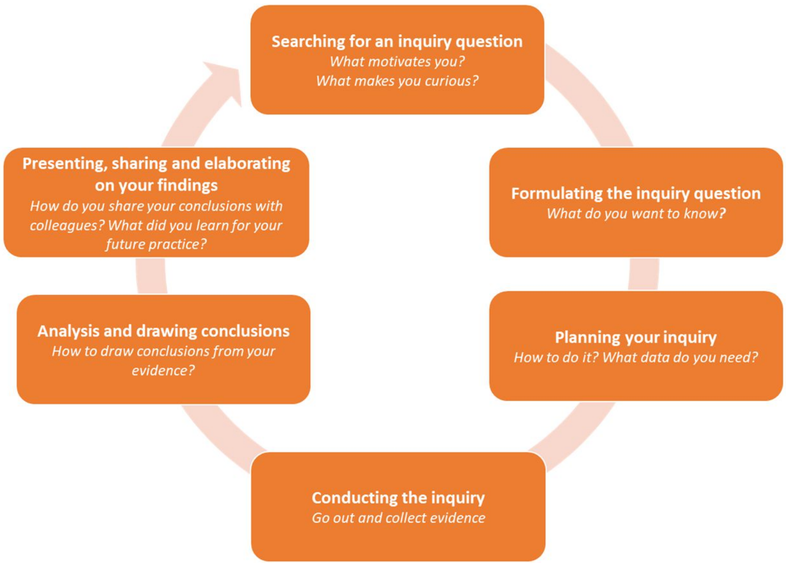

Figure 2. Practitioner inquiry cycle adopted in 3DIPhE project (De Lange, 2020).

In the 3DIPhE project, several groups of teachers worked in professional learning communities of teachers (PLCTs) on a topic/question that is related to IBL in class. Both the teacher (through PI) and student (through IBL) use very similar skills like generating ideas, asking questions, developing hypotheses, planning inquiries, gathering data and evidence, analysing, and making conclusions, working collaboratively and presenting/sharing/elaborating results. In the 3DIPhE experience, these two dimensions of inquiry, IBL and PI, reinforce each other by conducting PI in the context of IBL. Though it is not a necessity, the project partners experienced an added value of bringing the two together. By making PI more specific in the context of IBL, you give teachers direction and focus and, at the same time, amplify their teaching methodology of IBL.

The 3DIPhE project designed a professional development course for teachers that incorporates the six stages of the PI cycle and course implementation is structured around this PI cycle (Peeters 2020). How long a stage will take and what the exact actions are for each stage will depend on context and organization. However, there are some shared learnings that are essential, and form the design principles for the 3DIPhE course. Every stage should incorporate the following aspects

- Building a professional learning community
- Facilitating Practitioner Inquiry
- Promoting Inquiry Based Learning
- Reflection

FACILITATING REFLECTIVE LEARNING: BUILDING PROFESSIONAL LEARNING COMMUNITIES

Dana and Yendol-Hoppey (2019) defines a professional learning community as "a group of teaching professionals who meet regularly to learn from practice through structured dialogue and engage in continuous cycles of inquiry". The last part of this description refers to evidence the teachers need to provide for their learnings. Hord (1997) defines these as "... a place where teachers inquire together into how to improve their practices in areas of importance to them, and then implement what they learned to make it happen". This teacher learning is only valuable if their students show improved results. Both ideas taken together is proven to be extremely powerful, as shown by the Hattie ranking of "252 Influences and effect sizes related to student achievement", in which the newly studied influence "Collective teacher efficacy" was ranked at number one (Hattie, 2017). The pursuit to become a better teacher is indeed a lot more interesting, more motivating, richer, more sustainable, and more efficient if this takes place in a group of peers: other teachers, colleagues that share this ambition. If in each context a group of teachers has this insight, they can become a PLCT and have a lot of professional fun.

In the 3DIPhE project PLCT's were established (built) as a strategy to valorise and improve all learnings of all members of the PLCT. These members were in general physics teachers that were motivated to complete their own PI. 3DIPhE project partners, being experts in physics and STEM education, were guided in building PLCT's of groups of teachers according to a structured strategy. Using the framework of educational design research all learnings of facilitators of PLCT's have been collected, discussed, and captured and eventually led to the development of a course on how to coach a PLCT of physics teachers.

Focusing on the facilitator's role, some key learnings reported by the 3DIPhE partners for designing PLCTs are:

- The facilitator must have an open mind and even prepared to stretch some ideas
- The facilitator has a leading role: the PLCT facilitator is a central person in the community. They plan and organises the workshop. An effective facilitator will be able to use different styles when needed and has the capacity adapt and engage all to be a real leader. Some of the characteristics of such a leader: they can inspire the PLCT members, they can motivate, they have a vision on the effectiveness of working in

PLCTs, they can take decisions, they can discuss, argue, negotiate, find solutions, compromise between members of the PLCT, etc.

- The facilitator is engaged on the content and on the process.
- Facilitators should have good social skills like communication, creativity, positive thinking, high expectations, they should feel and pick up the team spirit within the PLCT and act accordingly, supportive, and at the same time truthful, providing quality feedback even when things do not evolve as desired, emphatic, paying attention to all members, remain focused on the goals of the group, and many more.
- One of the main competences of the facilitator in a PLCT is to make a planning for the entire inquiry cycle, for example, a whole school year: what is the main focus of the different workshops during a year, the timing, keep up motivation and speed.

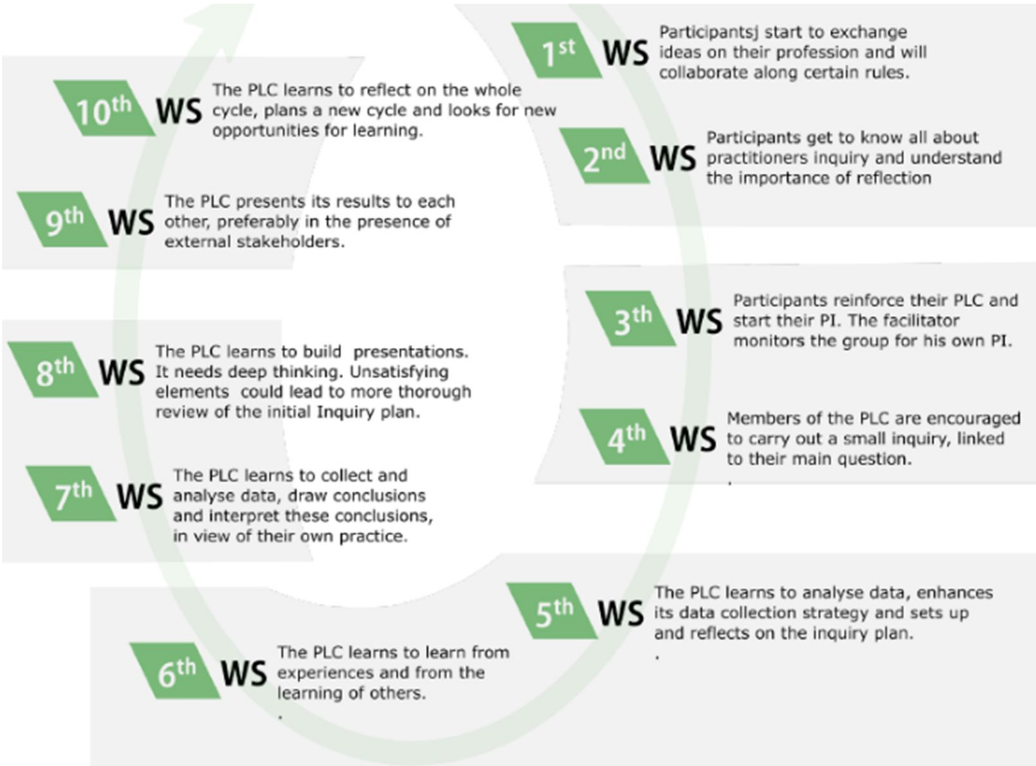

Figure 3. 3DIPhE guide for organizing ten PLCT workshops (Peeters, 2020).

These key learnings from the 3DIPhE experiences of organizing PLCTs have been used to prepare a guide for organizing a series workshops by a competent facilitator, e.g. an example with a series of ten workshops is illustrated in Figure 3 (*Peeters, 2020).* Prior to the first workshop, the purpose and organisation of the PLCT were considered, i.e., context, strategies to motivate, practical issues, all ideas that were needed to not only start with a PLCT, but also to guarantee its success. Then for all planning all subsequent workshops, "Why", "How" and "What" questions were considered in detail, often enriched by several alternative approaches and experiences expressed by 3DIPhE partners. The "Why" question was often inspired by the teacher's motivation and determination to have achieve better students learning. The "How" question very often referred to strategies that enhance collaboration, reflection and dialogue among members of the PLCT, through so-called protocols. The "What" question is highly determined by the phase of the sequence, the teachers' input and needs and feedback and reflections. Throughout the whole sequence, guidelines were also provided to inform the facilitator conducting their own PI.

DISCUSSION AND CONCLUSIONS

The project 3DIPhE was active from September 2017 until August 2020 and involved seven partners from Belgium, Ireland, Poland, and Slovenia, who met regularly for more than two years with physics teachers from different schools in PLCTs, co-created many IBL units with them, developed protocols for supporting teacher carrying out their own PI as part of a local PLCT. Two dimensions of inquiry (PI and IBL) were linked but additional learnings were derived from a third dimension of inquiry considered in this project, namely examining inquiry processes in professional learning communities of teachers. During the project, over one hundred in-service teachers of physics and indirectly over one thousand students taught by these teachers from across these countries participated in this study. The overall learnings and recommendations of the 3DIPhE project were derived from a synthesis of each project partners' evaluation of their second iteration of PLCTs as well as partner's responses to a final survey.

While there were cultural and structural differences in the partner countries regarding education systems and models of professional learning, there were many common challenges faced by teachers which included: limited access to equipment for doing experiments in the school; limited time to prepare experiments before the lesson; an overloaded curriculum and lack of student motivation. The structure of the workshops in each country was different as they were designed around the availability and needs of the teachers. In some cases, teachers attended during their holidays, at weekends or directly after a full day teaching. In some contexts, regular short workshops were held while in others spaced out full day workshops were used and in others clustered full day workshops were provided.

A core goal of the 3DIPhE project was to promote the sustainable use of IBL in the classroom and the usability and sustainability of teacher education resources and programmes developed through previous projects. While many educational projects have a significant short-term impact, they fail to create a sustainable change in teacher's classroom practice. Increasing teacher's motivation is expected to have a long-lasting sustainable impact on their classroom practice (Timperley, 2011). Therefore, the approach adopted by the 3DIPhE project to influence teacher's motivation to use inquiry approaches was to support teacher's working as a PLCT to carry out their own PI (Timperley et al. 2007, Dana and Yendol-Hoppey, 2014).

During the project, six teachers went through two sequences of the workshops on development of the IBL teaching skills. Nevertheless, observations of these teachers during the IBL workshops and their opinions expressed in focus group discussions revealed that the format of a two-stage and two-sided approach gave them a much better insight into the IBL method and gave them much more self-confidence in using the method than the traditional approaches of learning the IBL only by following the-ready-to-use materials. Even teachers, who initially thought they had some experience in IBL implementation in their own classes, admitted that they really appreciated the revealing idea of going step by step throughout the entire IBL cycle using a series of protocols developing skills in teaching by inquiry. Teachers emphasized a great role of the interaction with other PLCT members on self-reflection on their own materials and development of a critical-friend attitude towards other teachers' work. We believe that the format of the IBL courses for teachers proposed in the 3DIPhE project not only serves the development of the IBL teaching skills, but also gives the deep insight into the spirit of this method.

Without effecting the teachers' ownership (which is very important in PI), the partners identified it was important to promote IBL in an indirect way during a PLCT. This can be done though using appropriate examples of IBL as inspirations, and discussing problems faced by teachers while implementing IBL and how they feel when using IBL in class. In this way, teachers become motivated to choose IBL related inquiries themselves. This steering towards IBL should be carried out systematically. Other suggestions include modifying existing protocols from previous PI experiences, discussing IBL principles on regular basis with PLCT members and raining inquiry problems. Key learnings (which are called design principles) for the PI course were collated during two iterations of PLCTs across four countries, namely:

- All workshops incorporated the three pillars inquiry - fostering PLCTs, doing PIs and supporting use of IBL in the classroom
- Always keep in mind the learning of the students, so inquiry questions, data collection, … must be related to this goal (more specific IBL).
- the agenda and timeline must be structured and flexible.
- Don't overload workshops/course
- Small changes are the best.
- Share, extend and elaborate on key learnings and findings.

Inquiry for learning was the central focus of the 3DIPhE project and this inquiry happened at the student, teacher and partner levels. This paper presents the design and implementation of the 3DIPhE project, which was evaluated using an EDR approach over a three-year period. This approach allowed the project partners to systematically investigate how and where learning occurred throughout the project, in terms of

- IBL approach to students learning physics.
- PI by teachers inquiring into their classroom practice.
- Inquiry processes in a collaborative PLCT of teachers.

The key learnings and recommendations of the 3DIPhE project can be used to influence teacher's motivation to use inquiry approaches and support teacher sustained teacher professional learning and are openly shared in an e-book with four volumes (De Lange, 2020; Lovatt, Grimes & McLoughlin, 2020, Peeters, 2020; Sokołowska, 2020).

ACKNOWLEGMENTS

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UNDERSTANDING TEACHER IMPLEMENTATION OF BIOECONOMY ACTIVITIES THROUGH THE LENS OF EXPECTANCY VALUE THEORY

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Through a USDA funded grant, the Sustainable Bioeconomy Program, an interdisciplinary educational innovation was designed to stimulate high school students' career interest and to foster increased diversity in bioeconomy industries in the south-eastern US. This qualitative study investigated the motivations underlying teachers' decisions to implement the project's bioeconomy-focused lessons in their classrooms. Teachers' online course forum responses and post-course interviews were analyzed and coded using a priori task value constructs from Expectancy Value Theory to understand teachers' thinking about planned implementation and then their enactment of classroom lessons. After coding, teachers were put into high, medium and low enactment groups. Teachers with the lowest level of enactment expressed the highest cost and lowest percentage of utility for themselves. Teachers who had the highest level of lesson enactment described the highest level of the lessons' utility for students and the lowest level of cost to themselves. Teachers in the medium enactment group perceived the highest level of utility teacher and a medium level of cost. These preliminary findings suggest that higher lesson implementation is based on teachers' inherent interest, a focus on the value of the lessons for their students, and a reduced focus on the personal costs to themselves.

Keywords: Expectancy value theory, Teacher professional development, Bioeconomy

INTRODUCTION

Biobased product employment (excluding biofuels) grew 17% from 2014 to 2016 and contributed $459 billion to the U.S. economy (Golden et al., 2018). In conjunction with such growth, there is a need to develop the workforce in bioenergy, bioproducts, and the bioeconomy (EISA, 2007). However, STEM experiences can vary greatly between students; socio-economic factors, geographic region, racial background, and gender influence course persistence and future careers (Alegria & Branch, 2015; Andersen & Ward, 2014; Brown et al., 2016). Schools designated as high poverty tend to have fewer teachers who are certified in their content areas, fewer advanced courses offered in STEM subjects, and higher turnover than do wealthier schools (Darling-Hammond & Hammond, 2015). Rural schools also face geographic isolation and limited access to university-provided programs, equipment, and resources (Goodpaster et al., 2009).

THEORETICAL FRAMEWORK

The Expectancy Value Theory of Achievement Motivation (EVT; Eccles, 2009) demonstrates empirically how individual's expectancies, ability beliefs, and values directly affect their choices, performance, effort, and achievement. Other influences are socializers (e.g., parents, teachers) and one's interpretations of previous life experiences. This study uses one part of the framework, task value (Eccles & Wigfield, 1995), to understand teachers' thinking about the value they hold for the intervention activities. Task value has four major components: "attainment value, intrinsic value or interest, utility value, and cost" (p. 216). These task values were used to understand how teachers weighed the relative costs versus values when they decided whether and why to implement lessons or other materials from the teacher professional development project.

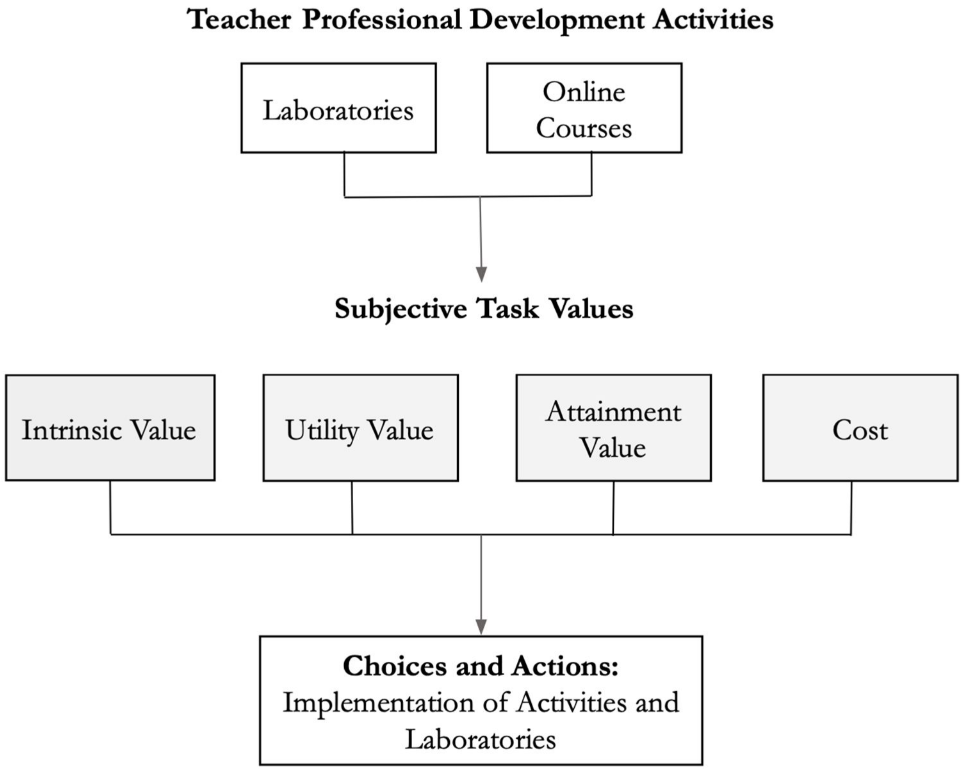

Figure 1. Teacher Professional Development Activities linked to Subjective Task Value Constructs.

RESEARCH QUESTIONS

1. How and to what extent did teachers implement what they learned into their practices?
2. How did teachers perceive the relative costs of the coursework and the classroom implementation aspects of the TPD and did these differ by implementation level?
3. What, if any, is the relationship between teachers' task values and their lesson enactment?

METHODS

Research Design

This qualitative pilot study (Creswell & Creswell, 2018) investigated the underlying reasons for teachers' decisions to implement project lessons in their classrooms, using task value constructs from EVT.

Context

The Sustainable Bioeconomy Program (all names are pseudonyms) was an interdisciplinary collaboration between a College of Education and a College of Natural Resources at a research university in the south-eastern US. Funded by the US Department of Agriculture, it was designed to stimulate high school students' career interest and to foster increased diversity in bioeconomy industries through an educational innovation. Twenty high school teachers from ten counties in Eastern North Carolina were originally selected to participate in 2-3 online graduate level bioeconomy courses and to gain experience with 17 bioeconomy laboratories and activities over a three-year period. Participation in summer workshops gave teachers hands-on experiences with laboratories and lessons, and they selected which labs they wanted to implement and were provided all of the needed equipment and supplies. These experiences and support provided teachers with the tools to provide their rural, diverse students in lower income high schools experiences with hands-on laboratories and to promote career pathways in the bioproducts and bioenergy industry.

Data Collection and Analysis

For this pilot study, 16 teachers were organized into implementation groups, which was blind to the coders. For the school year implementation, teachers were asked to enact at least two lessons with their students.

Teachers' post-course interviews and three class forum responses, totaling approximately 187 pages of double-spaced transcripts, were analyzed and coded using a priori task value constructs from Expectancy Value Theory. The construct of Utility value was split into two categories after beginning coding, to delineate whether the teacher viewed the course content as useful for their classes and/or their own career path (UT) or directly useful for their students (US). Teachers' expressions of interest and enjoyment in learning new content was coded as Intrinsic (I). Those which described appreciation of new knowledge as a citizen, confidence in doing the labs, or as positive for their rural/farmer community were coded as Attainment (A). Cost (C) was coded for instances when teachers expressed concerns about the time and effort required, student ability, or lack of confidence. In order to standardize the values, we converted the raw numbers into percentages by taking an individual's number of codes for UT, US, I, A, and C and dividing them by the total number coded for that individual. Every teacher's value and cost data were compared to their lesson enactment.

FINDINGS

How and to what extent teachers incorporated what they learned into their practices

The activities that teachers implemented were weighted as high effort activities and low effort activities. High effort activities included new labs or labs from the teacher professional development that they modified for their classrooms, teacher professional development activities, and bringing students on related field trips. These activities were multiplied by 2 for a weighted value. Lower effort activities included doing a related demo, related lab from previous year, using teacher professional development examples, curriculum night, and teacher conference participation. These activities were multiplied by 1. Weighted totals were calculated for teachers based on self-reported enactment from interview data. Implementation was categorized as Low (0-3), Medium (4-6), High (7+), as seen in Table 1.

Table 1. Teachers' weighted implementation.

Implementation	Participant	High Effort Activity (x2)	Low Effort Activity (x1)	Weighted Total
Low	111	0	0	0
Low	105	0	1	1
Low	120	1	0	2
Low	107	0	2	2
Low	106	1	1	3
Medium	114	2	0	4
Medium	118	2	0	4
Medium	103	3	0	6
Medium	112	3	0	6
Medium	110	3	0	6
High	115	5	0	10
High	104	4	2	10
High	117	5	1	11
High	121	5	1	11
High	102	6	0	12
High	113	7	2	16

From the analysis of the teachers' self-reported data, 5 teachers were classified at a low level of implementation, 5 teachers were classified as a medium level of implementation, and 6 teachers were identified at a high level of implementation. From the data, it was found that there were differences in which kind of labs and activities teachers used in the implementation groups. The Low group typically did no new labs and either used examples or added one activity to their current teaching practices. Teachers in the Medium group typically did 2 new labs and sometimes one new activity. The teachers in the High group most often did 2 new labs and also added 3 new class activities, as seen in Table 2.

Table 2. Lesson enactment type by teacher implementation group.

No. of Teachers	Lesson Enactment	High Effort Activities	Low Effort Activities
5	Low	33%	67%
5	Medium	100%	0%
6	High	84%	16%

How teachers perceived the relative costs of the coursework and the classroom implementation aspects of the TPD and whether they differed by implementation level

Costs were divided into Courses and Classroom implementation, and subcodes were assigned for each group, as seen in Table 3. All of the teachers expressed the most concerns (costs) related to the online courses. All of the teachers had the fewest concerns (costs) related to classroom implementation. The High implementation group expressed the fewest classroom implementation costs.

Table 3. Cost subcodes for Course and Classroom implementation.

Cost Sub-Codes	Example for Courses	Example for Implementation in Classroom
Curriculum issues	Not in curriculum; not relevant; not designed for their students	Wouldn't be able to use material from the online course in earth science.
Teacher Response – Content	Nothing new/novel; math was too hard; had been a while since I wrote a paper	Online course content was too heavy for students.
Teacher Response – Affective	Sometimes it was frustrating when I didn't get it.	Didn't like it.
Student Abilities	Too difficult for students.	Students lacked attention span; above their reading level; lack of student interest
Logistical – Teacher Professional Circumstances	Teaching responsibilities required too much time to focus on online courses more	Delayed arrival of equipment/materials; moved schools; lab too long; cyberattack; trouble with parents to do research
Logistical – Teacher Personal Circumstances	Time; family obligations	
Online course design	Not seeing other people; not able to learn from others; held to timing of others' posts	

From the analysis, all of the teachers expressed the most concerns (costs) related to the online courses. All of the teachers had the fewest concerns (costs) related to classroom implementation, and the High implementation group expressed the fewest classroom implementation costs (Table 4). With implementation, teachers had the highest frequency of costs associated with Curriculum Issues and Student Abilities. For the online courses, teachers expressed greater costs for Content Response and Affective Response (Table 5).

Table 4. Percent of cost statements by subcategories for different teacher implementation levels.

Implementation Level	Online Class Costs	Classroom Implementation Costs
Low	77.4%	22.6%
Med	81.6%	18.4%
High	86.7%	**13.3%**

Table 5. Types of implementation and course costs by teacher implementation levels.

Implementation Costs						
Group	**Curriculum Issues**	**Response – Content**	**Response – Affective**	**Student Abilities**	**Logistical – Teacher Professional Circumstances**	
Low	**6**	1	2	**7**	3	
Medium	**6**	1	2	**1**	8	
High	**1**	0	1	**6**	5	
Online Course Costs						
Group	**Curriculum Issues**	**Response – Content**	**Response – Affective**	**Logistical – Teacher Professional Circumstances**	**Logistical – Teacher Personal Circumstances**	**Course Design**
Low	1	**6**	**25**	0	2	5
Medium	2	**12**	**18**	9	9	7
High	2	**22**	**16**	1	4	11

The relationship between teachers' task values and their lesson enactment

For each level of enactment, teachers' costs and values were totaled and calculated as a percent (Table 6). All of the teachers described the usefulness of the PD to themselves. The Low implementation group was 3.0 times more likely to talk/write about Cost related to online coursework or implementing lessons than were the teachers in the High implementation group. The teachers in the High group were 1.6 times as likely to talk about the Attainment value and 1.8 times as likely Utility value for Students than the Low implementation group.

Table 6. Teachers' task values by enactment level.

No. of Teachers	Lesson Enactment	Utility Teacher	Utility Student	Intrinsic	Attainment	Cost
5	Low	25.6 %	11.4%	21.7%	11.9%	**29.4%**
5	Medium	29.5%	15.2%	22.2%	11.5%	21.7%
6	High	26.4%	**20.5%**	24.7%	**18.7%**	9.7%

Limitations

For this study, several factors need to be considered: 1) Transitioning to remote learning during Covid may have negatively impacted lesson implementation, 2) The sample size was small, the population of teachers could be unique, and the study was 1-2 years in duration, 3) If we had asked different questions or used a different analytical framework, we might have come to different conclusions, and 4) We made the choice to have 3 groups, low, medium and high - other groupings would have given different results.

CONCLUSIONS

These preliminary findings indicate that although the teachers participated in the same professional development, with the same level of financial and material supports, there was differential implementation of lessons. It is our belief that teachers might have implemented more activities and lessons if there had been better support through the program structural supports, such as visiting schools on lesson days. Our study suggests that teachers' task values and their perceptions of the cost(s) influenced their enactment of the new lessons. The "magic" combination for highest implementation with our teachers was high personal interest, high attainment value (which is tied to identity; Eccles & Wigfield, 1995), high utility value for students, and low perceived costs. We found promise in applying aspects of the Expectancy Value Framework to help us understand teachers' beliefs and values that contributed to teachers' motivation to implement lessons following the same professional development. From this study, recruitment for PD with teachers ought to consider using essay prompts that could better indicate which teachers are likely to implement new lessons. We also suggest having teachers explain the decisions underlying what they chose for their teaching video submission and use this to ascertain and select teachers whose explanations focus on the value for their students.

From the teacher interviews and forum posts, we also identified a need for more relevant and appropriate online courses for teachers. In this program, teachers took online courses with undergraduate students at the university, and consequently, the courses didn't closely match the needs of teachers. In future projects, it will be ideal to design specific courses for teachers, such as MOOCs. In addition, issues of diversity, equity and inclusion did not resonate for teachers. Though teachers were primarily selected from high-needs schools with diverse populations, these topics were absent from their class forum posts and interview transcripts. We suggest revising the course materials to better stimulate thinking about DEI, rural, and ability issues for teachers.

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TEACHER RESIDENCY PROGRAM: CONTRIBUTIONS AND LIMITS TO THE SCIENCE TEACHERS PROFESSIONAL DEVELOPMENT

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In this article, we present the contributions and limits of a formative experience developed in the Teacher Residency Program (TR) scope with two resident teachers of the Natural Sciences area in an application school. We emphasize that the TR is situated as a teacher professional induction program, implemented in 2019 at the Federal University of Juiz de Fora, being one of the few programs of this nature existing in Brazil. In this sense, describing the trajectory built with the residents and reflecting on the process and its formative implications is of fundamental importance for the memory and evaluation of that program and bringing contributions to the field of research on teacher education. We realized a focus group (FG) with the residents at the end of the program, which was conducted from a semi-structured script, in which we sought to explore the motivation of them to participate in the TR and the contributions and limits of this program to their professional development. Concerning the contributions of the TR to their professional development, the residents pointed out that the TR made it possible to expand the initial training, providing differentiated experiences, which were categorized in the following contributions: i) interdisciplinary experience; ii) experience of different teaching styles and practices; iii) experience of collaborative work, with supervisors and other residents; iv) experience of research at school; v) experience of inclusive education; vi) experience of fieldwork and practical classes. The experiences valued by the residents reaffirm the importance of the dimension of immersion and on-site training. The experience of research at school and the didactic and academic production fostered by the collaborative research are linked to the dimensions of authorship, collaboration, training through language and reflection, reaffirming the teacher's identity as a producer of knowledge.

Keywords: Continuing professional development, In-service Teacher Training, Collaboration.

INTRODUCTION

Teacher training, more than simply a topic, is a social problem of the greatest relevance nowadays, especially in the Brazilian context, marked by discontinued policies, the devaluation of the profession, and little social discussion regarding its concrete social value in contemporary times, as well as on the foundations of teacher training and associated practices, as announced by Gatti and collaborators (2019).

In line with Marcelo (2009), we consider the concept of teacher professional development (DPD) as the one that best fits the conception of the teacher as a teaching professional, since it emphasizes the teacher's learning and development process rather than his/her training process, demarcating a differentiation with training based on courses that do not establish a relationship with professional practices. In this way, we understand teacher training as a *continuum*, from which the constitution of knowledge and professional identity occur in an idiosyncratic and procedural way, though it occurs through clearly differentiated phases: in the experience as a student, in the initial training, in the period of initiation to teaching and continuing education;

it is continuous learning and involves a variety of learning formats (Gatti *et al*, 2019; Marcelo & Vaillant, 2017; Nóvoa, 2019).

Marcelo (2009) systematized an emerging perspective of teacher professional development (TPD), guided by the following concepts: i) the active construction of knowledge by teachers; ii) recognition of TPD as a long-term change process; iii) contextualization in teachers' practices; iv) reconstruction of school culture; v) the view of the teacher as a reflective practitioner; vi) the conception of the TPD as a collaborative process and vii) flexibility of training paths.

In the same direction, Gatti and collaborators (2019) carried out a synthesis of the discursive consensus that has been built by the field of research on teacher education, highlighting and describing the following aspects: i) reflection on the articulation of theory and practice; ii) the valorization of the investigative posture; iii) the approximation between training institutions and the school; iv) valuing the construction of learning communities; v) teaching conceived as a professional activity based on a solid repertoire of knowledge; vi) the importance of training teachers for social justice; vii) the importance of considering the beliefs and knowledge that teachers have about teaching and learning in training.

The systematization carried out by the aforementioned authors has common points, as they emphasize reflection, collaboration, teaching practices and the production of knowledge by teachers. But they are also complementary, especially regarding teacher training aimed at promoting social justice, which has also been highlighted by Zeichner (2011).

The research on teacher education in Brazil has pointed out one of the major problems of training in the country due to the excessively theoretical nature of the initial teacher education courses and their departure from schools' reality (Gatti *et al*., 2019). In addition, the professional induction of teachers, which is when novice teachers start their activities in schools, is something that needs greater attention from public policies, managers and trainers, given the crucial importance of this period for training and education (Nóvoa, 2019). According to Nóvoa (2019), the first years as beginning teachers are the most decisive in the professional teaching life, since they mark, in many ways, our relationship with students, with colleagues and with the profession, being the most important time in our constitution as teachers and in the construction of our professional identity.

To solve the problem of the departure of the teachers training from schools' reality, has been the subject of several initiatives, one of which is the teacher residency programs, which have been carried out for more than a decade in Brazil under different circumstances and conceptions, involving both initial and continuing teacher education (Faria & Diniz-Pereira, 2019).

What is in common between the diverse experiences and projects of residency in education is the idea of immersion in the field of professional practice, based on in-service training, which implies a link between the resident and the schools intensively and systematically, under the supervision of highly ethical and professionally qualified teachers, bringing them closer to medical residencies.

In 2018, the Federal University of Juiz de Fora (FUJF) created a Teacher Residency Program (TR), characterized as a teacher professional induction program, at the postgraduate level, aiming to improve Basic Education teachers' training based on the development of teaching skills *in loco*. The aim is to complement the education received in initial training with experience in a school environment of recognized excellence. This environment is João XXIII Application School (AS) of FUJF. The program lasts 12 months and has a workload of 2880 hours of activities during the year, representing 60 hours a week on an exclusive dedication basis, with a scholarship being offered, enabling conditions for training and immersion in school. The TR's target audience is newly graduated teachers (up to three years), and entry takes place through a selection process.

The activities proposed for such a program involve three areas: i) teaching; ii) performance in administrative-pedagogical sectors and iii) academic production, which requires participation in graduate courses, study and/or research groups, and the development of a Teacher Education Work (TEW), which consists of an academic-related product to teaching practice, in the form of research and/or proposition of educational action plans, interventions, projects or pedagogical resources. In the first year of TR, 2019, eleven scholarships were offered, distributed among the following areas: Human Sciences (2), Natural Sciences (2), Mathematics (1), Language (2), Arts (2), and Pedagogy or Superior Normal (2). In this article, we will focus on the trajectory of the Natural Sciences residents, whose guidance was carried out by the authors in collaboration.

Based on documentary analysis of the FUJF's Teacher Residency project and resolution, Callian and Magalhães (2019) identified five formative dimensions considered essential for teacher training in contemporary times: i) immersion, ii) authorship, iii) collaborative networks and communities, iv) training through language and v) reflection. However, the authors emphasize that this "does not guarantee that the practices are linked to them; however, making them explicit and analyzing them makes the concepts more visible and can lead us to reformulate the practices that are in progress" (Idem, p. 182).

We understand that reflecting on the trajectory built with the residents and its formative implications is of fundamental importance for evaluating and improving that program. Thus, this action research's central aim was to identify the contributions and limits of the TR developed since 2019 for the FUJF (Brazil) to the continuing professional development of the two Natural Sciences residents.

METHODOLOGY

This research was developed from the theoretical-methodological perspective of collaborative action research (Ibiapina, 2008), which was chosen for associating two dimensions of research in education that we consider fundamental: the production of knowledge and the continuing education of teachers, enabling the realization of studies and proposal intervention based on practical situations, which combine theory, practice, research, reflection and action based on collaborative work among teachers to transform schools into critical communities of teachers who problematize, think and reformulate practices with a view to professional emancipation. According to the author, collaborative action research starts from three basic conditions: the study is triggered from a specific social practice that can be improved; it is carried out taking into account the spiral of planning, action, observation, reflection, new action; it is preferably developed collaboratively.

The two residents of the Natural Sciences area have degrees in Chemistry and Biological Sciences and both have master's degrees as well. They are identified in this article as CR and BR, respectively. At our first orientation meeting, we discussed an initial proposal for the Teacher Education Work (TEW), based on the school's demand for science curriculum restructuring. We proposed to carry out collaborative action research, aiming at building a more integrated curriculum, articulating contends of Biology, Chemistry, and Physics, seeking meaningful learning of the central concepts of sciences. From then on, the residents were gradually integrated into the teaching, extension, and research activities that we developed at Application School and started to work with us in classrooms, in pedagogical meetings, in the orientation of interns, in collective projects and commissions, integrating our study group.

In order to know the residents' perspectives on the training and guidance process carried out in the teaching residency program, we held a focus group (Gatti, 2012) at the end of the program, that was conducted from a semi-structured script, in which we sought to explore their motivation to participate in the TR and the contributions and limits of this program to their professional development. The focus group lasted 90 minutes and was recorded in audio and video. Data analysis was performed by content analysis (Bardin, 1977).

RESULTS AND DISCUSSION

From the analysis of the focus group, we highlight as a central aspect of the residents' motivation to participate in the program the offer of the scholarship, which enabled them to articulate work and training, since its value overlaps the teacher's initial salary. According to them:

> *"The scholarship is very tempting" (BR)".*
>
> *"We can finish graduation, participating of the continuing teacher education to work on what we like with a decent remuneration" (CR).*

In this way, the offer of the scholarship plays a fundamental role in enabling in-service training and the immersion of residents in the school reality, contributing to the appreciation of the teaching profession, which is urgent in the Brazilian scenario (Gatti, 2019).

Concerning the contributions of the TR to the professional development, the residents pointed out that the program made it possible to expand their initial training, providing differentiated experiences, which were explored throughout the focus group, thus mapping the following contributions: i) interdisciplinary experience; ii) experience of different teaching styles and practices, adopted by the different monitored teachers during the TR; iii) experience of collaborative work, with supervisors and other residents; iv) experience of research at school, expanding previous experiences with academic research; v) experience of inclusive education; vi) experience of fieldwork and practical classes.

To this extent, the main contribution of the TR expressed by the residents is related to the experiences that it provided due to the immersion process that characterizes the program. Immersion in school, made possible by TR, therefore, has a central role in the articulation between theory and practice, which has been considered a gap in teacher training (Gatti et al. 2019; Nóvoa, 2019), enabling reflection and production of knowledge by the resident teachers.

Among the variety of experiences acquired in the TR, the residents highlighted the training in inclusive education, which permeated the entire course, from the study for the selection test to the subject of inclusive education and the experiences fostered in the Application School, since at the initial training this issue had not been addressed. The TR's focus on inclusive education, which represents the AS' concern to guarantee the learning of all students and which has recently materialized through the creation of a special education sector, is in line with the concept of teacher training focused on social justice (Gatti, 2019; Zeichner, 2011).

They also highlighted the opportunity to participate in the planning and monitoring of scholar visits to different spaces of non-formal education in and outside the city, that have contributed to the cultural enrichment of the students and also the teachers. In this way, Nóvoa (2017) defends the importance of the offer of a solid cultural and academic formation to the teachers.

The residents also emphasized the interdisciplinary and collaborative work that they experienced with the other residents, the supervisors, and other AS' teachers, corroborating the presence of the collaborative dimension identified by Callian & Magalhaes (2019) in the FUJF Teacher Residency project. In addition to these different experiences, according to the residents, TR provided them: academic production, due to the production of articles, abstracts for congresses, book chapters, and the TEW, providing reflection and research on teaching practices and also the production of knowledge by teachers, that is a fundamental aspect of their professional development (Marcelo, 2009; Gatti, 2019; Nóvoa, 2017).

Besides, they considered the opportunity and encouragement for the continuity of training promoted by the TR important, since both intend to continue the training process and the reaffirmation of professional identity as teachers of basic education in the public system. In this degree, the program has contributed to the identity constitution of beginning teachers, fundamental in the period of professional induction (Marcelo & Vaillant, 2017; Nóvoa, 2017, 2019).

In the field of science education, in addition to fieldwork and participation in collective projects, they called attention to the experience of experimental classes - which provided the expansion of the repertoire of practices, and also the opportunity to experience research at school, based on action-research developed with the supervisors, which according to CR, was encouraging to continue training after the TR, having been approved in the doctorate:

> *"I strongly believe that research at school was what moved me to have the courage to try the doctorate" (CR).*

Another differential of the TR and which is associated with the continuity of training is the academic production that it is generating (didactic materials, articles):

"*These are opening paths, for example, CR passed the doctorate, the other residents who are finishing TR will try to get their master's degrees; and they certainly have a great chance of succeeding as all of this will add up" (BR)*.

In this way, TR stands out as a stimulus and real possibility to continue training:

"After you graduate and start working in teaching, it is difficult to reconcile continuing training with work" (CR).

Regarding the limits of this experience and suggestions for a new edition, the following was pointed out: i) improve the experience in administrative-pedagogical sectors, with emphasis on insertion in teaching coordinations, which was not feasible; ii) excess of evaluative activities in the subjects organized in modules, which required a lot of time and effort, compromising immersion in other activities; and iii) different infrastructure and working conditions from the Application School, which does not match the reality of other public schools.

The mapping of the TR contributions made in this study shows the materialization of the five formative dimensions pointed out by Callian and Magalhães (2019): immersion, collaboration, authorship, reflection, and training through language. The experiences valued by the residents reaffirm the importance of the dimension of immersion, of on-site training. The experience of research at school and the didactic and academic production fostered by TR are linked to the dimensions of authorship, collaboration, training through language and reflection, reaffirming the teacher's identity as a producer of knowledge.

CONCLUSIONS

From the research, we apprehended that the central contribution of the TR was to provide the expansion and deepening of teacher education based on significant experiences involving: interdisciplinarity, collaborative work, field activities, inclusive education, and school research, which were constituted as meaningful experiences for both residents.

We believe that the Application School working conditions and pedagogical proposal, expressed in its Political Pedagogical Project, were fundamental to provide such experiences, highlighting the collective work projects, interdisciplinarity, and the school's growing commitment to inclusive education. On the other hand, Application School's differentiated infrastructure and working conditions, which places it in a very privileged position to other public schools in the country, constitute, according to the residents, as a training limit, since the practices held there that demand differentiated resources cannot be transposed, at least directly, to the other schools.

However, despite this reality, the TR meant for both of them the reaffirmation of their identity as teachers of basic education in the public system. Finally, it is important to highlight that the Teacher Residency Program has provided significant experiences also for us, supervisors, who had the opportunity to try new forms of teaching and collaborative work, to discuss and reflect on our practices and their implications.

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AFFORDANCES OF ONLINE PROFESSIONAL LEARNING

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In the United States, the Next Generation Science Standards (NGSS) include a focus on computational thinking. Similarly, The Framework for Science Education for Responsible Citizenship in the European Union emphasizes a shift from STEM to STEM. Both frameworks highlight the need for science education to mirror professional practice, which increasingly involves computing. As such, we focus on how elementary school teachers learned about computing in an online professional development.

Keywords: Teacher professional development, technology in education and training, science education

INTRODUCTION

Increasingly, professional scientific practice demands engagement with computer science, as evidenced by fields like computational biology, bioinformatics, and computational statistics. There is also a growing recognition that K-12 science education needs to reflect professional scientific practice more closely. In the United States, the Next Generation Science Standards explicitly identify computational thinking as key scientific practices for learners. Similarly, The Framework for Science Education for Responsible Citizenship in the EU identifies the need to integrate across STEM disciplines and to include the arts in science learning. For computational thinking to become a practice that is taken up in K-12 classrooms, teachers must understand what computational thinking is and how to integrate it within scientific practice. There is a real concern with how to train pre- and in-service teachers in computing, so they can engage and support students in computing in ways that mirror professional scientific practice. In this paper, we report on an asynchronous online professional development designed to assist upper elementary teachers in integrating computational thinking with science education concepts related to circuitry.

Asynchronous online professional development is one of the more promising possibilities to provide computer science and computational thinking training for pre- and in-service teachers (Fishman et al., 2013). Professional development offered in an online format has similar affordances to in-person professional development (Fishman et al., 2013), but also includes unique affordances not present in face-to-face professional development. Asynchronous online professional development allows teachers to skip, review, and complete material at their own pace, providing opportunities for coaching and expert support, greater content mastery, and reflection.

Background

Effective professional development has seven key characteristics (Darling- Hammond et al., 2017): It focuses on content, incorporates active learning, supports collaboration, uses models of effective practice, provides coaching and expert support, offers opportunities for feedback and reflection, and is of sustained duration. By providing professional development that is content focused, teacher learning is situated within their own classroom contexts. This is especially important for areas like science and computing where there is discipline-specific content and pedagogy that needs to be covered. Teachers also need opportunities, through active learning, to engage in the kinds of learning they will be engaging their students in, and to collaborate with one another and share ideas. Further, by providing models of effective lesson plans, teachers are able to clearly understand what best practices look like within a specific domain. Coaching and support is delivered one-on-one to focus on the needs of individual teachers within the professional development setting. This individualized support is augmented through opportunities for feedback and reflection, which help teachers to grasp a vision of what expert practice looks like within the specific disciplinary and curricular content. Finally, effective professional development must be sustained enough in duration that teachers have "adequate time to learn, practice, implement, and reflect upon new strategies that facilitate changes in their practice" (Darling-Hammond et al., 2017, p.vi).

In recent years, there has been a growth in the development and delivery of online professional development, especially during the COVID-19 pandemic, but more research is needed to understand the affordances of online professional learning in disciplinary contexts (Fishman et al., 2013). In this paper, we focus on the need for time for reflection and the provision of coaching and extra support in effective professional development. During conventional face-to-face professional development, coaching and extra support is available, but can be limited. Such individualized instruction may be limited because teachers receive all instruction as a group first, and facilitators regulate and schedule time for activities during the professional development. A need to get through large quantities of content and a constrained time frame may not allow for sufficient opportunities for individualized coaching and extra support or enough time for teachers to reflect on what they have learned sufficiently to know what they still do not understand.

METHODS

Context & Participants

The Elementary STEM Teaching Integrating Textiles and Computing Holistically (ESTITCH) professional development provides teachers (grades 3-6) with the skills and knowledge to carry out the ESTITCH curriculum within the classroom. Centered around the themes of immigration, migration, and forced relocation, the ESTITCH curriculum integrates computer science and computational thinking into existing science, social studies and language arts teaching standards through electronic textiles (e-textiles) projects. E-textiles combine craft materials and sewing practices with sewable, programmable electronic components, including a microcontroller and a variety of sensors and actuators.

Teachers had access to the ESTITCH online professional development in the Canvas learning management system for two months. The online course provided opportunities for content acquisition and pedagogical knowledge development, with participants making and programming each of the three e-textiles projects described below. Facilitators also offered office hours via Zoom, to provide additional support, particularly with troubleshooting and debugging e-textiles projects.

The e-textiles projects are carefully sequenced so that the skills developed in one project build to the next project. The first project was a programmable paper circuit timeline based on a work of children's literature included in the ESTITCH curriculum. The second was an e-textile quilt square that replicated quilt patterns used to assist formerly enslaved peoples navigating the Underground Railroad. Lastly, teachers created a programmable quilt square connected to a meaningful moment in their lives (see Figure 1).

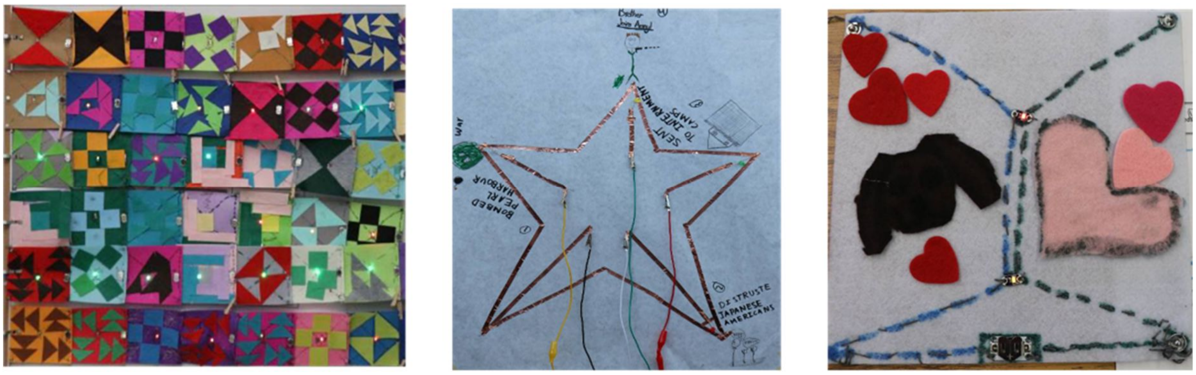

Figure 1. ESTITCH freedom quilt squares, paper circuit timeline, and meaningful moments projects.

Recruitment for the online professional development was conducted across the state of Utah. Of 27 teachers who enrolled in the professional development, 23 completed the training. Prior teaching experience ranged from no experience to several years of experience within the same grade. Notably, several of the teachers who signed up also taught in their native language in dual-language immersion programs. Teachers who participated in the professional development included native speaking Mandarin and Portuguese immersion program teachers.

Data Collection & Analysis

We performed exit interviews with each teacher to gather information about their expectations coming into the professional development, their experiences during the professional development, and how they thought professional development experiences would aid them with computer science and computational thinking instruction in the classroom. We also conducted a post-survey inquiring about teachers' experiences with the online professional development. For this paper, we focused on analysis of teacher reflective exit interviews concerning their experiences during the PD. We used emergent thematic coding to examine the interviews (Braun & Clarke, 2006; Nowell et al., 2017). First, we read the transcripts of all teacher interviews as a corpus of data, immersing ourselves in them as one might immerse themselves in a novel. Then, we went back and conducted an initial coding of the data, identifying important sections of the interview transcripts and labeling them. Through subsequent rounds of thematic coding, we refined our codes and identified patterns in our data. One set of codes dealt with the affordances of online professional development and we delve into those findings here.

FINDINGS

Our findings highlight the learning affordances provided to elementary teachers by the online asynchronous format. We found that the online asynchronous format provided time for coaching and extra support. Teachers utilized the online format in many ways to optimize their learning; however, our analysis revealed two affordances that are unique to the online asynchronous format: time and space to review material.

Time and Space to Review

Some teachers remarked that the online format of the professional development was difficult and that they would have preferred a face-to-face training. However, several teachers appreciated the online asynchronous format because it allowed differentiation in many ways. Because of the asynchronous nature of the professional development, teachers did not worry about keeping pace with other teachers, as they would have in a traditional professional development. Teachers also had sufficient time to review and master difficult content, as well as to reflect on their experiences to prepare for classroom implementation. One teacher commented:

> I really liked being able to kind of take my time to process it. 'Cause when in the face to face it, it was kind of a lot of information and stuff and packed into, you know, a few days. And I really liked being able to read the articles, mark 'em up, process it, think about. And I would even sometimes stop after the video and create something for my classroom, right from what I was learning. And, for back- for back when we go back to school, and then come back to it [the course material]…that was really powerful (Interview, 7/28/20).

The online asynchronous professional development afforded more time for teachers to review materials, work at their own pace, and even stop instruction and to work on creating artifacts for the classroom while instructions were still fresh. Teachers also leveraged the digital space to review other teachers' discussion posts. Posts by other teachers provided tricks for working with the e-textiles materials and provided a compendium of possible mistakes encountered by the teachere when working on their projects, mistakes likely to be encountered by students in the classroom.One teacher remarked:

> You know, some of [the projects] work, some of them don't work. And so, it was nice to just … read everybody's comments and stuff and that's why it doesn't work for students or, Oh, I understand. And so then when I went back and did some of the projects over, it works so much smoother, so I could like take it back to my students and say, this is what you need to do.

In this teacher's comment, we see how the online discussion forum provided an opportunity for reflection at the teacher's own pace but with the benefit of the group's collective wisdom about making the e-textiles projects in the ESTITCH curriculum. The online format allowed teachers to create a shared forum and stored all the common problems teachers encountered. This shared forum provided opportunities for reflection, as teachers were able to post, access, read, and find solutions to problems they were encountering. Teachers were able to access all the problems all other teachers encountered and the solutions, allowing teachers to more fully understand the computer science and circuitry content, to devise strategies to help students, and to prepare for teaching the ESTITCH curriculum in the classroom. Teachers even created new spaces outside of the PD to collaborate. For example, one teacher said, "So we just kinda did it together like that through texting or Face-timing each other and working through it and troubleshooting and stuff like that" (Interview, 07/24/20). In this way, teachers' participation in the online professional development was more sustained than it would have been in a one week, in-person professional development.

DISCUSSION

Online PD was able to provide comparable, and in some cases better experiences than in-person PDs, aligning with arguments some scholars make in favor of the online format (Fishman et al., 2013). According to teacher interviews, the ESTITCH online professional development was able to provide enhancements beyond a face-to-face professional development in relation to the seven aspects of effective professional development identified by Darling-Hammon and colleagues (2017). First, the online asynchronous format allowed teachers to delve deeply into the content of the ESTITCH curriculum, especially in areas they did not understand. Teachers were able to make and, in some cases, remake the three e-textiles projects in the ESTITCH curriculum until they solidly grasped the circuitry and computer science concepts involved. This was supported by the online discussion forums, which provided a compendium of possible problems and their solutions. These forums provided teachers opportunities to reflect not only on their own learning, but also on what might happen during classroom implementation. The asynchronous portion of the professional development provided the most affordances allowing teachers to pace their progress, and review professional development materials and community posts to gain greater mastery and understanding of computer science and science content and pedagogies. Additionally, the professional development allowed time for teachers to gain greater insights into troubles students my encounter, providing teachers with strategies effectively convey computer science principles and plan for classroom application. Despite not meeting in-person, teachers were able to create connections with other teachers and receive help from one another and facilitators when needed. In many cases, these interactions extended beyond the time bounds of a one-week, face-to-face professional development, contributing to the sustained duration of interactions.

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COASTRO CITIZEN SCIENCE PROJECT: CONTRIBUTIONS TO TEACHING PRACTICES, ATTITUDES, AND BELIEFS TOWARDS SCIENCE

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Attitudes and beliefs towards science are key factors for changing teachers' professional practices. However, structuring teaching professional development practices, considering all these domains, is as challenging as making its effects reach students. To respond to these challenges, CoAstro: @n Astronomy Condo emerged. This citizen science project intended, among other aspects, to understand how changing teachers' attitudes and beliefs influenced their teaching practices and affected the school community. To this end, nine primary teachers, without initial science training, were engaged in astronomy research, led by five astronomers and also engaging five science communicators.

Individual interviews and a focus group were carried out. Teachers were asked about their attitudes and beliefs and how the project changed their practices and influenced the school community. Data analysis was made using data categories defined previously.

The CoAstro's results reveal that the teachers' engagement in astronomy research led to changes in their attitudes (interest and proactivity; understanding and use of scientific knowledge) and beliefs (about astronomers' work and the way science is built) towards astronomy. Those changes led to teaching practices modifications in terms of methodologies and resources used, and collaborative work with peers.

The CoAstro project allowed us to understand how participation in citizen science projects, and the appropriation of learning outcomes, can contribute to teachers' professional development, specifically related to their needs and the needs of their schools, impacting on the surrounding school community.

Keywords: Teaching Practices, Science Education

CONTEXT

The term citizen science (CS) refers to public engagement in different stages of scientific processes. CS can easily create a win-win context: it attracts more researchers to science communication and, on the other hand, allows the public to participate directly in scientific processes (Riesch & Potter, 2014).

In addition to the advantages of CS to scientific research, this method also has powerful educational and science communication outputs. Accomplishing science communication goals is, indeed, one of the most common purposes of citizen science, pointed out by scientists and citizen science project managers (Burgess et al., 2017). Indeed, the advantages of associating science communication and science education have long been known (Walker et al., 2018), namely through CS projects (Gray et al., 2012) helping to bridge the gap between scientific research and science education (Gilbert et al., 2011).

Thus, engaging teachers in CS processes is a natural path enhanced by the "school effect" and the "teacher effect" in students (Gilbert et al., 2011; Heafner, 2019), but also in their families and the surrounding school community. This multiplier effect of influences that the school allows is unique and highly positive. Therefore, it is in this synergistic context of science education, science communication, and scientific research in astronomy that CoAstro emerges.

COASTRO: @N ASTRONOMY CONDO

CoAstro is a citizen science project which, during one school year (2018/2019), had the participation of five astronomers (from the Instituto de Astrofísica e Ciências do Espaço – IA), nine primary school teachers, and five science communicators (these belonging to the Porto Planetarium – Ciência Viva Center – PP-CCV).

CoAstro was organized in two major stages: (i) the engagement of primary school teachers, with the Research Group on the "Origin and Evolution of Stars and Planets" at IA; (ii) the engagement of teachers, astronomers, and science communicators into astronomy education activities for the school community.

Teachers' engagement in astronomy research

In the first CoAstro stage, teachers could choose between two scientific projects: "Stars" and "Planets". The "Stars project" aimed to analyse standard stellar spectra to allow the determination of the composition of 57000 stars and the characterization of their brightness, using Data Release 2 from the European Space Agency (ESA) – GAIA Mission. Using Python's coding program, the "Planets project" aimed to develop a planetary transit video (a video as a planet passes in front of a star). That task was necessary to analyse of light curves to signal the presence of potential exoplanets: planets outside of the Solar System. The main features of the two scientific projects are summarized in figure 1.

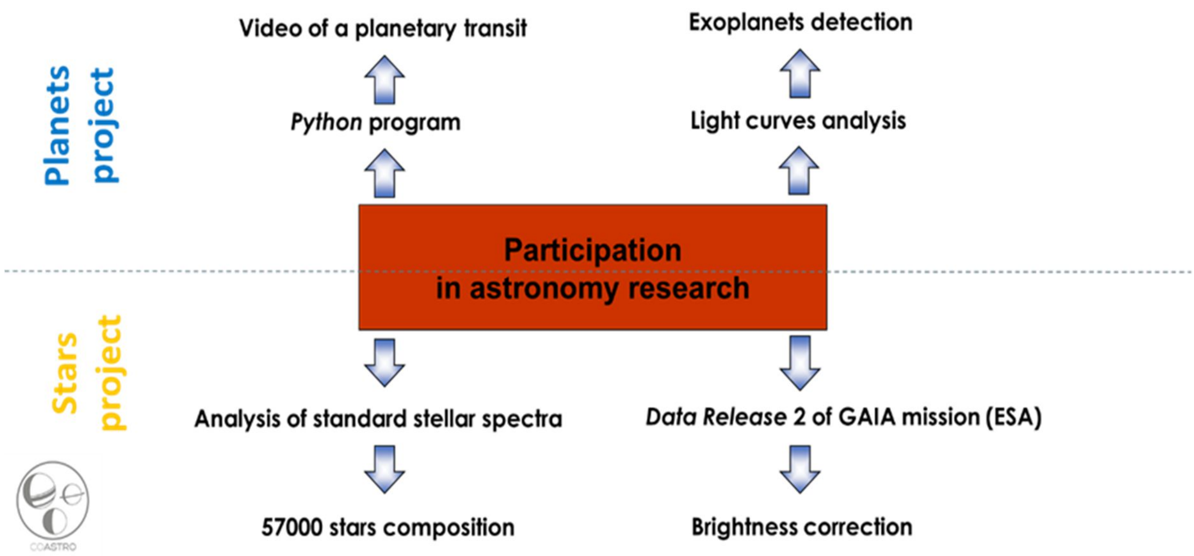

Figure 1. Astronomy research tasks.

This stage culminated with the presentation to the school community of the astronomy research results carried out with teachers' participation.

Astronomy education activities for the school community

This stage included astronomy education carried out in the school community (figure 2). It started with 25 hours of in-person teacher training, based on an extensive astronomy activities kit. This teacher training and all the work done in the first CoAstro's stage (2.1) allowed teachers to build astronomy education initiatives. So, starting from the specific context of their schools (it's potential and limitations), teachers freely devised a way to engage their school communities effectively. Astronomers and science communicators supported the implementation of these activities.

Figure 2. Examples of CoAstro´s educational activities.

METHODS

Considering that participant's attitudes toward science are an essential condition for understanding and engagement with science (Oliveira & Carvalho, 2015), we aimed to know the CoAstro teachers' knowledge (Costa et al., 2020), scientific attitudes, and beliefs (Costa, 2021), and understand how those aspects influenced teaching practices and affected the school community.

To do so, we conducted a qualitative investigation, specifically a case study with nine primary school teachers (eight females and one male, with an average age of 44.8 years), with no initial training in science.

We used an interview survey, document analysis, and participant observations (table 1).

Table 1 – CoAstro techniques and instruments of data collection.

Technique	Instrument	Data collected
Interview survey	Interview scripts	Attitude towards science and epistemological beliefs
Document analysis	Records produced by the participants	Type of activities carried out; their scope; target audience
Observation	Observation records (field notes)	Relevance of participating in CoAstro

We choose to e-mail the interview script and receive the answers the same way. Whenever necessary, the participants were contacted, by e-mail, to clarify doubts from the preliminary analysis. A focus group with all teachers followed the interview. Based on the interview objectives, an analysis framework was produced with categories and subcategories (table 2), from which the content analysis of the interviews was made.

Table 2 – Categorization structure of the interview.

Category	Subcategory
A. Teachers' attitudes towards science	A1. Interest and proactivity A2. Understanding and use of scientific knowledge
B. Teachers' epistemology beliefs	B1. Amoral B2. Creative B3. Developmental B4. Parsimonious B5. Testable B6. Unified
C. Teachers' educational practices	C1. Planning C2. Communication C3. Quality

	C4. Nature of the work C5. Coverage / scope C6. Effects
D. Effects on the school community	D1. Awareness of science D2. Enjoyment D3. Interest D4. Opinion

The following section summarizes the CoAstro´s main results in each analysis categories.

RESULTS

As a citizen science project, CoAstro had scientific research outputs. Indeed, we identified the teachers' contribution as a step in determining the composition of 57000 stars and the characterization of their brightness. We also identified teachers' contribution as a step to the validation and consequent publication, in Monthly Notices of the Royal Astronomical Society, of the first discovery and characterization of a planet identified by Planet Hunters TESS (a citizen science platform to detect exoplanets). However, in the present paper, we look to the CoAstro outputs on its second stage (the engagement of teachers, astronomers and, science communicators into astronomy education activities for the school community).

Despite the teachers' initial difficulties with the astronomy research tasks required, they were dazzled by the experience and relevance to their personal and professional development.

Regarding attitudes towards astronomy, we found that CoAstro played a very relevant role in promoting or expanding interest in this science to enhance its learning. Thus, the project contributed to awareness, pleasure, and interest in astronomy, albeit with varying degrees of depth. At the same time, the understanding and the usage of this science have increased. CoAstro reinforces the scientific belief in the: i) science creativity, interdisciplinarity, and amorality; ii) scientific knowledge validation process. So, in CoAstro attitudes and beliefs changed due to the teachers' engagement in astronomy research, but also due to the horizontal interpersonal relationships established and to the co-design of the project by the participants: astronomers decided the best way to engage teachers in astronomy research, and teachers decide the best way to use astronomers in their educational activities with the school community.

With CoAstro, there were changes in teaching practices in terms of methodologies, resources, and dynamics of collaborative work with peers. Indeed, teachers carry out astronomy education activities with their students (and other school community members) and beyond the curricular imperative and structure. Thus, teachers started to structure initiatives in an inquiry-based learning framework, which moved to an eminently interdisciplinary nature. They also promoted exhibitions and lectures. All those initiatives were clearly supported by the resources made available by astronomers and science communicators.

With other teachers, the increased motivation for the practices (because they better master the concepts and processes of astronomy) and the quality of those practices were evident and noticed by the students and led to a greater appreciation of their work by the school community. CoAstro stimulated collaborative work with teachers' peers.

So, CoAstro had huge educational effects on students, and all the school community. That in terms of awareness of science, and science enjoyment, interest, understanding and opinion.

CONCLUSION

CoAstro demonstrates the greater relevance that CS projects can have if they add educational goals in addition to the scientific goals. Indeed, schools are suitable environments to flow scientific results and processes with efficiency and agility. Thus, CoAstro contributed to: the school opening to families, but also to the families opening to school; scientific research and astronomy communication opening to lay public, but also for the public to be open to scientific research and science communication. CoAstro seems to stem last-longing public effects and reach audiences that would hardly ever be engaged with astronomy. What has just been described was made possible due to the participation of teachers in CS who, after changing attitudes and beliefs towards astronomy, changed their teaching practices and how they collaborate with their peers.

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PCK OF PRE-SERVICE AND IN-SERVICE TEACHERS IN RELATION TO THE USE OF DRAWINGS

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The purpose of the study is to assess how the pedagogical content differs between pre-service teachers and in-service teachers. The drawings that teachers draw on the board to illustrate their interpretations in human biology lessons at the lower secondary level were analyzed. The respondents studied the professional illustrations and then redrew them as they would present them to the students and recorded their interpretation on video. The analysis showed that in-service teachers were more systematic in their interpretation, more likely to connect their speech to already acquired knowledge, and used fever terms. However, both groups of respondents have successfully transformed the original drawing into the suitable form. A difference between pre-service and in-service teachers was found in the interpretation, because pre-service teachers followed a text from a textbook to a great extent, while in-service teachers tried to explain the topic in their own words.

Keywords: pedagogical content knowledge, pre-service teacher education, training and development

THEORETICAL BACKGROUND

Pedagogical content knowledge

Future teachers' training focuses mainly on knowledge of the field of study and the competencies they need in their professional life. Pre-service teachers face two key questions throughout their studies in teacher training faculties: 'What to learn?' (the issue of selecting educational content) and 'How to teach?' (problem of transferring subject content, use of teaching methods and forms, etc.). The second question concerns the choice of curriculum, especially form and level of knowledge transformation, and is still in the interest of didactics, researchers, and teachers. In this case, we can talk about the so-called pedagogical content knowledge (PCK).

Shulman (1987) defined PCK as a special form of content knowledge that goes beyond knowledge of a given subject to the level of curriculum knowledge. PCK is a connection between content-related knowledge and pedagogy and is actually a level to which the teacher understands how individual topics are organized, represented, and adapted with respect to different levels of knowledge, skills, and interests of students (Shulman 1987, p. 8). Magnusson et al. (1999) expanded Shulman's definition of PCK and defined four basic components: 1) goals for teaching the topic, 2) level of understanding of the topic by students, 3) teaching strategies chosen for teaching the topic, and 4) ways to assess whether students understand the topic. These components are universal and appear in the professional pedagogical literature, and are often mentioned in the training of future teachers as well (Berendsen & Henze, 2019).

Pedagogical content knowledge (PCK) develops over time and through experience. Teachers learn how to teach specific content in particular ways to improve student understanding and enable them to acquire knowledge and key competencies (Loughran, Berry & Mulhall, 2012).

Concerns have emerged in European countries, as well as in the United States, whether the training of pre-service teachers and in-service teachers' professional development are able to successfully prepare teachers with the good pedagogical content knowledge they would need to improve their own teaching practices (Gess-Newsome et al., 2011). Researchers and educational policy makers agree that a higher level of PCK leads to quality teaching, which improves student outcomes (Baumert et al. 2010; Schmidt et al., 2007). Therefore, teacher training in many countries has started to focus mainly on developing an understanding of pedagogical content, and a large number of studies have also addressed this issue. However, few studies have examined how PCK directly affects teacher teaching activities (Barendsen & Henze, 2019).

Drawings and their use in teaching

Drawing can be understood as a tool that is suitable for creating personal knowledge, especially through creative problem solving (Rybska, 2016). Drawing is also important from the point of view of science, which requires data recording, so that it is possible to obtain an overview and formulas (Katz, 2017). Drawing itself can often be more comprehensible and effective than long verbal descriptions (Katz, 2017), and in many cases drawing can be used as a suitable alternative to verbal expression (Patrick & Tunnicliffe, 2010).

In the literature, we encounter five reasons why drawing should be recognized in addition to writing, reading, and speaking as a key element in science education: 1) drawing increases student involvement; 2) drawing develops visual literacy and helps to create new and at the same time support current knowledge; 3) comprehension is often associated with visual models; 4) drawing can be considered as an effective learning strategy that helps to organize students' knowledge and understanding; 5) thanks to drawing, students are able to think in a clear and concrete way, and they are able to better exchange and clarify meanings between peers (Ainsworth, Prain & Tytler, 2011, 2011). Drawings are often used in teaching as a supplement to oral interpretation; however, their processing is also influenced by the level of teacher's pedagogical content knowledge.

METHODOLOGY

Aim and research question

The aim was to assess the extent to which respondents were able to create a simplified version of the complex professional illustrations intended for eighth graders. Differences were observed between pre-service teachers who have only minimal experience in practice but were familiar with detailed and up-to-date knowledge in the field of human biology, and in-service teachers who have experience with didactic transformation from their teaching. The research question was 'How does knowledge of pedagogical content differ with respect to the use of drawings in human biology lessons between pre-service and in-service teachers?' Differences in the drawings were also analyzed.

Sample and data collection

There were 22 pre-service biology teachers (19 women, 3 men) in the master's study program focused on biology education and four in-service biology teachers (only women) with different lengths of practice (teacher 1: 4 years; teacher 2: 5 years; teacher 3: 11 years; teacher 4: 24 years). Ten illustrations selected for drawing were taken from textbooks of medical physiology, somatology, and functional anatomy. Specifically, we used illustrations representing the structure of the heart, tooth, spinal cord, kidney, neuron, ear, eye, skin, bone, and reflex arc.

Each student received selected illustrations retrieved from professional publications and tried to transform them appropriately into a form corresponding to the cognitive level of eighth graders. Due to covid-19 lockdown, data collection was not carried out in the form of inspections in the classes, but in an alternative on-line way. Based on the detailed instructions, the respondents recorded their interpretations and sent them to the researchers together with the scanned drawings.

Data analysis

The data obtained were evaluated using specific criteria established in advance. First, the drawings were analyzed from a content point of view. It was observed which concepts are drawn and described in comparison to the original illustration, whether some concepts were included in addition, or whether some concepts were missing. The respondent's interpretation itself was also evaluated. We focused on specific aspects of the interpretations of the respondents with stress put in professional terms. Finally, we also observed whether the respondent mentioned the functionality of a given part of the human body in the interpretation. The analysis was carried out by two independent researchers. Subsequently, their conclusions were compared, and in case there was not a consensus, another person, a biology didactic, who was not directly involved in the research was invited.

Although we have already evaluated all the drawings, we decided to present only one selected drawing, namely the drawing of the heart.

RESULTS

The first step was a simplified analysis of five selected textbooks that are used in human biology teaching in Czech schools (Tab. 1). According to predetermined criteria, it was monitored whether they contained selected illustrations, how they are processed and presented, concepts related to them, etc. This analysis was also essential to compare how respondents follow the text of the textbooks in their interpretation.

Figure 1 shows the structure of the human heart. This illustration was taken from a script for university students (Machová, 2006) and used to investigate the level of didactic transformation of pre-service and in-service teachers.

Table 1. Results of the simplified analysis of five textbooks.

Drawn and described sections of the heart	Selected textbooks				
	1	2	3	4	5
Superior vena cava	yes	yes	yes	yes	yes
Inferior vena cava	yes	yes	yes	yes	yes
Aorta	yes	yes	no	yes	yes
Pulmonary artery	no	yes	yes	yes	yes
Right atrium	yes	yes	no	yes	yes
Right ventricle	yes	yes	no	yes	yes
Left atrium	yes	yes	no	yes	yes
Left ventricle	yes	yes	no	yes	yes
Pulmonary veins	yes	yes	no	yes	no
Pulmonary valve	no	yes	no	yes	yes
Tricuspid valve	no	yes	no	yes	yes
Mitral valve	no	yes	no	yes	yes
Aortic arches	yes	no	yes	no	no
Septum	yes	yes	no	no	no
Pericardium	yes	no	no	no	no
Coronary veins	no	no	yes	no	no
Coronary arteries	no	no	yes	no	no

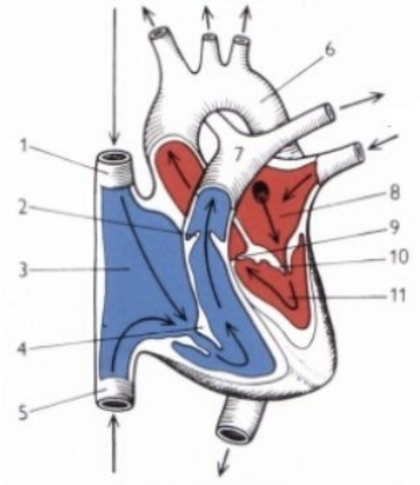

Figure 1. Original illustration retrieved from script for university students (Machová, 2006).

Legend: number 1 – 5 represent selected textbooks of human biology for lower secondary school: **1:** Černík, Martinec & Vodová (2015, p. 28, fig. 40); **2:** Navrátil & Ševčík (2017, p. 37, fig. 4.5); **3:** Dobroruka et al. (2010, p. 101, fig. unnumbered); **4:** Žídková et al. (2018, p. 43, fig. 23); **5:** Vaněčková (2007, p. 69, fig. unnumbered).

Only one pre-service teacher chose a black and white drawing, and she shaded part of the heart with oxygenated blood (Fig. 2). When discussing the created drawings, this method was described as rather confusing. All other respondents used the traditionally used representation of oxygenated blood with red and blood without oxygen with blue.

The realization itself was interesting, too (Tab. 2), three of the pre-service teachers drew the picture in advance and then commented it, and one pre-service teacher tried to interpret and describe the picture at the same time.

Table 2. General aspects of pre-service teachers' (S) and in-service teachers' (T) drawings and interpretations.

Student / Teacher	Colors	Processing of drawing	Used captions (number)	Correctness	Length of interpretation
S1	yes	parallel with interpretation	yes (5)	yes	1:57
S2	yes	drawn beforehand	yes (14)	no	2:14
S3	yes	drawn beforehand	yes (12)	no	2:30
S4	no	drawn beforehand	yes (14)	yes	3:26
T1	yes	preprinted	yes (9)	yes	5:26
T2	yes	preprinted	yes (9)	yes	1:31
T3	yes	parallel with interpretation	yes (9)	yes	6:55
T4	yes	parallel with interpretation	no (0)	yes	4:12

It is a little surprising that three of four in-service teachers used pre-printed or projected illustrations (Fig. 4). During the discussion, the teachers stated that they normally do it because they have more time to better clarify the function and structure of the heart. One of the in-service teachers (T2) had labels directly on the pre-printed picture. According to her opinion, students cannot take notes from her speech. Teacher 1 gave the students a pre-printed picture, but it contained numbers, which were preceded by captions, which were also written by the teacher. In the end, the pupils should color the illustration with red (part with oxygenated blood) and blue (part with non-oxygenated blood) colors.

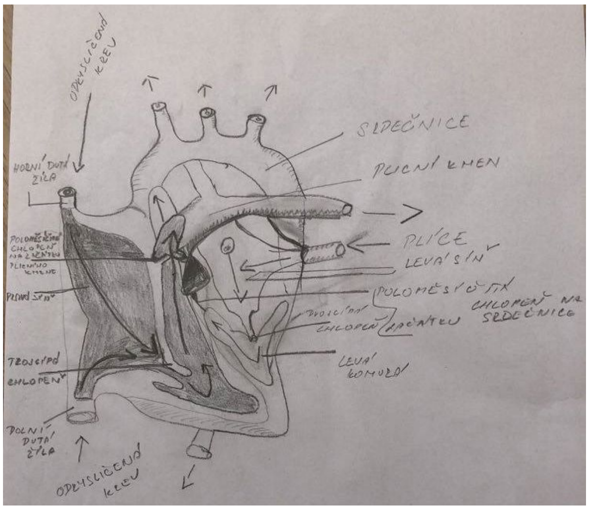

Figure 2. Drawing performed by pre-service teacher (S4).

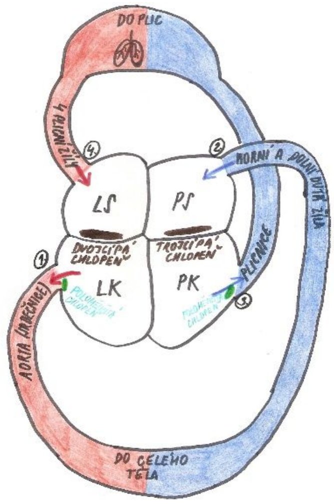

Figure 3. Drawing performed by the pre-service teacher (S3)[17].

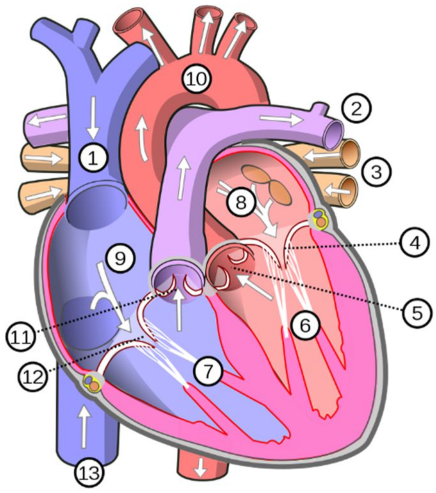

Figure 4. Preprinted illustration used by in-service teacher (T1)[18]

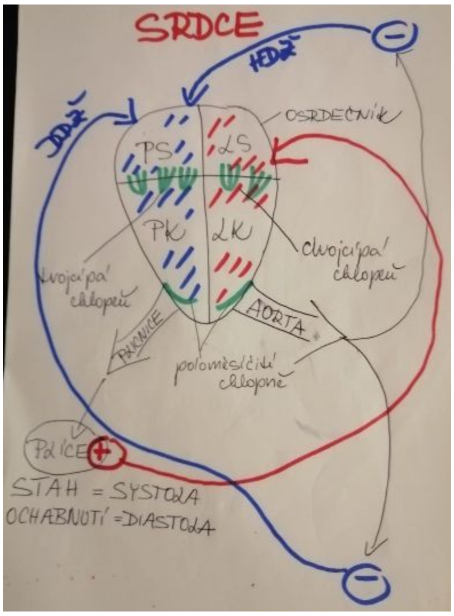

Figure 5. Drawing performed by the in-service teacher (T3)[1]

In terms of assessing the correctness of the drawing and interpretation, it was found that two pre-service teachers had side-flipped drawings (Fig. 3). They forgot about the so-called anatomical position of the human body, so they determined the left part of the heart as the right part and vice versa. Teacher 1 notified this fact in her interpretation, and she also added

[17] The letters used in the picture are Czech abbreviations for the following parts of the human heart: LS – left atrium, PS – right atrium, LK – left ventricle, PK – right ventricle

[18] Retrived from Wikimedia Commons (https://commons.wikimedia.org/w/index.php?curid=1399394; CC BY-SA 3.0, author MesserWoland).

mnemonics to remember the difference between ventricles and chambers. Teacher 3 supplemented her interpretation by diastole and systole, including an explanation of their principle and the connection with heart activity (Fig. 5).

All in-service teachers explained the function of the valves, only one of the pre-service teachers did so, and the rest of pre-service teachers mentioned the valves in their interpretation without explanation of their purpose. When compared to the text of the textbooks, it was found that pre-service teachers strongly followed the text from one of the textbooks (in some cases almost literally), while the in-service teacher formulated the interpretation according to themselves. All respondents used a comparison of heart size with a clenched fist. In general, pre-service teachers also used a greater number of terms than in-service teachers. During discussion about number of terms pre-service used argument that they learnt these terms too. In-service teachers tried to describe some professional terms in other words, not to introduce another new term or to liken it to other knowledge that students already had.

Table 3 compares the drawings created with the original illustration in relation to the concepts drawn and described. The pre-service teacher (S1) drew and described only a small part of the descriptions in the scheme of the construction of the heart, but all the basic terms were mentioned in his interpretation.

Table 3. Detailed analysis of heart structure drawings – terms described in comparison with the original illustration (see Fig. 1).

Drawn and described sections of the heart	Author of the drawing							
	S1	S2	S3	S4	T1	T2	T3	T4
Superior vena cava	no	yes	yes	yes	yes	yes	yes	no
Inferior vena cava	no	yes	yes	yes	yes	yes	yes	no
Aorta	no	yes	yes	yes	yes	yes	yes	no
Pulmonary artery	no	yes	yes	yes	yes	yes	yes	no
Right atrium	yes	yes	yes	yes	yes	yes	yes	no
Left atrium	yes	yes	yes	yes	yes	yes	yes	no
Left ventricle	yes	yes	yes	yes	yes	yes	yes	no
Pulmonary valve	no	yes	yes	yes	yes	no	yes	no
Mitral valve	no	yes	yes	yes	yes	no	yes	no
Tricuspid valve	no	yes	yes	yes	yes	no	yes	no
Extra terms (in comparison to the labels in the original illustration):								
Right ventricle	yes	yes	no	yes	yes	yes	yes	no
Pulmonary veins	no	yes	no	yes	yes	no	no	no
Septum	no	yes	yes	yes	no	yes	no	no
Pericardium	no	yes	yes	yes	no	no	yes	no

The term septum appears in the interpretation of one in-service teacher (T2), although in her drawing there was no description; in a similar way a pericardium can be registered in the interpretation of an in-service teacher (T3) and three pre-service teachers (S2, S3, and S4). The pre-service teacher (S3) did not include the description of the right ventricle and pulmonary veins, although both terms were mentioned in the explanation. This confirms a strong analogy with the original illustration of the heart structure taken from Machová (2016), where these sections of the human heart also miss.

CONCLUSION AND DISCUSSION

It is not surprising that teachers generally proceeded systematically in their interpretation, more related their interpretation to what students should already know, and more explained the function of individual parts of the human heart. Pre-service teachers very often followed the text in the textbook, while in-service teachers interpreted the content in their own words.

If pre-service teachers should acquire an appropriate level of PCK, they need the assistance of a supervisor during their training at university, but especially during pedagogical practice in schools (Halim et al., 2010). One of the possible ways to develop PCK is the implementation of action research, in which the pre-service teacher would cooperate with a didactic and especially with an in-service teacher (Halim et al., 2010). Such supervision, however, must be carried out by experts who are able to reflect on different teaching styles and think critically about the content, but also about the pedagogical dimension (Jordan, Phillips & Brown, 2004). As part of the pedagogical practice of pre-service teachers, feedback should be provided immediately after the lesson, preferably from an expert from the university as well as a teacher from practice. If feedback is to be relevant and promote the understanding of the nature of PCK in pre-service teachers, it is essential that supervisors themselves are able to reflect their abilities (Feldman, 2005).

It can be said that all the respondents did successful didactic transformations of the illustration that they adapted to the age of the pupils. However, the content part deserves greater simplification, especially for pre-service teachers. It turned out that their interpretation contained a large number of terms. In-service teachers reduced this number and generally used fewer terms. It should not be forgotten that two pre-service teachers made a fundamental mistake in their drawings, which could lead to the development of misconceptions about students in the future.

According to Bektaş (2015), some pre-service teachers had fixed misconceptions related to the content of the subject and mainly did not have sufficient knowledge in relation to the pedagogical component, i.e., they do not know the appropriate methods and forms of teaching or methods of assessment. Pre-service teachers subsequently stated that they prefer to use traditional methods and forms of teaching to overcome this lack of experience in teaching specific topics (Bektaş, 2015). Of course, errors related to the field content are a problem, but the lack of pedagogical skills is a major obstacle for the future teaching profession and especially for the application of innovative approaches.

As already mentioned in the theoretical background, there are studies that show that there is a correlation between the PCK of the teacher and the effectiveness of his teaching and the student results. For this reason, it is necessary to focus on PCK and include it as an essential component of pre-service teacher education programs, as well as professional development programs, in order to prepare teachers more effectively (van Driel & Berry, 2019; Schmelzing et al., 2013).

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FOSTERING SELF-EFFICACY: ASTRONOMY EDUCATION PROFESSIONAL DEVELOPMENT

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In this qualitative study, we report on the effects an astronomy education professional development had on teachers' self-efficacy and confidence in teaching astronomy content. The data presented here is a subset of a larger dataset. Five in-service teachers participated in the 2019 iteration of the program. The data informing this paper stem from daily reflections, observations, focus group discussions, participants' presentations, and open responses from the follow-up survey; analysis followed a thematic process. The results show that while the participants initially felt a lack of confidence in teaching challenging astronomy content, the professional development program succeeded in enhancing teachers' self-efficacy in terms of content knowledge, including increased confidence to teach astronomy in schools.

Keywords: astronomy education, teachers' professional development, self-efficacy

INTRODUCTION

The interdisciplinary nature of astronomy comprises various cognitive processes, including spatial reasoning, imagination, and visualization (Eriksson, 2019), making it an intriguing area to study (Ampartzaki & Kalogiannakis, 2016). Students learn astronomy through an integrated STEM approach, including developing critical and computational thinking, handling complexity, and improving technical skills. Learning astronomy requires teachers' preparation and proper training (Panou & Violetis, 2018). Hence teaching astronomy courses out-of-field is the norm (Mizzi, 2013). Astronomy contents are not often the focus of teacher professional development (TPD) and certification (Brunsell & Marcks 2005; Bailey, Lombardi, Cordova, & Sinatra, 2017). Chastenay (2018) noted that lack of training and feeling incompetent to teach astronomy are the foremost reasons for encountering limitations and unwillingness to teach K-12 astronomy. The sense of less confidence to teach comes from unfamiliarity with concepts and difficulties in teaching the complex contents. Teachers who lack content knowledge are less likely to have strong self-efficacy beliefs, more likely to encourage students to memorize factoids, and may inadvertently promote alternative conceptions (Danaia & McKinnon 2007; Sadler, Coyle, Miller, Cook-Smith, Dussault, & Gould, 2010; Bailey et al., 2017). Teachers prepare students for the future; empowering them with content knowledge could translate to better-prepared students and make them enthusiastic about studying and contributing to the advancement of astronomy (Frost, 2012; Panou & Violetis, 2018).

This paper describes how a TPD focused on astronomy education impacted in-service teachers' self-efficacy. Specifically, the TPD presented here is organized for the science teachers to equip with tools and resources to have a comprehensive and applicable understanding of scientific contents and influence them to improve their practice.

Research Question

What are the in-service teachers' perceptions of self-efficacy related to an astronomy education professional development program?

THEORETICAL FRAMEWORK

This study is grounded in Bandura's work on self-efficacy (1977), defined as an individual's belief in their capacity to organize and execute the required action to achieve certain goals. Teachers' self-efficacy is their belief in planning, designing, and implementing lessons to accomplish desired learning outcomes (Skaalvik, & Skaalvik, 2010; Brígido, Borrachero, Bermejo, & Mellado, 2013). Catalano and Durkin (2019) stated that teachers with high self-efficacy could implement effective strategies, commit more to the profession, and be less likely to burn out. Self-efficacy is an essential factor for teaching, positively impacting students' achievement and behavior (Yoo, 2016). In addition, self-efficacy increases teachers' ability to make decisions and empowers them as leaders who positively influence students (Runhaar, Sanders, & Yang, 2010). Confidence includes self-efficacy as a determinant and refers to the belief that one can do what has to be done. Therefore, self-efficacy works as a stimulus to achieve the goal, attempt greater responsibilities, and fulfill the cognitive demand to increase confidence (Brígido et al., 2013; Komarraju & Nadler, 2013).

Brigido et al. (2013) reveals a significant relationship between science teachers' self-efficacy and the subject matter they teach. Science teachers who lack confidence and are anxious to teach complex science content experience low self-efficacy. On the other side, teachers educated with proper science content and teaching skills have a high level of self-efficacy (Catalano & Durkin, 2019). Yoo (2016) informed that gaining new knowledge is positively associated with enhancing teachers' efficacy. TPD is a process of improving the quality of teachers' teaching by increasing their professional confidence, sense of self-efficacy and enhancing leadership quality to reform the education system (Frost, 2012; Lumpe, Czerniak, Haney, & Beltyukova, 2012). TPD increases teachers' self-efficacy beliefs, a driving factor for the teaching practice (Peters-Burton et al., 2015). Lumpe et al. (2012) assert that TPD enhances teachers' self-efficacy significantly and positively correlates with students' attainment.

METHODOLOGY

This paper is based on qualitative data, specifically from in-service teachers, to explore and understand a central phenomenon: self-efficacy. The cohort of in-service teachers is considered a case; through a thematic analytic process, the researchers sought a holistic view and an in-depth understanding of phenomena (Braun & Clarke, 2006; Creswell, 2014). Data stem from essays, reflections, observations, focus group interviews (FGI), participants' presentations, and open responses to a follow-up survey. After transcription, data were iteratively coded in NVivo, identifying and analyzing the emerging themes.

Context

The 2-week astronomy education TPD was organized by the College of Education and Human Development and College of Science at the University of Texas, San Antonio, and incorporated NASA's Universe of Learning (UoL) content. The TPD included Subject Matter Experts

(SMEs) presentations (astrophysics, space exploration, ground and space telescopes, and the Future of Astronomy), hands-on activities, MicroObservatory (online sessions), field trips (McDonald Observatory, Scobee Education Center, and Witte Museum), Science Olympiad, and final presentations by participants.

Participants

Five of the participants were in-service teachers (three female; two male) from three different school districts serving students from diverse backgrounds. Their backgrounds are briefly described here, using pseudonyms for anonymity. STN, a biology major with 24 years of teaching experience, volunteered to teach astronomy and found astronomy to be a challenging subject matter. APS realized that she wanted to know more about astronomy and actively sought opportunities to add to her knowledge base. SAI was a novice teacher looking for opportunities to develop his astronomy teaching skills. NET, an elementary teacher, did not have previous experience teaching astronomy content and expressed a lack of confidence in understanding and teaching scientific concepts. She was dedicated to expanding her knowledge and translating what she learned into engaging lessons. TSJ had earned a biology degree but enjoyed being a physics teacher; he wanted to instill curiosity about astronomy in his students.

FINDINGS AND ANALYSIS

Motivations for Participation and Expectations

As part of the application process, teachers submitted an essay on how participation in the TPD would help them improve their teaching. Although not explicitly required to be reflective writings, in essence, these essays were written as such. Three of the five teachers mentioned difficulties with understanding and teaching astronomy content, including inadequate knowledge, which leads two of the teachers' lack of confidence and identified astronomy as a challenging topic to teach. However, two of them noted a deep desire and need for opportunities to expand their knowledge and skill. The teachers' responses revealed the causes behind feeling a lack of confidence to teach the astronomy content and their keen interest in improving their skills, which led them to apply in the workshop.

Acquisition of Knowledge and Gaining Confidence

Generally, participants noted that the content did not overwhelm them, and they were interested in learning more about astronomy. After sessions on stars and exoplanets, a participant wrote, "I have to say I do have a better understanding of the stars and their life cycle, how the planets formed, and general information about the galaxies." The participants mentioned how embedded visualizations and hands-on experiences helped them understand even more abstract content. As one participant put it, "Hands-on lessons help get a grasp on content knowledge, and you can see and hear other peoples' views. That is where the learning occurs because you will probably pick up an idea that you would not have thought of." As a specific example, although none of the teachers were familiar with the workings and differences between telescopes at the beginning of the TPD, they found learning about them interesting. One noted, "You got to see the logic behind why telescopes like those are constructed the way they are.

Because you got to explore each lens and what it does, individually first before putting it together."

Before the field trip to the McDonald Observatory, the participants were asked to write about their expectations. Their responses reflected their keen interest in seeing how the big telescopes work, how astronomers use the telescope to collect information, and how the night sky looks in an area without light pollution. The participants found the visit useful as they came to better understand the scientific underpinnings of telescopes and noted that they would take the new insights to their classrooms where the concept could be applied for both physics and astronomy. After a planetarium visit, teachers mentioned that they understood the night sky better. A participant wrote, "I understood a little bit more about the constellations since it was more visual, and that's more of my learning style." The stargazing history of ancient people similarly helped the teachers to understand astronomy as part of the human experience. As one of them noted, the visit to the museum helped recognize "Science is an evolving process," and this was a lens she would now share with students. In summary, after each part of the TPD, the teachers expressed growing confidence in understanding astronomy and in their ability to teach it.

Difficulties in Understanding Some Content

Dark Matter was a challenging topic for the teachers. They sought to understand the difference between dark and ordinary matter and encountered hurdles plotting associated data as a part of the activity. Three of the in-service teachers found this discussion conceptually difficult and expressed a sense of anxiety and frustration. One of them mentioned that not having a background in physics and astronomy caused substantive difficulties in making meaningful connections on this topic.

Teachers' Post-workshop Perceptions

Participants had to present their takeaways from the TPD in a presentation session. Two in-service teachers highlighted the in-depth understanding they acquired related to how telescopes work in their final presentations. In the follow-up survey, teachers were asked to write briefly about how their participation in the program might influence their future teaching. Three of the five teachers noted that they felt prepared content-wise to teach astronomy, and two of them stated they saw the benefit in their access resources, human and material, through the workshop. These responses stand in direct contrast to their perceived ability to teach astronomy before participating in the workshop.

DISCUSSION AND CONCLUSION

In-depth Knowledge

As evidenced in daily reflections and discussions, the teachers began the TPD with a tentative understanding of astronomy content and became more cognizant of each day. Before the TPD, they felt that their content knowledge was inadequate; the literature recognizes this and links it to teachers feeling intimidated, leading to instruction heavily reliant on memorization (Brunsell & Marcks, 2005; Bailey et al., 2017). Throughout the two weeks of the TPD, teachers increasingly made the science and the language of the field their own. By the time they presented on the last day, they had talked about astronomy and astronomy teaching confidently.

The findings are associated with the literature that links teachers' beliefs and depth of understanding to increase self-efficacy (Plummer, & Zahm, 2010; Brígido et al., 2013; Yoo, 2016). Lacking academic preparation, teachers feel unprepared and less confident to teach the astronomy content. The studies (Nadelson, Callahan, Pyke, Hay, Dance, & Pfiester, 2013; Wongsopawiro, Zwart, & Van Driel, 2017) stated that TPD is explicitly designed to help teachers construct new knowledge and improve their practice while enhancing self-efficacy. Self-efficacy can increase engagement with the topic and impact conceptual change.

Challenges in Understanding Advanced-level Content

The teachers' discussions and reflections related to Dark Matter, in particular, were evident in frustrations and anxiety. Although they were interested in the content and felt their students were interested in it, they noticed the topic was highly abstract and did not understand it well. Therefore, they expressed little to no confidence in their ability to teach this topic. A study review (Abell, 2013) asserted that teachers are less confident to explain the advanced level science contents. However, in-service teachers' interest in acquiring advanced astronomy content knowledge requires further research.

Improving Pedagogical Content Knowledge (PCK)

Teachers' response to the takeaways reflected their belief to improve their practice as they gained content knowledge and access the resources for teaching (Wongsopawiro et al., 2017). Hence, TPD improves content knowledge and stimulates teachers to enhance their pedagogical content knowledge (PCK). Shulman's (1986) study illustrated the fact of PCK that a teacher's quality of knowledge helps them improve their pedagogy. PCK is a cyclical process that refers to teachers' transformation, reflection, and evaluation of their practice to enhance their learning and skills. Teachers' belief in their capability is an essential factor for the effective execution of PCK to lead self-efficacy (Mizzi, 2013). Peters-Burton, Merz, Ramirez, and Saroughi (2015) noted that science teachers who participated in TPD reported having authentic science concepts, being more confident in teaching, and keen on learning more concepts. Teachers' positive attitudes to change and improve their PCK could significantly impact students' learning outcomes (Ertmer & Ottenbreit-Leftwich, 2010).

Empowering Science Teachers as Future Leaders

The five in-service teachers represented three school districts with diverse students' populations, including economically disadvantaged, non-educationally disadvantaged, section 504 students, English learners, students with disciplinary placements, dyslexia, and drop-out risk (TEA, 2021). STEM is an area of education where social justice warrants focused consideration as it pays scant attention to social aspects, especially social inequalities (Dimick, 2012). Professional development focuses on improving teachers' quality of teaching, but what is the next step? Barko and Putnam (1995) illustrated that teachers' knowledge significantly impacts decision-making. Teachers' beliefs reflected in their ability to adapt to change and their positive attitude toward expanding their knowledge (Ertmer & Ottenbreit-Leftwich, 2010).

Astronomy needs more exposure as an educational subject matter. It is a unique area that requires science processing skills to understand concepts. TPD can work as a catalyst for educational change by improving teachers' pedagogical content knowledge and boosting self-efficacy. Self-efficacy could be the stimulus to increase confidence to drive the teaching-learning process to instill an interest in students to astronomy at an early age to create the experts for the future.

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TEACHER LEARNING AS BOUNDARY CROSSING DURING INTERDISCIPLINARY COLLABORATION

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Professional development, teacher collaboration and availability of quality curriculum have been named as three important sources of support for teachers involved in the teaching of interdisciplinary curriculum. However, there is limited research on how these measures support teacher development in an interdisciplinary context. This study examines the learning potential of collaborative development of interdisciplinary curriculum in secondary schools in Singapore. In a researcher-initiated intervention, an English teacher and a science teacher collaborate in a teacher design team to plan and carry out a lesson that teaches students to critically read science news articles. A qualitative case study approach is adopted to examine the learning potential of the boundaries encountered by teachers in a researcher-initiated teacher design team. As the teachers negotiate the discontinuities they experience during these boundary encounters, their attempts at sense-making have the potential to give rise to learning opportunities. This learning potential is understood through four learning mechanisms that may be evoked at boundaries - identification, coordination, reflection and transformation. Qualitative content analysis of data collected from reflection logs, meeting transcripts and interviews of one case study found evidence of all four mechanisms describing learning opportunities in the areas of curriculum and pedagogical knowledge. Further analysis and comparison of boundary encounters across cases would surface aspects that promote boundary crossing. These findings could inform the design of teacher collaboration as a source of professional development in interdisciplinary contexts.

Keywords: Interdisciplinary teaching, teacher professional development, teacher collaboration

INTRODUCTION

Interdisciplinary approaches to teaching and learning are often promoted as a necessary means of preparing students to meet the challenges of an increasingly globalised world (e.g. OECD, 2019). However, such approaches are not common features in school curriculum, which is usually structured around discrete subjects. Teachers involved in planning and implementing integrated curriculum often face obstacles such as a lack of pedagogical and curriculum knowledge (Lam, Alviar-Martin, Adler & Sim, 2011). Evidently, inadequate teacher development is an impediment to the successful implementation of integrated curriculum. To address this issue, it has been suggested that there should be an availability of quality integrated curriculum, teacher collaboration and opportunities for professional development (Margot & Kettler, 2019). These three support measures for teachers can take place simultaneously. Teacher involvement in curriculum development and collaboration with other teachers have been reported to be key avenues of teacher learning (Voogt et al., 2011). If the effect of collaborative curriculum development on teacher learning can be demonstrated, the findings could shed light on practical considerations that facilitate the development of interdisciplinary programmes by teachers in schools.

Few studies have looked at the process of teacher learning in the context of developing integrated curriculum in a collaborative manner. In a report where English and science teachers collaborated to plan lesson resources for teaching students to critically evaluate science news media, McClune, Alexander and Jarman (2012) found preliminary evidence of the teachers learning from the process. The study reported in this paper builds upon the findings of McClune et al.'s (2012) study by examining the learning potential of collaborative curriculum development by English and science teachers in a researcher-initiated intervention in secondary schools in Singapore. Together with the researcher (author of this paper), one English and one science teacher form a teacher design team, a type of professional learning circle focused on the (re)design of curriculum (Handelzalts, 2009).

The theoretical approach adopted for the analysis of findings in this study is based on the observation that teachers who participated in interdisciplinary activities often reported learning arising from disciplinary differences (Grossman, Wineburg & Woolworth, 2001). Such differences are often regarded as obstacles for interdisciplinary endeavours, but they can also be opportunities for learning (Wenger, 2000). Since the differences between subjects can also be understood in terms of the boundaries between practices, the attempt to overcome these differences is a form of boundary crossing. According to boundary crossing theory, boundaries are defined as "socio-cultural differences that give rise to discontinuities in action or interaction" (Akkerman & Bakker, 2011, p. 139). When people encounter boundaries of an unfamiliar domain or practice, the act of crossing them opens up "new possibilities of meaning" (Wenger, 1998, p. 109). From the perspective of boundary crossing, teacher learning occurs at the boundaries of interdisciplinary collaboration. After identifying the boundaries, the teachers' attempts at negotiating the boundaries are then examined through the lens of four distinct learning mechanisms – identification, coordination, reflection and transformation (Akkerman & Bakker, 2011). The study is guided by the following research question and sub-questions.

What is the learning potential of teachers' boundary encounters in an interdisciplinary teacher design team?

a. What are the boundaries encountered by teachers in an interdisciplinary teacher design team?
b. What are the learning mechanisms evoked at the boundaries encountered by the teachers?

METHOD

A qualitative case study approach was used for this study. The research intervention was conducted at three secondary schools in Singapore, with a teacher design team (TDT) formed in each school. A TDT comprises an English teacher, a science teacher and the author of this paper taking on the dual role of a researcher and facilitator. Each TDT is analysed as a case. This paper reports on the findings of one of the three case studies.

The two teachers who participated in this research study taught at a secondary school that caters to students from Secondary One to Four (13 to 16-year-olds). The English teacher, Vanessa (pseudonym) had been teaching in the school for a decade. Previously, she taught Mathematics at another secondary school. The science teacher, Rachel (pseudonym) had also been teaching for a decade in the school. She had experience teaching English to Secondary One and Two students for the first five years of her career, before teaching solely Biology for the next five years. Both teachers agreed to the request of their respective heads of department to participate in the study.

The task given by the researcher to the interdisciplinary TDT was to collaboratively develop a lesson to teach students to critically read science news. To guide their planning of the interdisciplinary lesson, the teachers were provided with resources by the researcher. These resources included a learning intentions model developed by McClune and Jarman (2011) and samples of learning activities. The process of lesson planning began with the selection of learning objectives from the "science knowledge" and "literacy skills" domains of the learning intentions model. The teachers then proceeded to design learning activities for the students based on the selected learning objectives. Through a series of six meetings held over a period of seven months from April to November 2020, the TDT developed a teaching plan and accompanying teaching resources for an interdisciplinary lesson. The lesson was conducted during curriculum time in January 2021 for a Secondary Four English class regularly taught by Vanessa. For the interdisciplinary lesson, both teachers were present and co-taught the lesson that lasted for an hour each week for two weeks. The study concluded after post-lesson interviews (30 minutes each) were conducted with the teachers in February 2021.

Each TDT lasted for around 1.5 hours, and the total time taken for all six TDTs was around 8 hours. Data collected from the TDTs was in the form of audio-recorded TDT conversations and individual reflection logs that the teachers were asked to record in a digital template after each TDT session. The template contained a series of open-ended questions adapted from Melrink, Meijer and Verloop (2007), designed to probe the learning experiences of the teachers. The audio conversations and post-lesson interviews were transcribed verbatim and the digital logs were submitted to the researcher after each TDT session. There were three data sources obtained from each of the six TDT sessions, comprising one transcript and two teacher reflection logs. In addition, the teachers each wrote a post-lesson reflection log which was submitted to the researcher.

The material in the teacher reflection logs, TDT transcripts and interview transcripts was processed and analysed using qualitative content analysis (QCA). The foremost step in QCA is the development of a coding frame containing main categories and subcategories. In the context of boundary crossing, the categories were formulated such that they describe the boundary encounters of the teachers. A boundary encounter comprises two components – boundaries encountered by teachers (derived from research sub-question a) and learning mechanisms evoked by the boundaries (derived from research sub-question b). Correspondingly, the two main categories in the coding frame directly reflect these two components (see Table 1). The subcategories for the first main category were derived in an inductive manner from the teacher reflection logs using the steps of subsumption laid out by Schreier (2012). For the second main category, the subcategories are the four learning mechanisms of identification, coordination, reflection and transformation that could be evoked by boundary crossing.

Table 1: Coding frame used to identify boundary encounters.

Category	Description
Main category 1: Boundaries encountered by teachers	
Learning outcomes for critical reading of science news	Teachers are unfamiliar with learning outcomes for critical reading of science news.
Integration of science and English subjects	Teachers experience challenges in integrating science and English learning outcomes in terms of curriculum, pedagogy and assessment.
Science topic for interdisciplinary lesson	Teachers lack knowledge about the science topic selected for their interdisciplinary lesson.
Epistemiologies of science and English	Teachers encounter differences in how the disciplines of English and science view knowledge, in terms of its nature, source and scope.
Curricular practices of science and English	Teachers are unfamiliar with the curricular, pedagogical and assessment practices of another subject.
Working styles	Teachers encounter working styles that are unlike their own.
Knowledge of students' aptitude and inclinations	Teachers make incorrect assumptions about students' aptitude and inclinations with regard to tasks and activities during interdisciplinary lessons
Main category 2: Learning mechanisms evoked at boundaries	
Identification	Discontinuity between practices is identified, but not overcome. - A practice is (re)defined in terms of how it differs from another practice (othering). - Two practices are considered as different, but each is recognised for its own value and contribution (legitimising coexistence).
Coordination	Means and procedures are put in place that establish continuity between practices. - A communicative connection between diverse practices is established. - A person and/or a boundary object translates understandings between diverse practices. - Boundary permeability is enhanced without deliberate choice through changing roles or rituals. - Routines and procedures are established across boundaries.
Reflection	New perspectives are formed about own and others' practices. - As one's awareness and understanding of the boundary grows, they begin to form new perspectives (perspective-forming). - By connecting the knowledge of both practices, one's perspective takes the other perspectives into account (perspective-taking).
Transformation	In response to a problem, elements from different practices are combined to create a solution. - There is a confrontation with an area of inadequacy or problem that causes a reconsideration of current practices. - There is recognition of a shared problem space in response to the confrontation. - Features from different practices are combined to create something new. - The hybrid product is embedded in practice with the help of routines or procedures. - The integrity of the existing fields is maintained while being connected to a new hybrid field. - Continued collaboration at the boundary is carried out to maintain the transformation.

The application of the coding frame to the material in the reflection logs and TDT transcripts was carried out using MaxQDA software. Coding took place in two phases. During the trial coding phase, 30% of the data set was coded twice for the purpose of refining the coding frame. During the main coding phase, all the material in the reflection logs and relevant portions of the TDT transcripts and interview transcripts were assigned to the subcategories in the revised coding frame. After the main coding, the data segments from categories 1 and 2 were arranged according to boundary encounters. The data segments from different sources were aligned with one another to provide a detailed and in-depth description of each boundary encounter.

FINDINGS

The boundary encounters of the teachers in the TDT are grouped according to the domains or practices where the boundary crossing took place. The three boundary encounters that are detailed in this section are divided into two groups, as they either took place at the boundaries between English and science, or between subject-based and interdisciplinary curriculum. To address the research question, the description of each boundary encounter includes the context that gave rise to the enactment of the boundary, the boundary itself, and the learning mechanisms evoked at the boundaries. Examples of all four learning mechanisms are included across the three boundary encounters.

Boundary crossing between English and science subjects

Encounter 1: Making sense of epistemological differences

The first TDT session was a critical reading exercise where the facilitator asked the two teachers to give their critical take on two science news articles. They were also asked to describe how they would use the articles during their respective lessons. As some epistemological differences between English and science became apparent during the discussion, Vanessa went through the identification and reflection mechanisms in their effort to manage the discontinuity.

Identification and reflection mechanisms. The boundary between the two subjects that was evident in the different critical reading perspectives of the teachers was explicated by Vanessa in her reflection log:

> "I looked at how the information was presented in the article but Rachel based on what kind of information was given and how accurate it was, something that a language teacher would not know of…I realised that both of us were reading the articles critically but from different perspectives." [Vanessa's reflection log for TDT1, Apr 2020].

As she learned about an aspect of information analysis that she was not familiar with, she first distinguished the two critical reading perspectives (*othering*) by stating that she focused on language use in the article while Rachel looked at the nature and accuracy of the factual content. She then *legitimised coexistence* of both perspectives by recognising that although they are focused on entirely different aspects of the article, both are valid approaches of critical reading.

Subsequently, Vanessa built upon the identification mechanism to form a new perspective about the role of understanding factual content in her own language teaching:

> "I felt that if my students were able to discern the technical information, then they would be able to focus on how language in an expository writing is used to convey a purpose…the technical ideas and concepts even without the extensive jargon could prove to be a stumbling block to my students understanding the article, what more to understanding it with a critical lens." [Vanessa's reflection log for TDT1, Apr 2020]

After learning about the analysis of factual content from Rachel, Vanessa perceived that focusing on language alone was insufficient in teaching her students to read content-heavy articles with a critical lens. Since language teachers typically do not dwell on the accuracy of factual information in their teaching, Vanessa recognised that this lack of emphasis could negatively impact students' learning, particularly in the area of expository writing. Through the reflection mechanism (*perspective-taking*), she figured that students' language learning needed to be supported by their learning of factual content knowledge.

Encounter 2: A glimpse into the English classroom

A persistent discontinuity that arose from the lesson planning process was that the teachers were unfamiliar with the curricular practices of the subject that they do not teach. To overcome this boundary, the teachers took the initiative to share some of their classroom teaching material with each other.

Coordination mechanism. Although Rachel had experience teaching English, it was confined to the lower secondary levels and she had no exposure to English teaching at the upper secondary levels. This lack of experience caused Rachel to feel uncertain about the students' responses to the critical reading tasks that the TDT planned for them:

> "It was a bit difficult to visualise what Vanessa is talking about sometimes, because we are not very used to what the English department is doing. So I've had to clarify with her some of the things that I don't really understand, or maybe to ask whether we need to scaffold a bit more to make sure that the students know what they're supposed to do, because it's something that is new to us." [Transcript of interview with Rachel, Feb 2021].

After Vanessa granted Rachel access to her Secondary Four students' assignments in Google Classroom, the latter was able to gain an understanding of the skills that the students learned during English lessons:

> "…because we shared some resources, I got to see some of the things that they do in class. And she actually let me join Google Classroom. So, it's interesting to see the students' discussion, their daily work as well, which is quite similar to what we did for the critical response lesson… so it's quite eye-opening to see what the English department is doing." [Transcript of interview with Rachel, Feb 2021].

The online repository of students' work served to *translate* the meaning of the learning objectives of English for the science teacher, allowing her to observe similarities with a critical response lesson she had previously conducted for her biology students. Learning from the visual documentation of students' assignments helped Rachel to cross the boundary between the curricular practices of English and science.

Boundary crossing between subject-based and interdisciplinary curriculum

As the teachers were new to the collaborative development of interdisciplinary curriculum for the critical reading of science news, they faced uncertainties in approaching the integration of their subjects. Moreover, the English and science learning outcomes that they selected from the learning intentions model were confined to their respective subject domains. The teachers had to conceptualise their own approach of curriculum integration.

Encounter 1: Developing a hybrid pedagogy

Transformation mechanism. In the midst of the lesson planning process with Rachel, Vanessa was *confronted with a problem* that became more pressing as the teachers continually sought ways to integrate the learning outcomes from English and science:

> "I felt frustrated at times as I do not want this to be another typical English lesson on responding to texts critically. The students need to see that it is a collaboration between the science and English departments. I hope that with this, the students would begin to use the skills and strategies they have learnt in English to their other subjects when they come across information – that our students become even more discerning users/receivers of the language." [Vanessa's reflection log for TDT4, August 2020].

Vanessa wanted the interdisciplinary lesson to present an opportunity for her students to transfer their language skills to other subjects, but she still felt that the science aspect was not prominent enough for the transfer of learning to occur. Besides noting it down in her reflection log, Vanessa also expressed this concern during the fifth TDT meeting:

> Vanessa: So how do we put that, I mean, how, in the sense that when we look at a product, we will look at what they have given us or what they have delivered, we can see that they have understood that you know, that critical thinking and critical reading is not just about...it's not just an English skill, but it's a skill, it's a life skill that can be applied to other disciplines as well.
>
> Rachel: I was thinking if we want to do a hot-seating, Hot Seat activity right, because they are adopting different perspectives, but no matter what role they adopt, they have to provide evidence for whatever claim they make-
>
> Vanessa: Correct.
>
> Rachel: Could we maybe create some sort of note-taking template for them when they listen to the questions posed to the people in the hot seat? For the explanations, usually in science we use the Claim-Evidence-Reasoning structure. A thinking routine to get them to explain certain claims that they make.
>
> Vanessa: Like that, what it means is that we can actually use a science strategy in terms of the note-taking right…Then, you know, the moment we use the science strategy with an English...then maybe they will see 'Oh, actually, you know, we can use skills from other disciplines to help us to understand'. [TDT 5 transcript, Aug 2020].

In response to Vanessa's concern about the lesson being a predominantly English one, Rachel suggested a *problem space* where the science learning objectives could be tied to the English learning objectives through the learning tasks given to the students. Since they had decided to carry out a hot-seating activity where students in the "hot seats" took on the roles of different stakeholders in a discussion on the ethics of organ transplants, they could leverage on the activity to integrate the outcomes of English and science.

Rachel's idea of adopting the thinking routine called "Claim-Evidence-Reasoning" (CER) as a template to guide students' thinking was well-received by Vanessa as she viewed it as a "science strategy" that would signal to the students to apply their critical reading skills to another subject besides English. Moreover, the CER template could fulfil the dual learning objectives of English and science – students being able to give reasons for their stand about an issue, and students being able to use scientific knowledge as supporting evidence for their claims. As such, the CER template was a *hybrid* pedagogical tool for the interdisciplinary lesson.

DISCUSSION

The findings of this study present an effort to understand how teacher learning takes place in an interdisciplinary context. From the perspective of teachers' attempts at boundary crossing during interdisciplinary collaboration, it is evident that the teachers gained renewed insights about teaching practices both within and beyond their subject areas. Furthermore, the teachers devised a means of integrating learning outcomes from English and science through a pedagogical tool. For this interdisciplinary TDT, the learning opportunities for teachers included gains in curricular knowledge, changes in perceptions about student learning and increased understanding of the applicability of pedagogical approaches across subjects.

Although the learning took place in the context of planning for an interdisciplinary lesson, the varied nature of the learning and the connections the teachers made with their own practice raise the possibility that it can influence the teachers in their day-to-day work. However, as the longer-term effects of the interdisciplinary TDT are not within the scope of this research study, it cannot be ascertained if the learning of the teachers is sustained and/or translated into beliefs or practice.

This teachers in this case study participated voluntarily in a small-scale intervention that was not part of any school-mandated programme. In this regard, the study circumvented the administrative and logistical barriers typically associated with large-scale interdepartmental collaboration in a school setting. As the interdisciplinary lesson was a standalone one that was not part of the usual school curriculum, the teachers were not overly constrained by curricular and assessment requirements. While research on interdisciplinary teaching tends to highlight the factors that hinder its implementation, this research focuses on the rich learning potential of teacher collaboration in contexts where some of these barriers are largely absent, for example, where structure and support are already established for interdisciplinary school programmes.

Clearly, participation in an interdisciplinary TDT has given the teachers an opportunity to broaden their subject and professional knowledge, opening the doors to interdisciplinary thinking in the process. Such thinking is essential for the effective implementation of integrated curriculum (McPhail, 2018). If the opportunities for boundary crossing in interdisciplinary collaboration can be enhanced, then the likelihood of teacher learning would increase. As one of the cases in a multi-case study, the findings from the TDT reported in this paper will be compared with those from two other case studies to elucidate the features of interdisciplinary TDTs that promote boundary crossing. Based on these features, recommendations will be made regarding the design of interdisciplinary collaboration as a source of professional development for teachers.

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COLLABORATIVE GROUPS & TEACHER PROFESSIONAL DEVELOPMENT: CONTRIBUTIONS FROM AN EXPERIENCE IN BRAZIL

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In this article, we present the results of collaborative action research, which aimed at fostering the professional development of a group of science teachers, based on critical reflection on teaching practices and approximation with the research carried out in the field of Science Education. The actions of the group were guided by discussions of articles related to teaching and reflection on their teaching practices, based on the production and video recording of didactic sequences using the reflective cycle proposed by Smyth (1989). The data sources for the research were the teachers' textual productions, the field diary, and the focus group carried out at the end of the process. Content Analysis was used to identify some evidence of the reflection and collaboration process. The data indicated that the process provided a movement of reflection and change concerning the role of the teacher from a transmitter to a mediator of the learning process; the approach to research in the education area, both from the perspective of critical "consumption" of its results and from the perspective of producers of knowledge, considering that teachers were simultaneously constituted as actors and authors of their practices, sharing them both with the community of teachers and with researchers. The collaboration among members was built throughout the process so that we identified all through the group's trajectory the progressive development of the forms of collaboration described by Little (1990), marked by growing levels of interdependence among teachers: i) storytelling and scanning for ideas, ii) aid and assistance, iii) sharing and iv) joint work.

Keywords: Collaboration, Reflection, Teacher Professional Development.

INTRODUCTION

In the last decades, many works have focused on teacher professional development (TPD) and the analysis of the processes of learning how to teach, given the importance of teachers in student learning (Darling-Haimond *et al*., 2017). According to Marcelo (2009), the TPD has been considered a collaborative and flexible long-term process of change for teachers, seen as practical-reflective, involving the active construction of knowledge contextualized in teaching practices and aimed at the reconstruction of school culture. In line with this perspective, we consider critical reflection on teaching practices, collaborative work among teachers, and the production and resignification of knowledge by them as fundamental to TPD.

According to Alarcão (2011), the reflective process involves a triple dialogue - with oneself, with others, and with the situation, to reach an explanatory and critical level. Freire (2007) highlights critical reflection on practice, allowing the critical consciousness to overcome naive curiosity. Both authors refer to reflection and consciousness levels about reality, valuing the systematization of knowledge, methodical rigor, and dialogue as strategies to move from a descriptive level that characterizes the naive consciousness to an explanative, argumentative, and transforming one, characteristic of critical consciousness (Freire, 2007). In this direction, Smyth (1989) proposes a sequence of four hierarchically organized actions (Smyth's cycle) to guide critical reflection on practice, as a means of professional development: describing (What do I do?), (b) informing (What does this mean?), (c) confronting (How did I come to be like this?), and (d) reconstructing (How might I do things differently?).

Several studies have pointed out the potential of the collaboration between teachers to their professional development (Bassoli, 2017; Darling-Hamond *et al*., 2017; Parker *et al*, 2021; Vescio *et al*., 2008; Vaillant, 2016) increasing the studies about what has been described in the literature as collaborative groups (Megid & Wasconcellos, 2015), communities of practice (Wenger, 1998) or learning communities (Parker *et al*., 2021). However, few studies have analyzed the collaboration meanings and forms and their relationships with the TPD. In this sense, Little (1990) distinguishes collaboration from artificial collegiality and describes four collaboration forms (storytelling and scanning for ideas, aid and assistance, sharing, and joint work), respectively relating them to increasing levels of interdependence among teachers.

Having the above perspectives outlined as a theoretical framework, as members of a research group focused on teacher education, we have encouraged the emergence of collaborative groups, composed of basic and higher education teachers, through a powerful partnership established with the Science Center of the Federal University of Juiz de Fora (Brazil). Such groups are understood as collaborative because they have the following characteristics that guide their *modus operandi*: voluntary participation, sharing of objectives, acceptance of the need to rethink their practice, and democratic decision-making (Megid & Wasconcelos, 2015).

In this work, we will discuss an experience with a collaborative group, which is circumscribed in a double movement: of training, through collaboration among teachers, and of research on this process, in which we seek to bring contributions to the questions: What are the contributions of the collaborative group to the participants' TPD? What is the role of collaboration (and its different forms) in the participants' TPD?

METHODOLOGY

This research was developed within the scope of the first author's doctoral process. The methodology used in the research was Collaborative Action Research (Ibiapina, 2008), which involves both training and researching on the process.

The collaborative group consisted of the authors of this work and four other teachers from basic education in the Natural Sciences field, mentioned in the research as Elza, Lisa, João, and Flávia. The group meetings were weekly, 3 hours long, totaling 27 meetings that occurred in the Science Center of the Federal University of Juiz de Fora, located in southeast Brazil.

The objectives of the training process, agreed with the teachers since the beginning of the process, were: to promote an approach to research in science education; to produce didactic sequences fomenting innovations in teaching based on research in science education; to stimulate critical reflection on teaching practices and the production of knowledge from research on the practice itself; to socialize the knowledge produced through the publication of a book and participation in scientific events.

The training process was organized in five phases described in the table below:

Table 1. Phases of the training process, duration, and developed actions.

Phase	Duration	Developed actions
1st	6 meetings	**First approximations between the members of the group and of these with the theoretical references:** discussions about the contexts in which teachers work, difficulties, conceptions and expectations, discussions of scientific articles, related to issues raised by teachers or researchers.
2nd	7 meetings	**Preparation of a project or teaching/research sequence:** Planning teaching sequences from the Science Technology and Society perspective (Karisan & Zeidler, Ramsey, 1993), considering the demands of the contexts in which teachers work. Travel to the city of São Paulo to get to know a model school and different non-school spaces for science education.
3rd	7 meetings	**Teachers in action in schools**: development of teaching sequences, which were video recorded.
4th	3 meetings	**Reflective analysis of the video recorded classes:** selection of the most significant episodes of the classes for the realization of Smyth's cycle (Smyth, 1989). Presentation to the group and collective discussion.
5th	4 meetings	**Sharing constructed knowledge**: production of communications in scientific events, book chapters, and experience reports.

Source: Survey data.

Data were collected through participant observation (which generated a field diary), video recordings of group meetings, interviews, focus group, and textual productions by teachers. The focus group, understood as a set of people selected and brought together by researchers to discuss and comment on a topic, which is the object of research, based on their personal experience (Gatti, 2012), was carried out after the end of the training process using a semi-structured script, in the Science Center. It had the participation of all members of the group and lasted approximately 2 and a half hours, being recorded in audio.

As a strategy to enhance critical reflection on pedagogical practices, we used the video recordings of the participating teachers' classes and their analysis based on the actions proposed by Smyth (1989): describing, informing, confronting, and reconstructing. After individual reflection, group discussions were held, expanding the reflective process. The data were analyzed using Content Analysis (Bardin, 1977).

RESULTS AND DISCUSSION

Based on the objectives of this research and the conception of TPD adopted, when reviewing the trajectory of the participating teachers, we found several indications of the TPD process triggered during the process with emphasis on: a critical reflection on practices, focus on learning, the curriculum, and the political-professional context; the search for change concerning the role developed in the classroom: from the transmitter of knowledge to that of the mediator; the production of knowledge based on reflection and research on the practice itself; (re) investment in the professional development process - understood as a long-term process that accompanies the entire teaching career - and the improvement of collaboration among teachers in this development process.

Critical reflection on the practice itself was the guiding axis of the group's actions, thus, we used several strategies to provide it, such as appreciation and problematization of experiences narrated by teachers, discussion of articles, recording of classes by teachers, and group discussion from Smyth's cycle, as well as text writing.

The development of critical reflection could be identified at different times, not only concerning the practice itself, but more broadly, considering the three axes of teaching action defined by Cachapuz and colleagues (2004): "epistemological axis", "learning axis", "curriculum axis", and also the political-professional axis (Bassoli, 2017).

We will highlight below some reflections triggered by Smyth's cycle on the role of teachers in the learning process since, from the analysis of their classes, they perceived inconsistencies between their discourses and their practices, when they are predominantly assuming the role of transmitters, rather than mediators.

> *"The research helped me support my practice, but also rethink it. Is my discourse consistent with my practice"*? (Lisa).

> *"I see myself reproducing the way I was taught: transmission-reception, and I see that my students are not participative subjects in their learning"* (Flavia).

> "*I realized from the filming that I was not exactly sure how to ask the questions"* (Elza).

According to Marcelo (2009), one of the characteristics of the TPD perspective is that "the teacher is considered a reflective practitioner, someone who has previous knowledge when accessing the profession and who is acquiring more knowledge from a reflection about his experience" so that the professional development activities "consist in helping teachers build new theories and new pedagogical practices" (p. 10-11). It was also pointed out by Carvalho and Gil-Pérez (2006) as a need for training Science teachers: "acquire the necessary training to combine teaching and didactic research."

In this way, it was possible to identify, throughout the process, the teachers' development of skills related to research on their practice - such as video recording of classes and conducting reflective cycles based on the actions proposed by Smyth (1989), as well as the development of skills related to the recording in written form and systematization of the results for their socialization. Also, it was possible to perceive in the teachers' discourse the appreciation and recognition of the importance of teachers' research, as well as the complexity and difficulties involved in the process of researching their own practice, as follows:

> "*With the participation in the group, it became clear to me, that although I read a lot, I was constantly seeking to master and improve the content that I didn't know how to research. There were some advances, I did not report the results, though.*" (Lisa).

> "*The discussions about the difficulties in the school environment, about how and what to teach and how to be teacher-researchers, made it possible for me to realize the importance (and the challenges) of researching my own practice, in order to contribute to the training of students. (...) It is important to highlight that this reflection became possible when I started to discuss and appropriate the literature on 'teachers as researchers', as well as when analyzing my classes through videos*" (Flavia).

Smyth's cycle initially allowed for individual reflection, but when it was shared with the group and systematized - as the teachers did when they wrote reports and chapters in a book (Bassoli, Lopes & Cesar, 2015), it favored a dialogue "with others", assuming an explanatory and critical level that allows "education professionals to act and speak with the power of reason" (Alarcão, 2011, p. 49). Thus, we realize the importance of theoretical frameworks for the reflection process, as expressed by Flávia, who demonstrates an alignment with the constructivist perspective, addressed throughout the process, and uses it as a parameter for analyzing her practice, confronting it.

> *"These video recordings, in addition to Smyth's cycle, proved to be powerful tools for analyzing my own practice, enabling me to become aware of some characteristics of my class that were not transparent to me (...). Thus, I do not allow this student to be participative, creative, nor do I offer support for him to build his own knowledge"* (Flávia).

In the same direction, João has used the theoretical references discussed in the group for the critical analysis of both the practice itself and its initial training, pointing out "the need to break with a series of paradigms, including the conception of neutral and unquestionable science and our vision of teaching and the role of the teacher" (João).

Thus, we understand that the training process provided an approach to research in education, contributing to the development of "teachers as researchers" (Roth, 2007), both from a perspective of critical "consumption" of its results and from a knowledge production perspective, considering that teachers were simultaneously constituted as actors and authors of their practices, sharing them both with the community of teachers and with researchers.

From the analysis of the group's trajectory, it was possible to understand that the collaborative character was procedurally being developed so that it was possible to identify along the group's trajectory (Figure 1) the development of forms of collaboration described by Little (1990): i) storytelling and scanning for ideas, ii) aid and assistance, iii) sharing and iv) joint work. In this sense, the development of these forms of collaboration was related to the deepening of interpersonal relationships, involving a growing professional interdependence among the group members, which evolved from narratives and exchanges of ideas towards joint work.

The first form of collaboration involves the exchange of informal experiences so that, in the construction of these stories, personal and social interests are often underlying. In our group, teachers' reports about daily occurrences in their schools were constant, especially in the initial moments of the meetings, sharing their anxieties and experiences with the other members of the group.

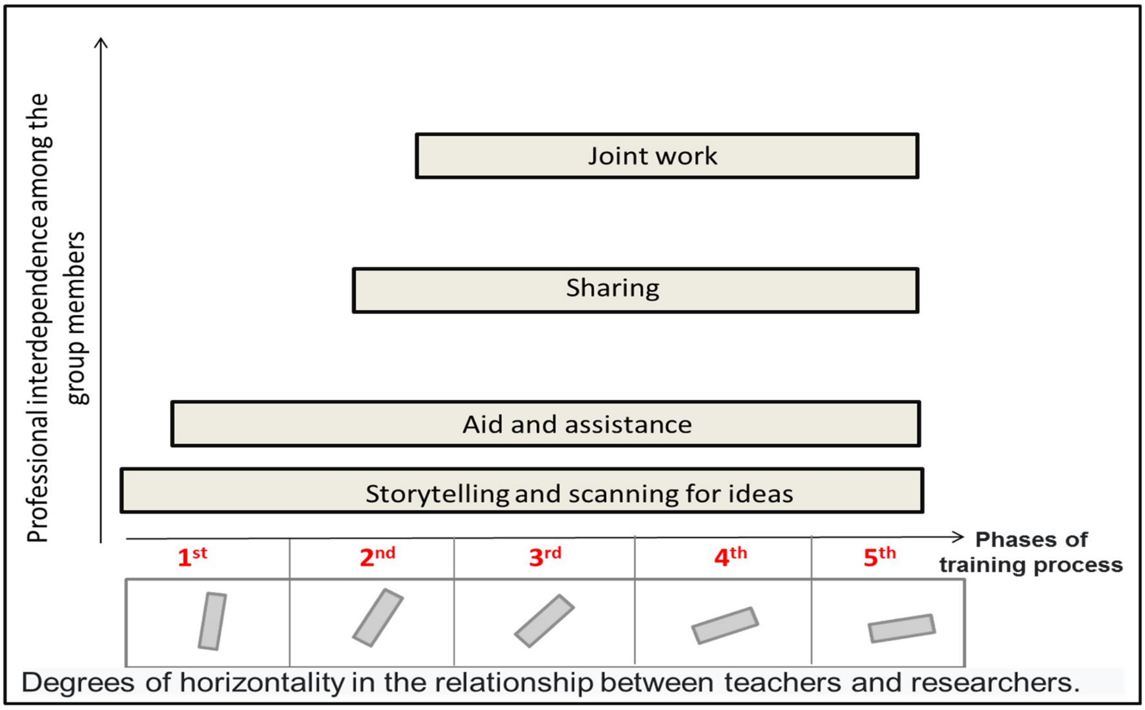
> *"I see clearly today, after our meetings, that continuing education is essential for a well-structured teaching practice, that* ***having someone to share our anxieties with helps us in our understanding of the school dynamics****".* (Lisa).

We agree with Louden (1992) that narratives are also configured as a form of reflection, relating to the first action proposed by Smyth (1989) in the DPD context, describing. However, we understand that they, by themselves, do not provide critical reflection, unless subjected to problematizing.

The second form of collaboration, "aid and assistance", was also valued by members of our group, as expressed below in Flavia's speech:

> *"From my participation in this first planning-action-reflection cycle, I found myself faced with numerous difficulties (...). However, **with the support of the group, I gradually overcame such difficulties** and developed a more critical view of my teaching practice"* (Flávia).

According to Little (1990), in many cases, help is provided according to a logic of technical rationality, usually from the specialist, who can be another, more experienced teacher. We realized during the first meetings (1st phase) this expectation towards us, authors. Therefore, we always seek to place ourselves in a position of non-centrality and non-authority concerning others, understanding that our role would consist of problematizing the narratives and actions to favor the explanation and understanding of their meanings. In this way, we gradually built a more horizontal relationship with the teachers, which is represented in the Figure 1, that systematizes the forms of collaboration developed throughout the group's trajectory, evolving from narratives ("storytelling and scanning for ideas") to relationships with increasing levels of interdependence between participants ("joint work").



Source: Bassoli (2017).

Figure 1. Representation of collaborative relationships that occurred throughout the phases of the training process and the process of horizontalization of relationships between the researchers and the teachers.

The third form of collaboration, "sharing", corresponds to an exchange of materials, methods and ideas, occurred as teachers created bonds of affection and trust. According to Little (1990), exposing their materials and ideas to others represents a conception of collaboration that is less private and more public, fostering a climate of sharing, which only occurs when teachers feel enough confidence to expose themselves, appearing as a path rich in potential for their professional development. That being so, we noticed that in the first meetings of the group the narratives were predominant, however, with the establishment of a climate of openness and trust, sharing began to occur at a different time for each of the group members.

Dialoguing with the actions of Smyth (1989), but beyond individual reflection, we understand that sharing is an important step towards the action of informing, if, when sharing teaching practices and materials, the theories underlying these practices are also explained.

> "*As the* ***reflections and exchanges of experiences took place****, I was led to reflect on another issue related to my teaching practice: the lack of planning. And,* ***with the group****, I was able to see how much this organization could contribute (and, in fact, it helped me) to the effectiveness of my actions as a teacher*". (Flávia)

Additionally, Little (1990) also points out joint work – which is based on the vision of meetings between teachers based on shared responsibility for the work of teaching, on the idea of collective autonomy, on supporting the initiatives and leadership of the teachers with regard to professional practice, which may involve the planning of a set of tasks performed by everyone, in an interdependent manner, or the definition of a set of base criteria that guide the independent action of each one in their classes. We understand that this form of collaboration has greater potential to enable the confrontation and reconstruction of practices unless there is a group intention to problematize them, otherwise, there is a risk that the group is always legitimizing their maintenance.

In the excerpts transcribed above, the teachers claim that the group provided them with exchanges of experiences, emotional and professional support, in addition to encouraging reflection; consequently, contributing to the professional development of the participant teachers of the collaborative group.

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TEACHERS' BELIEFS AND GOALS CONCERNING INQUIRY-BASED SCIENCE

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For several decades now, inquiry-based learning has been an important element of science education. However, research findings show that inquiry-based learning is applied only rarely in science classes. To increase the implementation of inquiry-based learning, professional development programmes that address science teachers' beliefs and attitudes need to be offered. In the course of a teaching initiative, we created a respective programme and investigated the participating teachers' beliefs and goals concerning inquiry-based science. The programme lasted about six months and was attended by teachers from five schools. For the purpose of data collection, we conducted two group discussions with the participating teachers, one at the beginning and one at the end of the programme. The data were analysed in two steps: In the first step, the transcripts of both group discussions were analysed via qualitative content analysis, facing differences in beliefs and dispositions between the first and the second group discussion. During this analysis, it became apparent, that the formulated goals and beliefs were fostering and hindering factors for teachers when making decisions about the teaching methods. For further analysis, we applied the Documentary Method according to Bohnsack. This approach shed light on teachers' tacit knowledge. The reconstructed orientational frameworks show that the participating teachers see "inquiry" as contradictory to "learning" at school. This might constitute one obstacle to the implementation of inquiry-based learning that has not been considered yet.

Keywords: inquiry-based learning, professional development, qualitative methods

INTRODUCTION AND CONTEXT OF THE STUDY

Inquiry-based learning (IBL) has been considered an important part of science education for decades now (Dewey, 1910; Schwab, 1960). As engaging in science practices is indispensable for students to acquire scientific literacy (Barron & Darling-Hammond, 2010; Roberts & Bybee, 2014) instructional approaches such as IBL have been incorporated in several science curricula and standard documents (e.g., BIFIE, 2011; NGSS Lead States, 2013; NRC, 1996). Nevertheless, international studies indicate that IBL is still not or only rarely implemented in most of science classes (Capps et al., 2016; Forbes et al., 2020; Hofer et al., 2016). To foster the implementation of IBL, it is unrewarding to develop an abundance of "ready-to-use" material. Instead, teachers need to be supported in professional development programmes that address their beliefs and dispositions towards IBL and meet their individual needs (Capps et al., 2012; Darling-Hammond et al., 2017).

The Austrian initiative IMST (Innovations Make Schools Top!) aims at promoting the pedagogical development of schools by supporting teachers in implementing innovative pedagogical approaches in their own classes. The initiative started in 1998 and is financed by the University of Klagenfurt and the Austrian Federal Ministry for Education, Science and Research. Despite providing a manifold support system for in-service teachers (regional networks, provided instructional material, project supervision, financial contribution to material costs etc.), IMST offers professional development programmes that bridge the gap between science education research and teachers' classroom practice. IMST encourages teachers to conduct own action research projects (Laudonia et al., 2018) to evaluate developed material, instructional strategies or their own classroom practice (Krainer et al., 2019).

As science education researchers working for the initiative IMST, we developed a professional development programme called 'Inquiry Steps'. In the course of the pilot phase of this programme, we collected data for two purposes: programme evaluation and science education research. In the following, we give an overview of the professional development programme and provide an insight into initial results of our research.

DESIGN AND METHOD

Inquiry Steps is a professional development programme that aims at promoting schools' pedagogical development by implementing IBL in schools' science programmes. For this purpose, science teachers are supported in planning and applying IBL units for their own science classes. In the 2019/2020 school year, *Inquiry Steps* was offered the first time. In this pilot phase, teachers from five schools (all levels from primary to upper secondary school) participated in the professional development programme. The participating schools were required to delegate teams of teachers (at least two teachers per school) collaborating in a project in order to establish a structural basis for IBL at the school, thus increasing the impact of the professional development programme regarding the schools' pedagogical development.

Overall, the pilot phase of the professional development programme lasted about six months and was organised in two strands: the professional development strand and the research strand (see Figure 1). Arranging the programme in two strands allowed us to fulfil the professional development goals while pursuing our research interests at the same time.

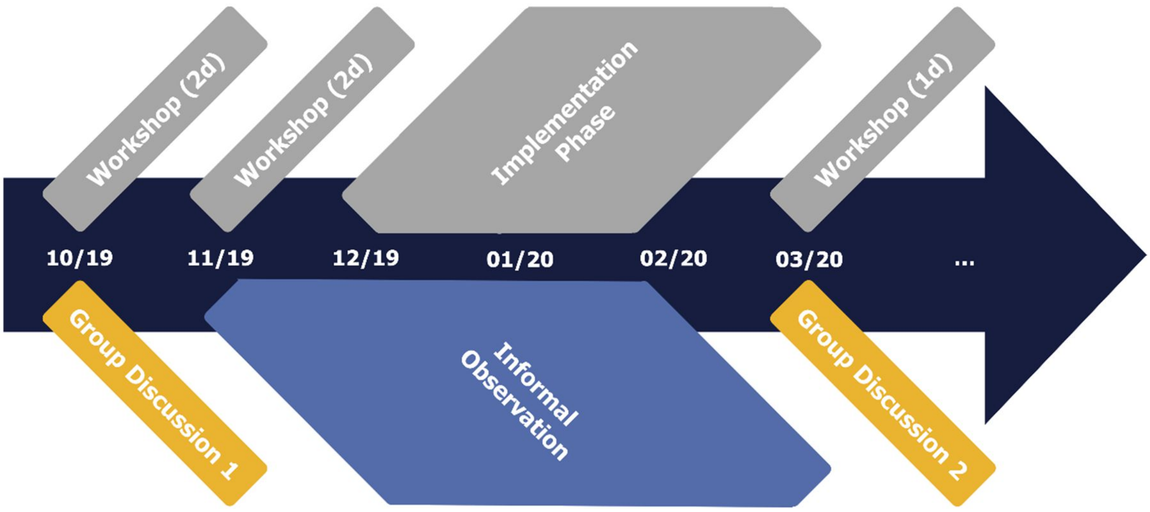

Figure 27. Schedule of the programme *Inquiry Steps* in the pilot phase. The upper part of the figure (in grey) shows the professional development strand, the lower part addresses the research strand (Hofer et al., 2020).

The professional development strand

As shown in Figure 1, the professional development strand of *Inquiry Steps* consisted of two different elements: three workshop parts (five days in total) at the University College of Teacher Education Lower Austria and one implementation phase at the teachers' own schools. In the first workshop part, the participating teachers formulated their individual expectations and needs and presented ideas for IBL-projects at their own schools. Beyond that, science education researchers provided a theoretical framework for IBL to the teachers. In short presentations, teachers learned about the instructional goals for IBL (Abrams et al., 2008), the levels of openness of IBL (Blanchard et al., 2010) as well as of scaffolding (Hammond & Gibbons, 2005) as an indispensable instructional strategy when implementing IBL in science classes. Beyond that, teachers got to know the principles of the Universal Design for Learning (Baumann et al., 2018) in order to consider their students' diversity. Based on this theoretical framework, the teachers were asked to revise and – if necessary – to re-design their initial project ideas.

The second workshop part focused on teachers' views of scientific inquiry. For this purpose, the teachers visited a research institute where they had the opportunity to keep in touch with "real" researchers in an authentic setting. During this visit, the teachers got an insight into a couple of research projects and had the possibility to talk to the researchers and ask them questions about their projects and activities. After this visit, the teachers discussed and reflected their views on scientific inquiry with the science education researchers followed by a brief input about Nature of Science (Lederman et al., 2013). Thereafter, the work on the IBL-projects was continued: the teachers specified and refined their project goals, worked on the planned instructional strategies, outlined the experimental setting and the required equipment, and started to create the teaching materials (e.g., information or instructional sheets) for the planned IBL units. After this workshop part, the teachers had to continue the work on their projects individually. In this phase, they were supported by the science education researchers. Beyond that, each team had the possibility to get financial contribution to material costs by the initiative IMST. After the teachers had finished the instructional design and the required equipment was available, the planned IBL units were proved with students (implementation phase).

In the third workshop part, the teachers presented their final IBL-projects to the other participants of the professional development programme, talked about their impressions and shared the experiences they made in the course of the implementation. Moreover, they were asked to reflect on successful and improvable aspects of their units and had to formulate plans for the sustainable implementation of the projects in their schools' science programme.

The research strand

In parallel to the professional development aspects of *Inquiry Steps*, we collected data in order to evaluate the professional development programme and pursue our research interests in the field of teacher professional development regarding IBL (see Figure 1). The focus of our research interest was reflected by the following research questions: What are the teachers' beliefs about and dispositions towards IBL prior to and after their participation in the professional development programme *Inquiry Steps*? Are there any differences?

To answer these questions, we conducted two guided group discussions (Cohen et al., 2018), one at the beginning and one at the end of the programme. Beyond that, we made informal observations in the time in between (see Figure 1). Both group discussions lasted about 60 minutes, were audiotaped and fully transcribed. To analyse the data, we applied the method of qualitative content analysis combining a deductive and inductive approach (Kuckartz, 2014). The categories used in the deductive step of the analysis were taken from Abrams et al. (2008) and Hofer et al. (2018), respectively. After having analysed the data deductively according to the main categories (learning environment, objectives, scaffolding), we inductively completed the coding manual by developing or revising subcategories.

In order to gain deeper insights into teachers' beliefs and dispositions, we decided to analyse the data one more time by applying the Documentary Method (Bohnsack, 2010). As suggested by Bohnsack (2010), the Documentary Method is especially useful to explore the tacit knowledge of participants in group discussions. When analysing data with the Documentary Method, the analytic stance has to switch from immanent to documentary meaning, from the question "What?" to the question "How?" (Bohnsack, 2010). To achieve this, we answered the "What?" in a first step by writing a formulating interpretation of the group discussions. In the next step, we selected those sequences of the transcript where many teachers were involved in the discussion and analysed these sequences more in-depth in the form of a reflecting interpretation (Bohnsack, 2010). As a result, we were able to reconstruct teachers' implicit orientations towards IBL that will be presented further down.

RESULTS

The results of the first step of analysis (qualitative content analysis) showed that the teachers extended and deepened their knowledge about IBL in several aspects, however, some of the gap identified in the first group discussion persisted even after the teachers' participation in the programme *Inquiry Steps*. For example, some of the teachers denied the necessity of a research question as starting point for IBL. The goal "learning about inquiry" (Abrams et al., 2008) was not mentioned by the teachers at all. Moreover, the teachers claimed that IBL would not match the curriculum and that younger students would be able to carry out research intuitively while older students could not carry out research anymore. The results of the qualitative content analysis are presented in detail in Hofer et al. (2021).

In the course of the qualitative content analysis, some parts of the group discussion arouse our attention. It seemed that the participating teachers would hold a common orientation towards learning that contradicts IBL in school science. This view of 'learning' is reflected in sequences such as the following (translated from German):

> *B146: […] That means I am learning a lot of things* <u>*alongside*</u>*, although I have the feeling that I am actually* <u>*not*</u> *learning anything, yes.*
>
> *B147: Mmm.*
>
> *B148: Well, I don't have to sit down and* <u>*learn*</u> *something, I learn* <u>*alongside*</u>*.*

Following this "discovery", we looked for parts of the discussion where teachers spoke about 'learning' and used the documentary method to reconstruct teachers' views on *learning* and on *inquiry*. For this step of data analysis, the following question was central: "Which shared orientational frameworks for *inquiry* and for *learning* can be reconstructed from the group discussions?" In the following, we present the reconstructed orientational frameworks on *inquiry* and *learning* in a first step and contrast them in a second step.

Applying the Documentary Method showed that teachers see *inquiry* as something positive and joyful. It is like playing, where students take active parts in and no predefined goals are needed. *Inquiry* allows for trial and error; it is open for alternative ways. Students are intrinsically motivated for *inquiry*. If they are motivated and interested in the problem, students will do some kind of *inquiry* automatically.

Reconstructing teachers' views on *learning*, we were able to identify different types of *learning* in teachers' mind. *Learning* is viewed differently depending on the area of application and the students' age. One type of learning we were able to reconstruct describes learning from the perspective of learning in early childhood. This type of learning is considered to be natural, consisting of trial and error and guided by the question "What happens if…". Contrary to this type of learning (*early childhood-learning*), learning as it takes place at school (*school learning*) is considered to be guided and artificial. There is no room for alternative ways or trial and error in *school learning*. Regarding students' age, teachers differentiate between younger students who rely on material – they learn intuitively by trying things out (haptically) – and older students who need concrete instructions and guidelines for learning.

In Table 1, the reconstructed orientational frameworks of *inquiry* and *school learning* are outlined by a few contrasting aspects. Comparing the two columns of Table 1, it becomes apparent that teachers' views on *inquiry* and teachers' views on *school learning* are not compatible – they are even contradictory. While *inquiry* is seen as joyful and playful, *school learning* is described as exhausting and joyless. *Inquiry* is seen as intrinsically motivated connected with students' active role, whereas they have a passive role in *school learning*, which is seen as rather passive. *Inquiry* is seen as open, something for that trial & error represents an appropriate method. *School learning* – on the opposite – has to be restricted and straightforward.

Table 1. The contradictory orientational frameworks for *Inquiry* and *School Learning* reconstructed from the two group discussions.

Inquiry	***School Learning***
joyful, playful	joyless, exhausting
intrinsically motivated	extrinsically motivated
active, students as producers	passive, students as consumers
open, trial & error	restricted, straightforward

In summary, *inquiry* as it is seen by the teachers is rather compatible with *early childhood learning* than with *school learning*. The older students become; the more *learning* diverges from *inquiry*. At the higher secondary level, *inquiry* is seen as effectively incompatible with *school learning*.

DISCUSSION AND CONCLUSION

The reconstructed opposing orientational frameworks for *inquiry* and *school learning* are worth discussing in terms of the implications for IBL. Teachers seem to associate IBL with their orientational framework for inquiry rather than with learning at school. This leads to contradicting goals for IBL and for traditional science classes. Teachers find themselves in a conflicting situation when trying to implement IBL what could explain findings from previous studies, where a focus on content learning was identified as an antipole to a focus on procedural skills and joy in conducting experiments (Hofer et al., 2018; Koliander, 2017). This conflicting orientational frameworks might be an obstacle for implementing IBL that has not been considered yet. As the conflicting orientational frameworks may impede the implementation of IBL, they need to be explicitly addressed in teacher education and teacher professional development, e.g., by giving pre- and in-service teachers the opportunity to reflect on their own views on *Learning* and *Inquiry*.

To find more evidence for this hypothesis, we will continue our research by analysing data from other projects (interviews, teachers' reports on action research projects) addressing teacher professional development in the field of IBL. Applying Documentary Method to these data as well, we aim at developing types of teachers' views on *learning* and *inquiry*.

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PHYSICS TEACHERS' TRAINING WEBINARS FOR TEACHING AND LEARNING INTRODUCTORY THERMODYNAMICS IN UPPER SECONDARY SCHOOL

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This study refers to a training program addressing upper secondary school physics teachers for the development of Teaching and Learning Sequences (TLSs) for introductory thermodynamics courses. To accomplish that, we presented essential epistemological and pedagogical elements of thermodynamics and proposed an alternative approach to the relevant lessons. To investigate the status of teachers' knowledge and approach to teaching and learning of this field, we conducted an online survey addressing physics teachers in the educational district of central Athens (Greece). The pre-webinar results (N=42) indicated that teachers were rather disappointed with the traditional approach that the official curriculum promotes, and they agreed on enhancing their respective knowledge and skills to design and implement a TLS that could improve the course and advance the respective educational research. The training program was held through four webinar sessions that lasted two hours each. The participants were 30 in-service physics teachers from different upper secondary schools in Athens. The webinars addressed the teaching and learning of introductory thermodynamics in terms of (a) epistemology, (b) traditional instructional approach, (c) alternative instructional approaches, and (d) design of a TLS. For the evaluation of the training program, we collected qualitative data during the webinars and after the last webinar, using recordings of four group discussions and five semi-structured interviews accordingly. Our results indicated that participating teachers were willing to change their traditional instruction towards a research-based TLS.

Keywords: physics teacher education, introductory thermodynamics, teaching and learning sequences

THEORETICAL FRAMEWORK

Theoretical framework for physics teachers' training

Contemporary science education research reveals that school students and university beginners engage with thermodynamics courses mostly in a superficial way, memorizing formulas and computational methods but not profoundly constructing essential concepts and laws. The pertinent research indicates that proper changes in introductory thermodynamics at the secondary school level can make a long-lasting difference (Leinonen et al., 2012).

Physics teachers' training can play a crucial role, especially when the official curriculum follows a rather traditional approach, in the sense that it has not been informed by recent research evidence. In such cases, a training program aims to intervene in the internal didactic transposition for the school knowledge to be taught (Christiansen & Rump, 2008); in other words, to facilitate teachers reorganize the content they have to teach to make it truly accessible to the students.

To accomplish that, teachers' readiness to redesign their Teaching and Learning Sequence (TLS) for their thermodynamics courses, is vital (Dunn et al., 2019). A prerequisite for this endeavour is for them to advance their knowledge of the subject matter epistemology and the pedagogical elements that would make a good fit for this particular content (Flores, Lopez, et al., 2000).

Gil-Pérez & Pessoa De Carvalho (1997) describe a physics teachers' training program in this direction, taking into account the theoretical and empirical conclusions that are drawn from educational research. Their framework includes four components that summarize numerous subordinate elements referring to physics as the school knowledge to be taught in general terms. Having these components adjusted to thermodynamics in particular, they are the following: (a) knowing thermodynamics as the subject matter to be taught, (b) knowing teachers' spontaneous ideas on thermodynamics and on teaching and learning thermodynamics, (c) acquiring theoretical knowledge about the thermodynamics teaching and learning process, and (d) teachers' involvement in thermodynamics education research and innovation.

Content of the training program

For the content of a training program addressing in-service physics teachers for the teaching and learning of thermodynamics in upper secondary school, we considered the theoretical components suggested by Gil-Pérez & Pessoa De Carvalho (1997), the empirical evidence deriving from preceding training programs (e.g., Flores, Lopez, et al., 2000; Kanderakis et al., 2011), and the particularities of introductory thermodynamics as knowledge to be taught from both the student side (e.g., Leinonen et al., 2012; Meli et al., 2021) and the teacher side (e.g., Bezen et al., 2016; Tobin et al., 2012).

Taking these elements into consideration, the training program addressed the following four aspects of thermodynamics: (a) epistemology, (b) traditional instructional approach, (c) alternative instructional approaches, and (d) design of a TLS. A detailed description of the proposed TLS can be found in Meli & Koliopoulos (2019). The main principles that penetrated the content throughout the training program were the following: (a) operationalization of the first functional steam engine (Newcomen's) as the object under study, (b) exclusive use of the macroscopic (classical) framework of thermodynamics for the interpretation of phenomena connected to thermodynamics processes, and (c) energy distribution representations (Energy Chain Model) for bridging qualitative and quantitative aspects for the interpretation of phenomena (Meli et al., 2021).

These principles significantly contradict the traditional approach of thermodynamics, namely the one introduced by the official physics curriculum and the respective textbook. Overall, the traditional approach replicates the structure of standard university physics textbooks (e.g., Young & Freedman, 2012), simply omitting all the "difficult" parts (mostly related to advanced mathematics) instead of attempting an appropriate didactic transposition for the secondary school level. Typically, this approach gives prominence to the following aspects: (a) the microscopic (statistical) framework of thermodynamics, introduced mostly through the kinetic theory of gases, precedes the macroscopic (classical) framework that focuses on energy-related concepts and principles, (b) symbolic and quantitative representations of phenomena are presented without qualitative and semi-qualitative intermediate models that justify the formulas, and (c) real-life applications of thermodynamics and respective cultural dimensions are illustrated as "decorative" elements that do not organically connect to the knowledge to be taught. Educational research suggests that these traditional epistemological and pedagogical features are in great contrast to contemporary constructivist frameworks since they do not take into account the students' prior knowledge and cognitive needs/capacities for this particular education level (Meli et al., 2021).

RESEARCH QUESTIONS

Our research objective is to explore the impact of the training program for teaching and learning thermodynamics on in-service upper secondary school teachers. We are particularly interested in the alternative elements they would be willing to introduce in their TLS for the respective thermodynamics courses because of their training. Therefore, the research questions are the following:

1. Which were the physics teachers' epistemological and pedagogical conceptions of thermodynamics before their participation to the training program?
2. What were the subjects (connected to the conceptions) that were most frequently discussed during the training program?
3. What were the subjects (connected to the conceptions) that were most frequently discussed how did they inform the teachers' views for the design of an alternative TLS?

METHOD

For better understanding physics teachers' existing conceptions and intervening with a call to action, we follow the design of a case study (Cohen et al., 2007). As Nisbet & Watt (1984) suggest for the phases of a case study, the training program (a) commenced with a wide field of focus, addressing physics teachers of the entire regional area and sharing an online questionnaire with broad epistemological and pedagogical context to interested teachers, (b) progressively focused to narrower fields during the webinars, and (c) checked the draft conclusions with a limited number of participants during the interview phase.

To identify how physics teachers conceived their knowledge of thermodynamics epistemology and pedagogy and to what extent they were willing to explore new approaches, the coordinators of the Regional Centre of Educational Planning for the upper secondary school science curriculum (central Athens) sent an online questionnaire to 150 physics teachers that taught thermodynamics during that school year (2020-2021). 42 teachers (73% males) answered the questionnaire; the vast majority (86%) had already been teaching this course for more than four school years and more than half (57%) were holding a postgraduate degree. The questionnaire included 22 closed-type questions (with a 5-point Likert scale), that derived from the components of the theoretical framework for physics teachers' training, and was quantitatively analysed in *SPSS*.

In addition to the questionnaire, the coordinators invited teachers to participate in a 4-part webinar series for the teaching and learning of introductory thermodynamics. 30 of them participated in the training program. The webinars were held for two hours every other week (November-December 2020) and included presentation sections and time for group discussions.

Within a week after the completion of the training program, we conducted 5 interviews that each lasted 30-45 minutes. They were semi-structured with 9 questions that covered the components that had been raised in the closed-type questionnaire. As with the group discussion passages, all interviews were recorded, transcribed, and qualitatively analysed in *NVivo*.

RESULTS

Physics teachers' conceptions of thermodynamics before to the training program (questionnaire)

Tables 1-4 present the questionnaire items and the results for each component of the theoretical framework for physics teachers' training.

Table 1. Questionnaire items and results (*N*=42) for the first component of the theoretical framework for physics teachers' training (knowing thermodynamics as the subject matter to be taught).

		1	2	3	4	5
1.1*	What is your assessment of your knowledge of the history of thermodynamics concerning the development of its concepts?	4,76%	16,67%	42,86%	28,57%	7,14%
1.2*	What is your assessment of your knowledge of the history of thermodynamics concerning the development of its methods?	9,52%	23,81%	47,62%	16,67%	2,38%
1.3*	What is your assessment of your knowledge of the history of thermodynamics concerning the cultural context within it was developed?	19,05%	30,95%	26,19%	21,43%	2,38%
1.4*	What is your assessment of your knowledge of the recent scientific developments in thermodynamics (interdisciplinary)?	9,52%	35,71%	42,86%	11,90%	,00%
1.5**	What is your assessment of your readiness for the enrichment of your knowledge of thermodynamics as a subject to be taught?	,00%	2,38%	23,81%	50,00%	23,81%
1.6**	What is your assessment of your potential to restructure, enrich, or alternate the standard suggested school knowledge of thermodynamics?	,00%	2,38%	28,57%	38,10%	30,95%

* *1=I know nothing about it* up to *5=I know everything about it*
** *1=I could not do it at all* up to *5=I can absolutely do it*

Table 2. Questionnaire items and results (*N*=42) for the second component of the theoretical framework for physics teachers' training (knowing teachers' spontaneous ideas on thermodynamics and on teaching and learning thermodynamics).

		1	2	3	4	5
2.1*	Do you believe that it would be useful to present more historical elements for the development of thermodynamics (e.g., inventions, creative solutions)?	,00%	14,29%	14,29%	40,48%	30,95%
2.2*	Do you believe that it would be useful to present the scientific methods that historically led to the development of thermodynamics (and not just the ultimate results)?	2,38%	14,29%	28,57%	33,33%	21,43%
2.3*	Do you believe that it would be useful to present the scientists' collaborative work that historically led to the development of thermodynamics (and not just the persons' that were directly connected to the ultimate results)?	2,38%	16,67%	21,43%	35,71%	23,81%

2.4*	Do you believe that it would be useful to present the connection of thermodynamics with social issues (historical and recent)?	4,76%	14,29%	16,67%	33,33%	30,95%
2.5*	Do you believe that it would be useful to further utilize experiments for the school knowledge of thermodynamics?	,00%	2,38%	23,81%	28,57%	45,24%
2.6*	Do you believe that it would be useful to present thermodynamics as an interdisciplinary scientific subject?	,00%	14,29%	21,43%	47,62%	16,67%
2.7**	Do you believe that thermodynamics is a scientific subject that should be it promoted as a meaningful and approachable one for all students?	14,29%	16,67%	33,33%	23,81%	11,90%
2.8**	Do you believe that students' real-life conceptions of thermodynamics interact with the scientific ones that are introduced as school knowledge?	9,52%	33,33%	38,10%	16,67%	2,38%

**1=That would not be useful at all* up to *5=That would be absolutely useful*
***1=I don't believe that at all* up to *5=I absolutely believe that*

Table 3. Questionnaire items and results (*N*=42) for the third component of the theoretical framework for physics teachers' training (acquiring theoretical knowledge about the thermodynamics teaching and learning process).

		1	2	3	4	5
3.1*	What is your assessment of the traditional methods that are used for the introduction of thermodynamics to students?	14,29%	42,86%	35,71%	7,14%	,00%
3.2*	What is your assessment of the traditional methods that are used for the students' penetration of thermodynamics?	14,29%	42,86%	40,48%	,00%	2,38%
3.3*	What is your assessment of the level of group learning during your thermodynamics courses?	35,71%	33,33%	21,43%	9,52%	,00%
3.4**	What is your assessment of your knowledge concerning contemporary alternative approaches of thermodynamics teaching and learning?	9,52%	38,10%	35,71%	11,90%	4,76%
3.5**	What is your assessment of your knowledge concerning students' conceptions on thermodynamics?	7,14%	38,10%	28,57%	21,43%	4,76%

**1=Not satisfactory at all* up to *5=Completely satisfactory*
***1= I know nothing about it* up to *5=I know everything about it*

Table 4. Questionnaire items and results (*N*=42) for the fourth component of the theoretical framework for physics teachers' training (teachers' involvement in thermodynamics education research and innovation).

		1	2	3	4	5
4.1*	What is your assessment of your teaching of the school knowledge of thermodynamics up to now?	,00%	52,38%	26,19%	19,05%	2,38%
4.2**	Are you interested in approaching the school knowledge of thermodynamics with a new teaching and learning sequence?	,00%	4,76%	23,81%	38,10%	33,33%
4.3**	Are you interested in approaching the school knowledge of thermodynamics with a new teaching and learning sequence that will be implemented to contribute to the pertinent educational research?	,00%	4,76%	26,19%	38,10%	30,95%

***1=Not satisfactory at all* up to *5=Completely satisfactory*

**1=I am not interested at all* up to *5=I am absolutely interested*

Summarizing, the above results indicated that physics teachers considered the level of their existing knowledge of thermodynamics epistemology below average, although they were positive in introducing such elements in their formal instruction. Regarding the pedagogical perspective, they believed that the official curriculum was rather inadequate in introducing and delving into thermodynamics concepts but, at the same time, they characterized their knowledge of alternative teaching and learning approaches as rather insufficient. Therefore, it was somehow expected that they agreed to participate in a training program for the design and implementation of a TLS for thermodynamics to make use in their classroom as well as for informing the relevant educational research.

Physics teachers' conceptions of thermodynamics during the training program (group observation)

Table 5 summarizes the most prevailing conceptions in terms of frequency (minimum 5 references) as they surfaced during each of the four webinars of the training program. These correspond to the respective questionnaire items (as presented in Tables 1-4).

Table 5. Frequency of references (5 references min.) to the questionnaire items during the four webinars (*N*=30).

	1^{st}	2^{nd}	3^{rd}	4^{th}	Total
1.1	5	0	2	0	7
1.5	3	0	0	2	5
1.6	1	7	10	8	26
2.1	5	0	3	0	8
2.2	2	0	0	3	5
2.4	1	3	1	2	7
2.5	0	6	0	0	6
3.1	4	5	1	1	11
3.2	1	9	0	0	10
3.5	0	5	6	1	12
4.1	1	0	2	3	6
4.2	0	0	1	8	9

During the webinars, group discussions (*N*=30) were oriented to both epistemological and pedagogical issues. Concerning thermodynamics epistemology, the participants mainly focused on the distinction between the macroscopic and microscopic approach and the non-linear historical events/ scientists' interactions that gave rise to the theory and the applications of the field. In reference to the pedagogy, they were concerned about practical issues, such as the constraints that the official curriculum sets, the different experiments that can be efficiently executed in the classroom, and the way alternative approaches can be implemented.

Physics teachers' conceptions of thermodynamics after the training program (interviews)

Table 6 summarizes the most prevailing conceptions in terms of frequency as they surfaced during the interviews for each of the interviewees. These correspond to the respective questionnaire items (as presented in Tables 1-4).

Table 6. Frequency of references (5 references min.) to the questionnaire items during the interviews (*N*=5).

	#1	#2	#3	#4	#5	Total
1.5	4	1	2	2	3	12
1.6	7	4	2	4	2	19
2.1	9	1	2	1	0	13
2.4	5	0	0	1	2	8
2.7	3	2	4	2	1	12
2.8	2	2	0	1	0	5
3.1	4	2	0	2	2	10
3.2	1	1	2	0	2	6
3.5	2	4	1	1	2	10
4.1	1	0	2	3	1	7
4.2	0	0	1	8	0	9

The qualitative analysis of the interviews (*N*=5) indicated that the training program facilitated physics teachers in putting existing and new knowledge of thermodynamics epistemology in a pedagogical perspective. The most prevailing elements of this holistic approach are related to the clear distinction between the macro/micro frameworks with prominence to the macroscopic energy concepts, the use of technological components as case studies for introducing concepts/laws, and the introduction of socio-economic context to justify the significance of the field. Indicative passages from the interviews, that suggested a differentiated approach to the TLS, are the following:

To begin with, we should omit the microscopic framework, it comes out of the blue, it creates misconceptions. We should instead focus on the cultural perspective, on small-range research so the students learn where the various thermodynamics principles are applied… I would give prominence to the way knowledge was developed, the historical perspective of thermodynamics, by adopting elements from the training program. I would possibly use passages that demonstrate the difficulties (scientists) faced when constructing steam engines and the method they used while constructing them and how this method was improved. (Teacher #1)

Well, what hadn't occurred to me before (the training program) is that I can at first bypass the kinetic theory of gases… I could go straight to the First Law of Thermodynamics and work towards the thermodynamics processes. I liked this suggestion very much… You gave me many ideas, because I used to start with the kinetic theory and then move on to the processes and I usually faced many problems there. Now I believe that I can seamlessly go straight to teaching the energy part, I mean the First Law, and work all concepts through that chapter and this is *extremely positive. I wouldn't decide doing this change on my own, but since you propose a ready-to-go idea, this is pivotal.* (Teacher #5)

CONCLUSIONS

In-service physics teachers that participated in the training program confirmed the trend shown in the relevant research worldwide that there is a growing scepticism over the epistemological and pedagogical approach of introductory thermodynamics at the secondary school education level (e.g., Bezen, 2016; Flores, López, et al., 2000; Gil-Perez & Pessoa de Carvalho, 1997). Official physics curricula do not yet apply a didactic transposition that properly fits the requirements of thermodynamics school knowledge, turning a blind eye to educational research recommendations for the adaptation of a constructivist approach. During formal instruction, several issues concerning thermodynamics epistemology and pedagogy come on the surface, making instruction even more challenging.

The training program for thermodynamics school knowledge attempted to reconstruct teachers' conceptions of thermodynamics epistemology, indicate the problematic spots on the traditional teaching and learning approach and introduce alternative ways for the design of a TLS. Pre-webinar results indicated that teachers' knowledge on these aspects, that would allow them to redesign their TLS was rather limited, however they demonstrated a positive learning attitude. During the webinars, the conceptions appeared to be somehow destabilized and change-oriented. This repositioning was more obvious during the post-webinar interviews, where the participants indicated in which direction they would adjust a training-informed TLS. The feasibility of the proposed approach was especially important for them, therefore it was essential that they seemed confident to go rather seamlessly from theory to practice.

LIMITATIONS AND FUTURE RESEARCH DIRECTIONS

The main limitation of this research is the lack of further results deriving from the class environment that would justify the training program impact on the participants. Due to the restrictions enforced due to the pandemic, it was impossible for the researchers to observe the respective courses in order to identify how the webinars affected in practice the design of alternative TLSs for thermodynamics courses and/or what was the learning outcome for the students.

A possible extension of this research is the broader use of the pre-webinar questionnaire to investigate physics teachers' epistemological and pedagogical conceptions in a national level or as part of a comparative study between countries with similar approach to the school science curriculum for units of thermodynamics. In addition, this instrument can also be easily adjusted for the exploration of teachers' conceptions on another specific physics field (e.g., mechanics, electromagnetism) or physics in general, for the design of respective training programs and beyond.

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USING A VIGNETTE TEST TO MONITOR HOW SITUATIONAL COMPETENCES DEVELOP OVER TIME

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In the context of professional competence research may problems are in continuous discussion, especially in the context of competence assessment. Often it is unclear what is meant with the term "competence", and this problem – in turn – is then reflected in the construction of tests. In addition, long-term studies are scarce and there is a black spot in the monitoring of competence development, as most studies follow a short-term pre-post experimental design. This study intends to address three issues in science education research: the difference between knowledge and competence, the problem to assess professional competences and the long-term development of professional competences. Here, competence is defined as a skill-oriented deep level entity that can be visualized with a situational vignette test. The three-year monitoring shows that pedagogical content competence is a stable characteristic, but general pedagogical competence changed with a negative trend independent of school level (primary vs. lower-secondary). This counterintuitive result was further investigated using competence profile comparisons. The profiles indicate a "contraction" of competences which may indicate that teachers were less motivated in the post test. Interestingly, this regression is at the expense of pedagogical aspects. These results need further discussion, especially in the context of developmental processes of teachers after they leave university.

Keywords: Evaluation, Teacher Professionalism, Educational Reform

INTRODUCTION

Professional knowledge and teacher competences have been widely addressed in practically all fields of educational research. Many studies have been dedicated to the topic of how relevant professional competences are in terms of instruction and student learning. Yet, in many studies, "competence" seems an opaque construct, especially in direct comparison to knowledge. Often knowledge and competence are used as interchangeable entities, but which they are not. In this paper I want to draw attention to the conceptual understanding of knowledge and competence and present a cognitive approach to theoretically discriminate between knowledge as a fact accumulation and competence as a skill which based on fact bundles. This differentiation allows to align knowledge and competence at two prototypical levels of classroom observations: surface and deep structure. Crossing these two approaches results in the need of an appropriate data collection method that is can function on both levels. I propose vignette tests to access both surface and deep levels of teacher knowledges and competences, and I will give an empirical example.

THEORETICAL BACKGROUND

Knowledge, the basis of instruction

Before any instructional action can be performed, any type of knowledge is needed. This knowledge – for example – can be based on every-day experience, recommended by non-formal reference or informed by professional education. In the field of teacher professionalism, one usually refers to university education, teaching experience, and further education as profound sources of professional knowledges (Egloff & Kade, 2006). In many cases these knowledges have been related to the three-dimensional model of content knowledge, pedagogical knowledge, and pedagogical content knowledge

(Shulman, 1987). These dimensions have been of controversial discussion on their relation to instructional performance: While some researchers find a very low direct correlation between knowledge and action/ instruction (Baier et al., 2018), others model a direct effect of competence and instructional quality (Kunter et al., 2013). Yet, as one takes a closer look at the research on the relation of knowledge and action one can identify various definitions of knowledge and action. Some researchers equal knowledge and competence while other draw a clear line between both concepts. The same is true for action. Sometimes action is determined by a quality measure on student level (e.g. "The teacher helped me when I got stuck on a task."), another approach is to determine instructional practice from an outside perspective that can be rated by observers.

Besides the framing of concepts, there is also a differentiation between intentional and functional definitions of the knowledge-action relation. While in intentional theories of action, knowledge is attributed a direct causality for action with a specific purpose, this is no longer readily possible in functional approaches, since the goal of action is no longer clearly defined (Gerstenmaier & Mandl, 2000) According to Hermanns (1987), intentional, purposive action is a special case of functional action. The concept of skill can be located between knowledge and action and accordingly has a procedural character. In this respect, skill describes a competence as a prerequisite for action. In addition to the question of the extent to which knowledge is relevant to action, there is also the question of how knowledge is represented (implicit/ explicit; procedural/ declarative). However, the representation of knowledge also depends on the situation in which it is acquired. To make matters worse, the application of knowledge depends on the situation in which it becomes relevant. In this respect, skill in the form of competence can be defined as the translator of knowledge into action.

According to Schaper (2003) competences are dispositions or cognitive, sensorimotor, social-communicative, emotional-motivational performance prerequisites and personality characteristics that can be actualised in action. Therefore, competence is closely related to an activity, situation or requirement and can be assessed situationally in comparison to the performance prerequisites and personality traits. The closeness to action of this definition of competence with its cognitive component has significant consequences for the acquisition of competence itself. From a learning theory perspective, performance and success in action are thus dependent on knowledge, mediation and goals (Anderson et al., 1996; Paas & Van Merrienboer, 1994; Lefrancois, 2006). From this perspective, content and knowledge should be staged in such a way that learners are induced to acquire schemas efficiently and in a way that is suitable for action (Kirschner et al., 2009). Schemas can also be understood as "chunks" (Anderson, 1996, p. 356) and individual chunks can together form a sequence of events. This chunking is the structuring of behaviour sequences into subsequences and can also be referred to as a script in the context of classroom action. Such scripts can then be processed as cognitive representations or concepts and translated into an instructional action.

In this framework competence can also be defined as a translation of knowledge into action in the context of a specific situation: Teaching competence: „is the capacity of a teacher to perform a reflected single action. Such an action is for instance might be asking an open question in a situated learning process. The performance of this action and its assimilation to a pedagogical necessity is an indicator of the existence of such a competence" (Maiello & Oser, 2009, p. 5). This means, that a certain situation may trigger off a pre-stored experience that helps to get through the situation. According to the Adaptive Control of Thought (ACT) theory, the knowledge or the experience that is retrieved can either be located on a declarative level or on a procedural level (Anderson & Lebiere, 1998; Anderson, 2007). Declarative knowledge is acquired from the outside and stored as fact units. These units can be clustered into chunks which represent bunches of facts of any combination. The declarative knowledge is also seen as easy to verbalize. Procedural knowledge (also known as production rules) summarise declarative knowledge chunks. For example, chunks can be acquired by declarative step-by-step units that define a single procedure (e.g. learning a sequence by heart) and acting it out. Chunks may also routinise by exercise and become non-reflectible, what makes them implicit and hard to verbalise. In that case a reflex-like action takes place. In general, procedural knowledge has been treated as a skill-oriented knowledge that is situationally activated and turned into action (Blömeke et al., 2015), which makes it a competence.

Figure 28 shows an integrated perspective of the relation of knowledge and competence, and how it can be related to observations. Unexperienced teachers may have acquired declarative knowledge and researchers may find out what these teachers perceive. Over time the novice teachers mature and at a certain point a researcher may assess the decision-making process. The difference between a novice and experienced teacher are: the first has a weak background for decisions and thus can only retrieve one solution that fits in a more or less proper way, the latter has experienced several options to act upon, but has to re-think about the reasons for the decision.

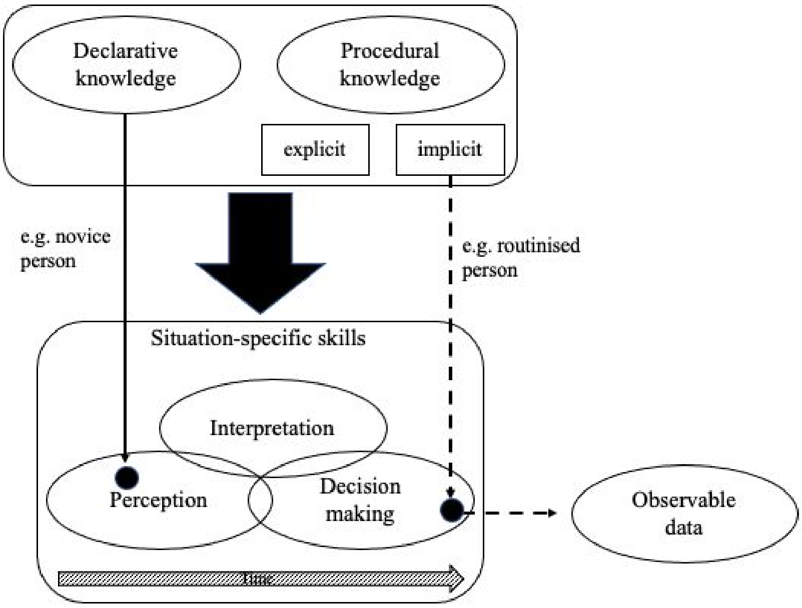

Figure 28: Model of knowledge-action relation and data acquisition.

One asset of Figure 28 is that is differentiates between what type of knowledge is used. In an attempt to combine cognitive research about knowledge types and educational research about the structure of competences and expertise the claim in Figure 28 is that instructors with little teaching experience mainly rely on declarative procedural knowledge when inside a teaching situation. Instructors with plenty of teaching experience use implicit procedural knowledge in most teaching situations. This idea is represented in

In close relation to the knowledges mentioned above, research in teacher education and teacher professional development has proposed to differentiate between surface and deep structures of instruction. While surface structures are easily observable on a low-inference level, deep structures need to be inferred from observable data (= high inference). The alignment of knowledge types and structural level can be combined in a 2x2 table (see Table 41). While instructional actions on the surface structure and declarative knowledge can rather easily be coded with low-inference rating, competence-related deep structures of teaching and implicit knowledge need to be coded with high inference, because they cannot be accessed directly by the rating person.

Table 41: Coding of instruction and knowledge.

		Level of coding inference	
		Low-inference coding	**High-inference coding**
Observation unit	**Instruction**	Surface structure	Deep structure
	Knowledge	Declarative knowledge	Implicit knowledge

Procedural knowledge and deep structures of teaching can be inferred from observable data. In other words, competence is reflected in observable utterances and actions which by themselves are based on the perception of a situation that trigger implicit knowledge in the deep structure of instruction and result in an observable behaviour. Research on the professional vision has shown that the classroom perception of teachers has two dimensions, noticing and interpretation (Wiedmann et al., 2019). While noticing depends on the teacher's attention, the interpretation includes three levels of complexity: the description of a situation, the explanation why the situation is as it is and the prediction of the consequences of the situation (Seidel & Stürmer, 2014). Explanation and prediction rely on the declarative knowledge of the teacher. This is the underlying idea of the test construction of the vignette test that was used as a competence test.

Test construction theory

In sum, if one wants to assess instructional competences of teachers one needs to address procedural knowledge in a test. Procedural knowledge can be triggered by having teachers comment on classroom situations. This open-answer approach is well-established in qualitative research in the social sciences. Besides just asking for comments, there have been manifold approaches to assess teacher competence. Three prominent ways are the following ones:

- Declarative knowledge tests: „Please outline as many different ways as possible of explaining this mathematical fact to your student. "(e.g., Krauss et al., 2008). This type of test tries to access the amount of teacher knowledge and experience and the idea is the more items they can name, the more competent there are. These tests are fairly easy to code and very efficient.
- Procedural knowledge tests: „Please, describe how you would prefer to teach…" Test items like that primarily ask either for the teachers' first choice that comes to his/ her mind, or for a model-like approach to a theoretical problem. The main advantage of this test is the evaluation of a teacher's theoretical knowledge on how to solve a theoretical situation.
- Combined tests: „Please, evaluate the teaching situation and reflect on the situation..“The combination of evaluation and reflection on a given situation gives researchers the chance to get insight into a teacher's mind and how he/ she arrives at a decision or a qualitative judgment.

Mena Marcos and Tillema (2004), in a review study on reflection and action among teachers, arrive at four categories of studies: a) studies that deal with the reconstruction of action-relevant beliefs, b) studies that grasp intentionality as pre-actional reflection, c) studies that capture classroom action as ex-post rationalisation, and d) studies that capture classroom action directly, for example via video recording. Mena Marcos and Tillema, however, see a deficit in the independence of the studies and therefore demand for assessment instruments that address the relation of thought and action. They see triangulative or mixed methods as an approach to researching reflection and action. In this paper, I understand triangulation in a broader sense as taking multiple perspectives on the same phenomenon and try to build the bridge called for by Mena Marcos and Tillema (2004) in terms of complementary data collection. This includes the above categories a) to c) and takes a first step towards data triangulation.

METHOD

Instrument

The vignette test is an instrument to approach competences in teachers. A vignette shows a classroom situation. Based on the underlying theory the vignettes can be discussed in terms of proper instruction in the sense of the underlying theory. In this case the underlying theory is constructivist and each situation was pre-analysed by science education experts. This procedure normatively imposes problems from a constructivist perspective. Teachers are asked to comment on the situations and (in the data coding) the score if they indicate a problem in their comment. The vignette test used in this study includes 8 situations with 40 items (21 for PCK and 12 for PK). PCK and PK can be sub-divided, each in three dimensions (Rehm et al., 2016):

- PCK_a – The competence to adapt to student learning for example to support linked learning or to establish cognitive activation;
- PCK_d – The competence to diagnose content specific issues such as false conceptions;
- PCK_m – The competence to methodologically arrange learning processes based on the content and build learning-supportive instructional sequences
- PK_s – The competence to support student learning;
- PK_d – The competence to diagnose and take the student perspective;
- PK_m – The competence to apply multiple methods for learning processes

Each vignette in the test is a short description of a classroom situation with an open-end question "Please, comment to this situation with as many words you need." There was also a time limitation, long situations were to be answered within 10 minutes, shorter situations within 5 minutes. The items automatically moved on to the next one, when the time limit was reached. The idea was to simulate real reflective conditions, because in reality teachers would usually take 5-10 minutes to reflect on preceding situations before they move on to prepare the next lesson. The comments of the teachers could pick up on the pre-defined problems. Each comment was later coded on a high-inference level at a 0 – 1 – 2 scale by three trained, but independent raters (see the descriptives section below) per problem. A zero score means that the comment does not refer to a pre-defined problem, a score of one point was given if the comment referred to a problem or indicated a reflection of the problem, and a score of two was given if the comment included an idea to solve the problem or alternative option for the problematic situation (even if it was not mentioned that the situation is problematic).

Data set and sample

This study used data that were acquired in the Swiss Science Education project. A detailed description can be found in Koch et al. (2016). In the project an experimental group of 125 teachers received individualized offers as to improve/ innovate their science teaching. In addition, a control group of 20 science teachers was followed. The data acquisitions were just before the project began (pre) and right after the project ended (post). The time period between pre and post was three years. For this analysis we could use data from 136 teachers with teaching experience between 15-18 years: 117 project teachers (60% lower secondary, 40% primary + kindergarten), and 19 control teachers (53% lower secondary, 47% primary + kindergarten).

Descriptives and data analysis procedure

The sample was 136 teachers, 117 in the project group (60% lower-secondary teachers), 19 in the control group (53% lower-secondary teachers). The average teaching experience was 15-18 years (SD≈10).

Data were analyzed using SPSS 25. Vignettes were rated by three independent coders, coder 1 was a reference person, i. e. a lower-secondary science teacher working on at a university of teacher education. Coders 2 and 3 were university students, the one with a background in primary school teaching, the other with a background in general educational sciences. Krippendorff's alpha (α_K) was used to compute the three-person inter-rater reliabilities for ordinal data. A value of α_K=.67 is recommended for sufficient reliability (Krippendorff, 2004). The PCK scale was .65; the subdimensions PCK_a=.71, PCK_d=.54, PCK_m=.66. The PK scale was .74; the subdimensions PK_s=.67, PK_d=.78, PK_m=.79. A repeated measures analysis of variance (ANOVA) was conducted with PCK/PK as dependent variables. Independent variables were group (project vs. control) and school level (kindergarten+primary vs. lower secondary). For exploratory person profiles, hierarchical and k-means cluster analyses were used. First, in the hierarchical analysis (Ward method), the number of clusters was determined, and in a second step this number was used in the k-means procedure to optimize the cluster identification. In the next step the pre and post competence values were attributed to the clusters.

RESULTS

The repeated measures ANOVA showed a significant within subject main effect of time (p=.001) and univariate tests indicated time effects for PK sub-dimensions, but not for PCK subdimension (see Table 42). Despite a p< .05 significance level one can see in Table 2 a positive trend for PCK_m over time which means that the teachers develop in the recognition of test problems, but there was no difference between the project and the control group or between school grades. The inspection of pre-post correlations (also in Table 2) showes statistically significant pre-post correlations for all competence dimensions in PCK.

Table 42: Competence development and pre-post correlations (n=92).

Competence	Sig. of ANOVA Main Time Effect*	Within Group Effect Trend	Pre-Post Correlation	Sig. of r (pre-post)
PCK_a	p= .569	0	r= .47	p= .000
PCK_d	p= .459	0	r= .45	p= .000
PCK_m	p= .168	+	r= .34	p= .000
PK_s	p= .048	-	r= .51	p= .000
PK_d	p= .001	-	r= .11	p= .293
PK_m	p= .108	-	r= .18	p= .079

*Note: Controlled for school grade (lower secondary vs. primary + kindergarten and group (project vs. control); + 0 -: positive neutral negative trend

All PK effects showed a negative trend, i. e. means decreased from pre to post, independent of any group attribution. A time*project group interaction was significant in PK_s (p= .026) and an indication was found in PK_d (p= .126). In PK_s the project group kept on the same competence level over time, whereas the control group decreased in their scoring. Also, a time*grade interaction was found in PK_d for p= .116): The lower-secondary teachers had a stronger decrease than the primary/ kindergarten teachers. The PK pre post correlations indicate that teachers who scored high in the pre test did not necessarily score high again in the post test, especially in the PK_d dimension.

In order to try explain these counter-intuitive results, a cluster analysis on pre-competences was conducted and pre-cluster-membership was used to visualize pre and post competence profiles (Figure 29 and Figure 30). The inspection of the dendrogram suggested a four cluster solution.

In cluster 1 one can see low scores on every competence and a progression in the post test toward improvements on PK_m and PK_s. In cluster 2 teachers scored high on PK_d in the pre test and were stable in the post test. There is a regression on PK_d. In cluster 3 the pre test showed high scores on PK_s which were stable in the post test. There was an improvement on PK_m. In cluster 4 we found high scores on PK_m, but the progression to the post test we could not identify a clear structure. There were improvements on PK_m, and there was a regression on PK_d.

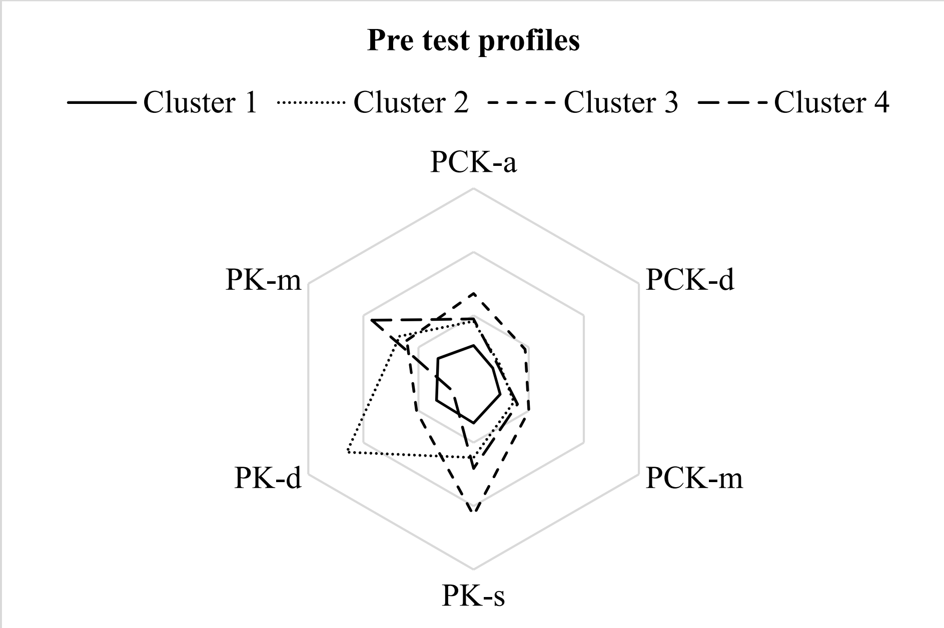

Figure 29: Competence profile of the pre test.

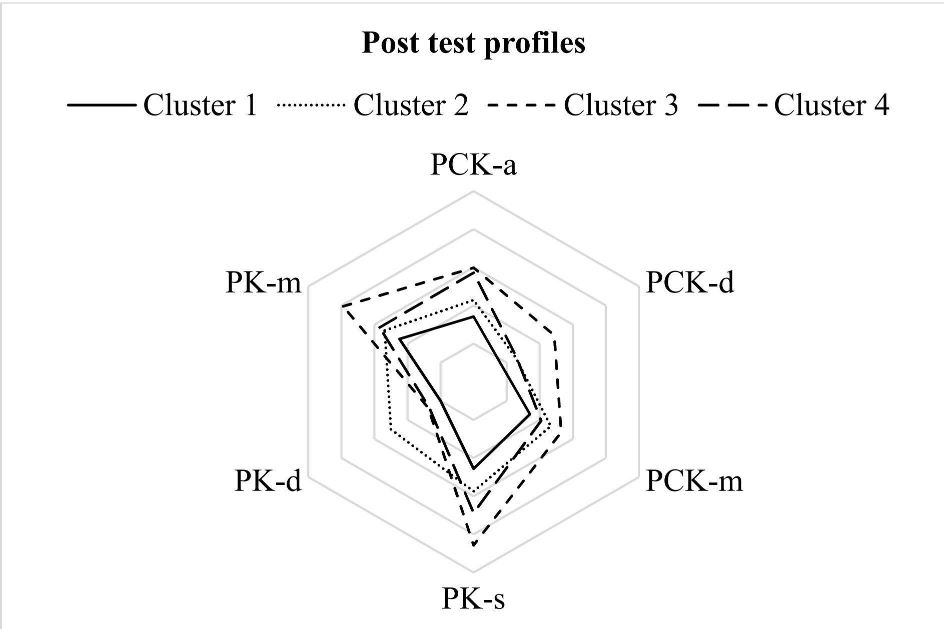

Figure 30:Competence profile of the post test.

The relative changes of cluster means are given in the Table 43 below: PCK_a shows increases in the clusters 1 and 5, PCK_m shows increases in the clusters 1 and 2.

PK_s has an increase in the cluster 1, but a decrease in cluster 3. PK_d diverges, while there are decreases in the clusters 1,2, and 3, there is an increase in cluster 4; PK_m drifts apart with increases in the clusters 1 and 3, but decreases in the clusters 2 and 4.

In terms of clusters, all clusters face similar but heterogeneous patterns, with increases and decreases on the competences. PCK_d seems to be the most stable competence in all clusters, while only for cluster 4 PK_d shows an increase.

Table 43: Changes in cluster means.

	PCK-a	PCK-d	PCK-m	PK-s	PK-d	PK-m
Cluster 1	29%	-2%	42%	31%	-41%	39%
Cluster 2	-6%	8%	28%	-7%	-57%	-20%
Cluster 3	-11%	5%	6%	-20%	-47%	30%
Cluster 4	21%	18%	3%	-2%	42%	-38%

With reference to the results of the ANOVA, cluster 4 is the only group of teachers that shows an increase on the PK_d competence. The cluster primarily consist of lower-secondary teachers (72% within the cluster) and the average teaching experience of all cluster members is 15 years (SD= 10). Almost the opposite development profile can be found in cluster 1, with many developments, but a plummet in PK_d. Cluster 1 members are 59% lower-secondary teachers with an average teaching experience of 12.5 (SD= 9.5) years. Cluster 2 has got a predominantly negative development profile; its members are 57% lower-secondary teachers with an average teaching experience of 17 (SD= 10.5) years. Cluster 3 consists of 49% lower-secondary teachers with an average teaching experience of 19 (SD= 15.5) years. The relative amount of project teachers in each cluster was around 73%.

DISCUSSION

This study we investigated long-term developments in teacher competence development. It was proposed to use a vignette test that allows to access and assess teacher competences on a deep structure level. In the initial analysis of variance ambiguous results were found: On the PCK dimension to methodologically arrange learning processes a positive trend toward improvement was found, but the trend did not differ between any of the grouping variables (project vs. control or lower-secondary vs. primary + kindergarten). Further analyses indicated that the trend may be attributed to test motivation. As the correlation of test motivation and the competence scores was zero for all except PCK_m, we assume that teachers found the problems of PCK_m interesting and perhaps spent more time to think about them, even though they were not aware that it actually was a test item.

The inspection of pre-post correlations showed a low and insignificant value for PK_d which indicates either the assessment or the data coding were not coherent. Perhaps the rating persons became more rigorous, but we did not have data to check for this phenomenon. As all other dimension have significant pre-post correlations one alternative explanation could be the problems that are attached to this dimension. They predominantly deal with the teaching person and his/ her work with the student pre-knowledge which is very difficult to assess in vignettes.

As the results of the ANOVA did not show many differences between the predefined groups, we used an exploratory approach to understand the data. A cluster analysis on the pre data suggested four clusters and these were compared with the post scores. Yet, the findings were very heterogeneous: While some clusters improved on one competence, another cluster showed strong drawbacks on the same cluster. Especially the clusters 1 and 4 seem to be counter-matches, because they develop in opposite ways. The most striking result of the cluster analysis was the insight into the development of the PK_d competence. Despite cluter 4, all other clusters decreased in the competence to diagnose and take the student perspective. In order to disentangle this finding, we used teaching experience and grade to explain the result, but hardly any differences were found when compared to the other clusters. We want to contextualise, that the competence to diagnose student perceptions is correlated to other competences and/ or beliefs of teachers, perhaps even content knowledge (which was not assessed in this study). Perhaps, also the idea of the importance in the consideration of student perspectives could explain the differences in the development.

Besides the discussion of results, we want to draw the attention also to the drawbacks of our study. First of all, we used a relatively small sample and some statistically insignificant effects may turn significant in a larger sample. Despite this, we also used a test instrument that is based on highly inferential coding. High inference coding has been under discussion for almost a century in psychology. Yet, it has also been a fruitful approach to understand phenomena and formulate new hypotheses. Finally, it is to state that this study is a secondary analysis of a data set that was not made for our research question. Thus, we lack interesting variables that could explain the group differences in the exploratory part of this paper.

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TEACHERS' DIGITAL COMPETENCE IN MODELLING AND EXPERIMENTING WITH AUGMENTED REALITY

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Understanding and creating physical models are a main part of the scientific way of acquiring knowledge and are embedded in curricula. Yet, pupils and teachers often have difficulties with these aspects of science lessons. Augmented Reality (AR) is a digital tool to superimpose virtual visualisations on real backgrounds. It can help linking models and experiments, which usually are not part of the same lesson. Nevertheless, both pre-service and experienced teachers consider their digital teaching competences insufficient.

Within the project diMEx (main project: Digi_Gap), a concept for continuing professional development (CPD) was developed to guide teachers in using AR in secondary school practical physics lessons and promote their digital media and modelling skills. The CPD was pilot tested in 2021 and a second CPD will be carried out in 2022 in the German state of Hesse. To assess the teachers' needs beforehand, data has been gathered from an online questionnaire, including teachers' individual needs for support, their different attitudes towards using digital media, open educational resources (OER), and user-generated content (UGC) in their class. The effectiveness of the CPD will be evaluated by measuring the development of the teachers' modelling competences, their digital skills for modelling AR experiments, and their willingness to use digital tools, especially AR, in school.

Keywords: ICT Enhanced Teaching and Learning, Modelling-based Learning, Teacher Professional Development

THEORETICAL BACKGROUND

Scientific Models and Modelling Competences

Creating and working with models is a main part of acquiring scientific knowledge and is embedded in curricula (German Conference of the Ministers of Education and Cultural Affairs, 2005). These active processes require modelling competences, hence the teachers' ability to work with models and to explain them to pupils. It also means explicitly discussing the construction of models and the necessary idealisations (Winkelmann, 2021). A modelling competence framework has been developed by Upmeier zu Belzen et al. (2019). It consists of three competence levels (models as copies of something, as idealized representations, as a theoretical reconstruction of something), with five aspects of models (the nature of models, multiple models, the purpose of models, testing models, and changing models).

Nevertheless, national and international studies have shown that teachers' and pupils' modelling competences are in need of improvement (Gobert et al., 2011; Nicolaou & Constantinou, 2014; Gilbert & Justi, 2016). Models and their construction are often not further addressed at a secondary school level (Oh & Oh, 2010) and only taught superficially in a positivist manner (Henze et al., 2007). Many pupils find them abstract and difficult, in contrast to experimenting (Winkelmann et al., 2021). Therefore, a training in modelling for teachers is needed, so models are more widely introduced in class.

An idea of combining models and experiments while acquiring scientific knowledge is designed by Teichrew and Erb (2019). Their cycle of knowledge acquisition consists of four topics, arranged in a circle: Pupils identify a phenomenon (1), construct a model for it (2), formulate a hypothesis from that model (3) and test the hypothesis in an experiment (4). To reflect the process, they reverse it: Based on the outcome, they test their hypothesis, review their model and its limits, to characterise the initial phenomenon and explain new experimental outcomes based on their knowledge.

Augmented Reality and AR Experiments

The digital tool Augmented Reality (AR) enables users to add virtual components to a real-world environment by superimposing visual information directly on a real-time camera view (Carmigniani & Furht, 2011). This process is possible via a smartphone or tablet camera, as well as through smartglasses. As Milgram et al. (1994) defined, AR is set in the Reality-Virtuality Continuum, and – instead of immersing the user in a completely virtual environment like VR – augments certain aspects of the real world. When using an AR-capable mobile device, applications can either access the internal sensors (e.g., camera, gyroscope, accelerometer) to detect a surface (markerless), or react to visual markers and triggers with a marker-based software (Johnson et al., 2010).

AR technology can be used in many fields, such as advertising, gaming, or navigation, but also in research and medicine (Carmigniani & Furht, 2011). In the last few years, AR has become more and more prominent in various contexts, including education (Altınpulluk, 2019). As a digital learning tool, AR enables linking an abstract concept to a real-life context, making it easier to understand (Bloxham, 2014). A promising example from physics class is overlaying real-life experiments with virtual, dynamic 3D models created by using *GeoGebra 3D Calculator*. This free browser and mobile app allows placing 3D objects modelled in *GeoGebra* (geogebra.org/3d) via a device's camera on any surface and adjusting them to the real experiment (Teichrew & Erb, 2020). This way, usually unobservable (micro- or macroscopic) objects with an explanatory power enrich the traditional classroom experiments by linking and comparing models and experiments in real time (see figure 1).

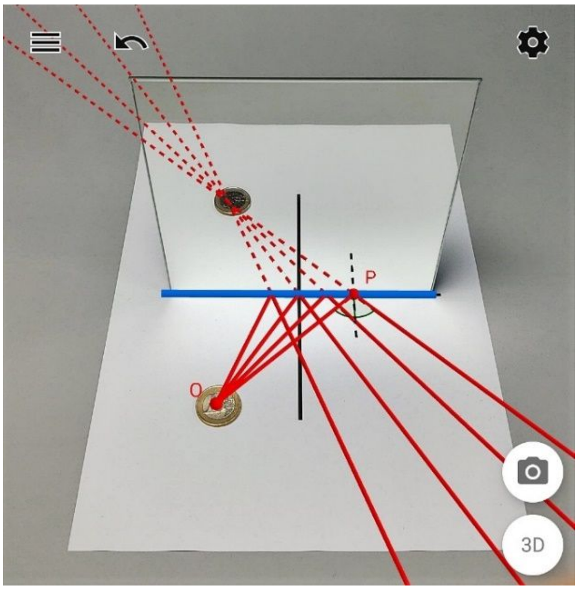

Figure 31. Image formation behind a real-life plane mirror with modelled rays of light.

Digital (Modelling) Competences for AR Experiments

In modern society, digital skills and competences are necessary for many domains of life. With digital media being an essential part of their everyday life, young people grow up as digital natives (Prensky, 2001). In school, the significance of digital media has grown, too, and teachers need to handle them competently. Therefore, digital competences have often been defined and structured in various competence frameworks, for example with the interdisciplinary TPACK framework (Mishra & Koehler, 2006) and the DigCompEdu reference framework by the European Commission (2017). For German-speaking countries, Becker et al. (2020) created the DiKoLAN framework, which aims at student teachers of natural sciences. However, those frameworks cover many aspects of digital competences that teachers should be trained in. Therefore, the presented project will concentrate specifically on those digital competences that are needed for implementing AR experiments in physics lessons. These include operating the software (*GeoGebra*) and hardware (tablets and smartphones), but primarily using the digital tool AR purposefully in the classroom, which is a combination of both technological and content knowledge and its didactic implementation (Guillén-Gámez et al., 2020). In order to promote modelling competences with AR experiments, these particular digital competences are needed. Both are necessary and their overlap must be trained in a CPD.

Successful Continued Professional Development

After the university studies and the practical internship in schools, continued professional development (CPD) marks the third phase of teacher training. It enables in-service teachers to face new challenges of their profession and meet further requirements while also impacting pupils' learning success (Polly et al., 2015). However, an effective CPD needs to fulfil specific requirements (Lipowsky & Rzejak, 2015), among them a longer period of sessions, the combination of input, practice and reflection phases, a focus on subject-specific learning needs, and providing helpful feedback to the teachers. Furthermore, integrating open educational resources (OER) in a CPD can positively influence the innovative use of teaching material – both searching for it and designing their own OER content (Karunanayaka & Naidu, 2017).

STUDY DESIGN

The aim of the interdisciplinary project "Digi_Gap – Bridging digital gaps in teacher education", funded by the German Federal Ministry of Education and Research, is to locate, analyse, and close digital gaps related to didactic, organisational, individual, and technological factors in educational processes (Academy for Educational Research and Teacher Training, n.d.). Within the subproject "diMEx – Digital Competences in Modelling and Experimenting" a CPD concept for implementing Augmented Reality experiments in physics classes is developed, conducted, and evaluated. The goal is to increase secondary school physics teachers' digital competences regarding dynamic 3D models. Furthermore, it investigates how a combination of real experiments with digital models in an AR learning environment can lead to a better understanding of models and a more frequent explicit use of them in physics classes, by reflecting the construction process of models and underlying idealisations. The following research questions are therefore addressed:

(1) Does a CPD about using AR experiments in physics lessons improve the teachers' modelling competence?
(2) Can the CPD improve the teachers' digital competences needed for creating dynamic 3D models?

(3) How does the teachers' willingness to use digital tools in class change by attending the CPD?

Preliminary Study: Teachers' Need for Professional Development

To develop the CPD, a preliminary study was conducted in summer 2020 (Freese et al., 2021). With an online questionnaire, the attitudes and experiences of secondary school physics teachers (n = 81) regarding the use of digital tools in class were examined. It contained seven Likert items and two additional open questions about a definition of and experiences with AR. Twelve applications of analogue and digital tools were presented, for which the teachers had to report if and how they had used them in class. Using scales by Vogelsang et al. (2018), the Likert items explored the attitudes and motivation for using digital media in lessons, the teachers' skills, and the availability of digital devices in school. Furthermore, the teachers' attitudes towards open educational resources (OER), created by internet users (user-generated content, UGC), were examined.

As the results of the preliminary study show, the teachers' experience in the use of (digital) media and tools in physics lessons is mainly limited to well-known applications, like photos and videos, or static drawings and sketches. The field of AR and VR calls for further training, as there is a lack of knowledge about the possible use and suitable tools. Only 15% of the teachers consider themselves able to use AR technology in their lessons. The open question to define AR was answered by 38 teachers, of which half of them match the definition given in Teichrew and Erb (2020). In the feedback questionnaire, the teachers expressed the wish for a CPD about digital tools which also takes care of beginners in this field. Furthermore, as expected, the lack of technical equipment at schools is criticised by almost 80% of the teachers.

Regarding OER and UGC, there is a high willingness (90%) on the teachers' part to share self-designed teaching and learning material on the internet. However, 83% have not yet made their material available online. Some teachers are concerned that the current OER teaching material has often undergone no quality control and cannot be used in all learning groups. In conclusion, the further training concept will include all school forms for networking and exchanging internally differentiated teaching material.

Main Study: A Concept for Continuing Professional Development (CPD)

Based on the preliminary survey results, a CPD concept for secondary physics teachers was developed. In five sessions over several months, the teachers learn to create AR experiments with the modelling software *GeoGebra* and implement them in their lessons. The CPD is based on the TPACK framework (Mishra & Koehler, 2006). It starts with the basic principles of models as a part of acquiring scientific knowledge, after which the teachers learn to use the software and platform *GeoGebra*. This includes searching for suitable existing 3D models on the platform's OER database and modifying them for their lessons. Subsequently, the teachers create their own models and enhance them with short info texts, images, and open or multiple-choice questions. Those dynamic teaching materials can later be uploaded themselves as OER on the *GeoGebra* platform, which allows them to be shared and reused by others. The focus of the input and workshop phase is not on the correct use of mobile devices like tablets, but on their didactically appropriate implementation with self-developed AR experiments. A self-study module and interviews accompany this practical phase. Lastly, the teachers reflect on the implementation with the whole group and their AR experiments are evaluated (peer and expert feedback).

Regarding content, the teachers can choose the physical phenomena they want to cover in their AR experiment – depending on what classes they teach and what subjects are in the curriculum. The *GeoGebra* OER database contains some of the organisers' prepared models, e.g., the subject areas mechanics, electricity, and optics (Erb & Teichrew, 2020; Teichrew & Erb, 2020; Teichrew et al., 2019).

The CPD was pilot tested from May to July 2021 at the University of Education Schwäbisch Gmünd, Germany. Due to the pandemic situation, only five secondary school teachers participated, and the first two sessions had to be held online via video conferencing. In the first session, in addition to a theoretical introduction to AR experiments, the teachers were trained to use *GeoGebra* on AR-ready tablets. A few already had some experiences with *GeoGebra* from other contexts, like mathematics classes. Between each of the five input and development sessions, the teachers had to use AR experiments in their lessons – starting with AR experiments prepared by the organisers, up to their own created models. Every following session, they would reflect on and discuss their experiences to enhance their models for the subsequent classroom use.

Some aspects of the pilot tested CPD concept were adapted after evaluating the results and the teachers' feedback. As the first two online video sessions did not reach the quality of on-site sessions, the main CPD was planned to take place exclusively at premises of the Goethe University Frankfurt, Germany. Because of the pandemic, the sessions were held in external conference rooms, with an elaborate hygienic concept and split groups. As the pilot testing took place while the schools were still closed, some teachers had difficulties implementing their AR experiments in remote learning. Therefore, the main CPD was supplemented by screen-sharing and online teaching tutorials. Sharing the screen with a projector is also a great way to make the AR experiment accessible to the class when there aren't enough devices for students to practice independently.

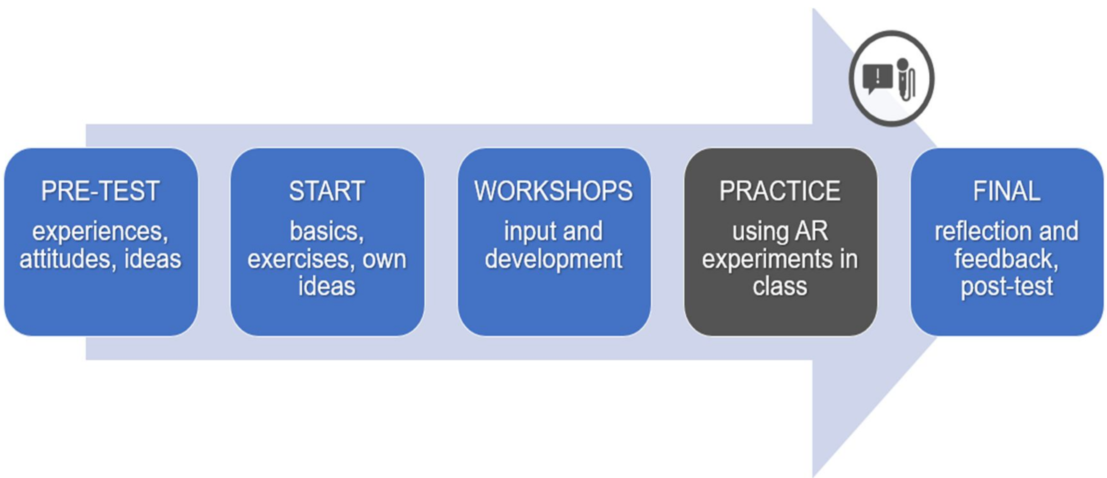

Figure 32. Structure of the main CPD.

The most noticeable edit was the structure of the input and implementation phases (see figure 2). With an overall duration of six months, the main CPD started in September 2021 by providing the teachers with basic information on AR experiments, exercises, and collecting their ideas on possible subjects. It continued with three consecutive workshop sessions to develop the *GeoGebra* 3D model. During the three-month practice phase (December 2021 to March 2022), the teachers had enough time to finish their model and to implement the AR experiment in their lessons. However, they have been accompanied by the organisers and were given online self-study modules written by the organisers, with detailed manuals on all aspects of *GeoGebra* models and AR experiments. The teachers have also been requested to participate voluntarily in semi-structured interviews in which they can give individual feedback.

The final reflection and feedback session is scheduled for March 2022, before the schools' graduation exams. The teachers' experiences with the AR experiments are presented and discussed in the group. They can exchange advice, aims and conditions for a successful implementation, and are furthermore given expert feedback by the organisers. The AR experiments are evaluated according to a rating system (see below).

Measuring Instruments

To answer the three research questions (see above), the pilot test of the CPD was evaluated with a pre-post survey, questionnaires at several times of measurement, and semi-structured interviews. For the main CPD, a rating system has been developed which focuses on the digital competences needed for modelling the AR experiments. It is based on the TPACK framework and has five variables which are validated with a template filled in by the teachers after implementing their AR experiment in class.

Table 1 gives an overview of the measuring instruments for research question (1), regarding the teachers' modelling competence.

Table 44. Measuring instruments for modelling competence.

Variable	Method	Basic instrument
Teachers' understanding of scientific models	Open questions	Windschitl & Thompson (2006)
Didactical handling of models in class	Closed-ended vignettes	Billion-Kramer et al. (2020)
Willingness to use models explicitly in the lessons	Self-assessment (post-test and follow-up)	Semi-structured interview, own design

Research question (2), regarding the digital competences needed for modelling dynamic 3D models, will be answered with the rating system shown in table 2. The AR experiments are evaluated by expert raters based on a profile template the teachers fill out after their lesson. It includes a learning objective, a screenshot of the AR experiment, and the link to the original *GeoGebra* model. In a follow-up inquiry, the teachers will be interviewed approximately six months after the CPD about their current use of digital tools, and their self-assessed ability to use AR experiments in class.

Table 45. Measuring instruments for digital competences.

Variable	Description of the highest competence level
Digital skills (TK)	The teachers can construct and operate their own dynamic 3D model from scratch and open it on a mobile device using the AR mode.
Content-related design (TCK)	The physical content of the dynamic model is accurate and the relations between all variables are transparent.
Didactical design (TCK)	The dynamic model is visually appealing: the user's view has been reduced to the relevant variables and only contains necessary labels. The list of algebraic commands has been properly shortened (auxiliary objects hidden). The model can be operated intuitively.
Didactical use of AR experiments (TPK)	The teachers have phrased an appropriate learning objective for the implementation of the AR experiment which matches its complexity and underlines the profitable character of this technology.
Digital modelling competence (TPACK)	By being augmented by the virtual contents, the real experiment is enhanced so that the underlying model can be easier understood. It is clear which parts of the phenomenon are represented by real experiment materials or by virtual objects (Teichrew & Erb, 2020).

Table 3 shows the instruments used for answering research question (3) regarding the teachers' willingness to use digital tools, such as AR, in class.

Table 46. Measuring instruments for willingness to use digital tools.

Variable	Method	Basic instrument
Teachers' attitudes towards using digital tools	Likert scales	Vogelsang et al. (2019)
Teachers' experiences with *GeoGebra*	Likert scales and open questions	Own design
Willingness to use digital tools, such as AR experiments, in class	Self-assessment (follow-up)	Semi-structured interview, own design

EXPECTED RESULTS AND CONCLUSIONS

After the CPD, we expect the teachers' modelling competence to improve due to reflecting the construction process of scientific models and the idealisations that go with them. This means a higher understanding of models to acquire scientific knowledge and a more confident didactical handling of them in class. This leads to an increased willingness of the teachers to explicitly use models and teach their construction process in their lessons.

The digital competences needed for modelling dynamic 3D models are expected to improve thanks to the instructed handling of the software *GeoGebra* and the associated mobile app, as well as the thoroughly prepared implementation of the AR experiments in class. This competence's highest level (TPACK) requires successful modelling, an appropriate content-related and didactical design of the model and teaching material, and a purposeful use of the model in class.

As a result of the improved digital and modelling competences, the teachers' willingness to include digital tools (especially AR) in their physics lessons is expected to increase. In general, we expect that the CPD will help make digital teaching and learning contexts more accessible. Teachers will be able to implement AR experiments particularly more effectively in schools.

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E-LEARNING TRAINING OF BIOLOGY TEACHERS WITH A FOCUS ON DIGITAL GAME DESIGN

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This work presents, in general, the intervention period of a PhD research in Educational Sciences, in the area of Educational Technology, with a focus on the training of Biology teachers for the development of constructionist teaching strategies, more precisely Digital Game Design (DGD). The research context is located in Portugal and in Rio Grande do Sul, Brazil, aiming to identify the DGD space in initial and continuous training of Biology teachers. In each context, two training courses were developed, one for practicing teachers and the other for teachers in initial training. The activities, in a total of sixty hours, were carried out through e-learning, supported by the Moodle platform, with a synchronous weekly meeting. During this period, teachers worked on their knowledge about Constructionism, Computational Thinking and Digital Game Design itself, developed on the Scratch platform (MIT). In addition to the challenges already inherent to teacher training, the concomitance of the COVID-19 pandemic impacted teacher participation, but also brought a new look into the need for frequent adaptation of teachers to current needs and the benefits of collaborative work within the school community.

Keywords: Technology in Education and Training; Initial Teacher Education; In-service Teacher Training.

INTRODUCTION

This work intends to present an overview of the activities developed in a teacher training course regarding the Design of Digital Games in Teaching Biology. The investigation entirely problematizes the space of Digital Game Design (DGD) in the initial and continuous training of Biology teachers in Portugal (PT) and Rio Grande do Sul (RS- Brazil). In a previous phase of this investigation, a documentary survey was carried out in the syllabus of training courses for Biology teachers in this research context. No mention was found to this teaching strategy. This result can corroborate the gap between initial teacher training and new educational technologies. In this way, the relevance of this topic is highlighted, as it precisely shows the need to include the DGD in the range of strategies presented to teachers in training, its feasibility as a training course and also as a teaching strategy in the classroom. The importance of reporting this experience is also evident, due to the fact that it was developed exactly during the adaptation period of both contexts surveyed to the pandemic caused by the SARS-Cov-2 virus.

Digital Game Design

Digital Game Design (DGD) is a Constructionist learning strategy, based on the creation and development of digital games by students, with the objective of learning topics of interest. As innovative as it may seem, this is not a new strategy. The Constructionist learning theory was proposed by Seymour Papert in the 1960s, inspired by his experience in teaching mathematics and in Piaget's theory of development.

It assumes that learning can be enriched and enhanced by using the computer, as long as it is the student who teaches the computer, and not the other way around. This theory of learning points out that students consciously build their intellectual structures, elaborating an external product, with the aid of a computer, where they can see the result of their reflection and action (Papert & Harel, 1991).

In this sense, the foundations of computational thinking are worked with students, based on challenges proposed in a virtual environment called *Microworld*. In this virtual environment, students can work out, test and develop hypotheses for solving problems (Papert, 1985). A very popular example and the choice for game development in this project was the Scratch platform (MIT Media Lab, 2021).

Projects developed by Scratch users can be narratives, presentations and games. These, after being published, are identified with the author's name and may be improved by other users. This improvement can happen through comments, made by the community and even the elaboration of new versions of another user's project (Resnick et al., 2009). These possibilities lead the community to engage in continuous and collaborative learning, which is also a prerequisite for constructionist learning.

It is worth highlighting some points that contribute to the development of digital games, which are also suitable environments for learning biology. The scientific method, in general, can be the basis for science teaching and learning (Aparecida et al., 2005; Demo, 2011). Therefore, in this investigation, was possible to approach the understanding of the scientific method to the DGD, comparing their steps: elaborating on a matter of interest;

developing research on the topic, developing and testing strategies for game design (hypothesis), reflecting on the feedback; adapting the project and present to peers.

DEVELOPMENT OF ACTIVITIES

The teacher training course “Digital Game Design: Building Constructionist Strategies for Biology teaching” was carried out for 12 weeks, a weekly synchronous meeting and a total of 60 hours of activities. For this, a Virtual Learning Environment was created on the Moodle platform.

Initially, b-learning format was used for continuous training, and on-site for initial training.The choice for the e-learning format for continuous training was due to the need to reach the full context: Portugal - throughout the whole country, and Rio Grande do Sul - throughout the whole state. In addition, there is greater engagement and flexibility of schedules for the participation of teachers working in the school context. In the initial training, a face-to-face intervention was planned, since the contexts surveyed were two teacher training courses, at partner universities: Universidade do Minho (PT) and Universidade Federal de Pelotas (RS). For both levels of training, face-to-face seminars to present the final projects were planned. The intervention process was planned in these phases:

- Disclosure: by sending e-mail to school groups and regional groups on social networks. To inicial training was make contact with the universities.

- Selection: to continuing education, were selected Teachers working in the subjects of Mathematics and Natural Sciences in the 2nd Cycle of Basic Education, or Biology and Geology in the 3rd cycle of Basic Education and Secondary Education. To initial training, students could be in any semester

- Development: the courses were developed in Portugal in the first semester of 2020 and, in Brazil, in the second semester.

After the selection, the teachers answered a questionnaire survey, self-assessing their Technological Pedagogical Content Knowledge (TPACK).) (Koehler & Mishra, 2009). This concept deals with the interactions between these dimensions for teachers to effectively integrate knowledge, strategies, technologies and content in their teaching activity. This survey was developed based on the work of Graham (2009) and Schmidt (2009).

In order to meet the needs of enrolled professors and the necessary demands related to shutdown periods determined by the authorities of each research context, the development of the course has undergone adaptations. The initial training courses were transferred to the e-learning mode. The Continuing Education course also had its modality fully adapted so that the final seminars for presenting projects were carried out through the Moodle platform.

The contents and activities developed were divided into modules, comprising from the theoretical bases, computational thinking and the Design of Digital Games itself. The activities were reflective but shared with colleagues through forums and presentation of class projects. In the last module, learning was resumed, with teachers writing a reflective text about the period of training. There were also self-assessment activities, through a new filling out of the TPACK survey and also a form for evaluating the course and the trainer.

CONSIDERATIONS ON SOME EMERGENT ASPECTS OF TRAINING

When proposing and developing a training course that deals with a sensitive topic for teachers, dealing with digital technologies through a collaborative teaching strategy and centered on the student, not the teacher, we faced several challenges and resistance, already known and mentioned in literature.

In addition to what was described, there were, simultaneously to the beginning of the course activities, the restrictions on circulation and social interaction, related to the pandemic of COVID-19. Therefore, the stressful situations related to the sanitary, social and economic uncertainties caused by the pandemic have been aggravated by the increase in working hours, adaptation to remote education and the home office. All of these issues may partly justify the difference between the number of new entrants and finalists in the course that was 50.5% on average in Initial Training and 30% in Continuous Training.

As it was possible to identify by the TPACK survey, we deal with a heterogeneous group in terms of knowledge and use of digital technologies in the classroom. The degree of confidence in the TPACK were important, both in adapting to the e-learning course and in the learning phase of the Scratch platform. The perception that the role of the teacher, in a constructionist class, is more to guide and monitor the students' productions, than to present didactic material or ready-made games, was an interesting turning point, especially in continuing education (Papert, 1993) On the other hand, in the reflective texts and surveys, the participants mentioned the overcoming of challenges of this period, as well as the adaptation of strategies and resources to current needs.

We emphasize here the understanding given by the empirical experience, that training in this context is viable at both levels and modalities. It is also worth mentioning that only training will not necessarily change an entire context and history of teaching practices. Teamwork and support from colleagues, that is, knowledge of context, according to the TPACK theory, comes to collaborate for the insertion of new teaching strategies in the school environment. This was clearly noticeable to teachers who had co-workers in the same training class and developed much more robust interdisciplinary DGD projects, which involved the school community more effectively.

The degree of confidence in the use of technological resources, within the theoretical perspective of TPACK, as well as the content analysis to be developed in reflective self-assessment texts, will be the basis for future work.

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QUANTITATIVE VALUATION OF THE REPRESENTATIONAL SURVEILLANCE DIMENSIONS

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The visual representations are in the core of science teaching, so their role reviewing in teaching is a key point in science education research. A descriptive, exploratory pilot study with quantitative approach was carried out in order to value the four dimensions of Representational Surveillance process: Epistemic, Pedagogical, Cognitive and Contextual. The metacognitive nature of this process allows the teachers to examine visual representations used in their teaching practices. A group of 22 university science teachers voluntarily participated in this study. A paper-and-pencil task was applied in order to collect teachers' explanations about their habits of representational surveillance in their classes. Descriptive and inferential statistics was used in data analysis. The results showed an important imbalance in the different representational surveillance dimensions, and a particular underestimation of the visual representation context in the process. The tested methodology resulted appropriate to review the use of visual representations in science classes. Therefore, this would be added as a significant resource to review the educative work with visual representations in science teaching planning and practices in order to pose reflective thinking, and to enhance science teaching practices.

Keywords: Visual Representations, Teacher Professional Development, Science Education

INTRODUCTION

The external representations are in the very core of all the disciplines that take part of the widespread field of the Natural and Health Sciences. These are public cognitive instruments that make available things or ideas that are intangible or far from us, and therefore an important part of the communicative system of sciences. They are made by a set of signs and certain rules or codes that mediate between an object or phenomena and our possibilities of interpreting, knowing, redescribing and transforming or using them to do something.

Particularly, those which are displayed on a bidimensional surface are known as visual representations. They have a prominent role for natural science teaching because of their capabilities to communicate. When an object or phenomena is described, the different semiotic systems (linguistic, mathematics, visual representations) act synergistically, revealing particular aspects of the same that offer a more complete understanding of the situation. For this reason, visual representations contribute to the meaning construction while they are being used as cognitive prosthesis (Pozo, 2017). Consequently, they are always present in science education, and they set up several conditions for science teaching and learning. Therefore, learning is settled by the external representation in use (Andrade, Freire, Baptista & Shwartz, 2022).

However, a great diversity of visual representations that are usually used in different ways and with diverse purposes exists. According to their ownership, the visual representations have been classified (Postigo & Pozo, 2004) as:

- Graphs, when a quantitative relation among the elements is considered
- Diagrams, when a conceptual relation is depicted
- Maps and sketches, when some selective spatial relations are represented
- Drawings and pictures, when it is intended to represent some reproductive features.

The visual representations are a fundamental part of the learning environment, so it is necessary to know the way that they are presented and used in science teaching practices to enhance teaching and learning, taking into account their rules and restrictions. In this sense, they are part of the semiotic hybrid that take part in the communication process, they hold the experimental work and enable the empirical data analysis.

Throughout science education, the graphical or visual literacy process must help students to go beyond the explicit and implicit processing levels to reach the conceptual one. Hence it is necessary to rethink traditional teaching practices where the representations are just considered as clear and easy objects to be grasped from transparent rules of understanding (Treagust, 2018). To do that, decision making should be founded on the different uses of visual representation (García García y Perales, 2006) as follows:

The *pedagogical use* that refers to the teacher's communicative intention:

- Expositive: visual representations are used to describe objects, models or phenomena.
- Problem-solving: visual representations are used to solve questions or problems.
- Instrumental: visual representations are used as tools in experimental activities.

The *scientific use* related with the nature, methods and characteristics of the research:

- Experimental: visual representations are used to represent the behaviour of a set of data.
- Theoretical: visual representations are used as a theoretical model about the behaviour of phenomena.

The studies about visual representations in science education have been flourishing from the past decades (Gilbert & Treagust, 2009, Treagust & Tsui, 2013). Some of them were focused on the graphical or visual competence, the presence of visual representations in explanations and activities included in science textbooks. Others were trying to identify some preservice teachers' understanding of several specific topics (Akaygun, Adadan & Kelly, 2019, Tippett & McClune, 2019) or to compare the role of visual representations in science learning and scientific practices (Evagorou, Erduran & Mäntylä, 2015). Nowadays, renewed interest exist about the role of visual representations when students are engaged in metacognitive activities that require making external representations during problem-solving (Ijirana, Mansyur, Rizal & Aminah, 2021) and the way that they can enhance people's understanding of the information in the current times of the big data and other experiences mediated by technologies.

According to the previously mentioned, the educative practices need to be reviewed taking into account the features of the semiotic systems that the teachers display while teaching science. In addition, the impressive changes occurred because of the pandemic of COVID-19 have posed a new challenge to keep teaching alive. Circumstances such as the emergency remote teaching (Hodges, Moore, Lockee, Trust & Bond, 2020) or the new hybrid learning settings (Tyagi, 2021) appeal for the development of new interfaces (Scolari, 2018) to guarantee pedagogical continuity and to enable the experimental activities in digital supplies. Consequently, the usage of visual representations is maximized these days and deserve special attention, which will likely increase in the next years.

Therefore, during science education, a graphicacy process is promoted. This requires the observation of the different aspects of the representational nature and the semiotic cognitive activities. In order to do that, the *Representational Surveillance* is the appropriate mechanism of control. It is a metacognitive process, which is useful in order to examine the role of the visual representations in science teaching and learning. As a systemic strategy to collect key evidence which spotlight their attention on the following four main dimensions:

- *Epistemic*, it is centred in each type of visual representations as a specific domain of knowledge. It includes their features and the quantity of informative elements that can be recognised in them.
- *Pedagogical*, it focusses on the application of visual representations in several teaching practices (planning, lectures, presentations, written tasks, experimental activities) and the way that they participate in the learning activities proposals and assessment.
- *Cognitive*, it refers to the students processing and interpreting the information included in the visual representations in order to construct scientific knowledge as well as the obstacles that could disturb the learning processes.
- *Contextual*, it pays attention to the role of visual representations in natural educative environments (academic, professional and daily life).

Moreover, each of these dimensions are constituted by four items (Table 1) which, all of them, require to be considered in a complete and harmonious process of surveillance. In this way, this new proposal offers a diagnostic tool to the teachers and researchers community in order to review the science teaching practices. So, they will be able to supervise and monitor the diversity of visual representations aspects included in the teaching and learning.

In the line of this theoretical framework, the objective of this work is to present the application of this new proposal to a quantitative valuation of the representational surveillance dimensions.

METHODOLOGY

This first study was conducted in order to describe the representational surveillance process in natural sciences teaching practices. A descriptive, exploratory pilot study with quantitative approach was carried out.

Participants: A group of 22 science university teachers (8 men and 14 women) of *Universidad de la República* of Uruguay voluntarily participated in this research. They teach some subjects in Veterinary, Medicine, Nursing and Agronomy careers with 3-25 years of teaching experience.

Instrument: An open paper-and-pencil task was applied in order to collect teachers' explanations about the different aspects of teaching and learning *of* and *with*, visual representations that should be taken into account during the representational surveillance process. Teachers were invited to respond the following request:

'Please, propose, at least, five inherent aspects of teaching and learning of *and* with *visual representations which should have particular representational surveillance. Write a text (around 1500 words) to complete each of these aspects to justify their importance and explaining how you would do that.'*

Data analysis: In order to value the texts written by the participants, relevant statements were recognized and classified according to the four dimensions. A discrete dichotomy variable was proposed and presence/absence was registered, thus the range of values was between a minimum of 0 to a maximum of 4 (Table 1):

Table 1. Dimensions and its valuation (VR: Visual Representations).

Dimension	As includes references to:	Values
Epistemic	1) Type of VR. 2) Representational character of discourse. 3) Sources of VR. 4) Quantity of information of VR.	0 a 4
Pedagogical	1) Pedagogical use of VR. 2) Proposed activities. 3) Multiple Representational Teaching models. 4) Assessment	0 a 4
Cognitive	1) VR processing. 2) Students' knowledge about VR. 3) Cognitive difficulties related with VR. 4) Procedural contents that include VR	0 a 4
Contextual	1) VR in schooling. 2) VR in professional activities. 3) VR in research activities. 4) VR in daily life.	0 a 4

Descriptive and inferential statistics was used in data analysis (SPSS v. 22). The statistical central tendency, medians and the first and third quartiles were calculated to estimate the dispersion. To detect global difference among medians, no parametric test of Friedman with 0.05 signification level was applied. To identify the significant differences among dimensions, Wilcoxon test of ranges and signs with Bonferroni correction was applied.

RESULTS AND DISCUSSION

The analysis of the collected teachers' explanations and reflections related to the different aspects of the visual representations showed that the participants could recognise a different number of the elements that need to be surveilled (Table 2).

Table 2. Examples of teachers' explanation by dimension analysed.

Dimension	EXAMPLES
Epistemic	P5: 'To review the type of visual representations in teaching proposal is fundamental' P7: 'It is necessary to include graphs with different amount of information' P13: 'Histology has its representational discourse. This must be explicitly enlightened in teaching'
Pedagogical	P17: "We must guarantee that the visual representations aren't used only to expose, but also to pose problems" P15: 'When we are planning our classes, it is important to review if the activities include the construction and the conversion of different graphic representations P5: 'The classes' planification and also, the pedagogical material design must be carried out including multiple representations of the subject-contents'
Cognitive	P8: 'It´s essential to check the processing level that is claimed by each visual representations' P12: 'Students have to get over different difficulties to access to graphic information and everyone can do it at the same time. That is the reason why we have to be conscious of their progress in such abilities so that can take them into account in our teaching proposal' P14: 'Students have very varied ideas about what the visual representations are and what they are for. These ideas must be checked to take them into account in the planification'
Contextual	P20: 'We need to be sure that visual representations used in clinical laboratory are present' P15: 'An aspect of particular interest is the inclusion of visual representations that appear in the papers that we use in the research'

The epistemic, pedagogical and cognitive dimensions were more considered by the professors than the contextual one as are shown in Table 3. These outcomes could be interpreted like an expression of their attributions to central topics in the educative process.

Table 3. Medians and interquartile range.

Dimension	Media	Interquartile range
Epistemic	2	1 a 3
Pedagogical	2	1 a 2,25
Cognitive	2	1 a 2
Contextual	0	0 a 1

The analysis of the statistical data reveals that significant differences existed according to the value of the dimension considered ($\chi 2 = 21,348$, $p < 0,0001$). It is to say that representational surveillance dimensions are not equally taken into account by the teachers (Figure 1) and with media scores that are not higher than 2 corresponding just to two of the mentioned items of the four of each dimension.

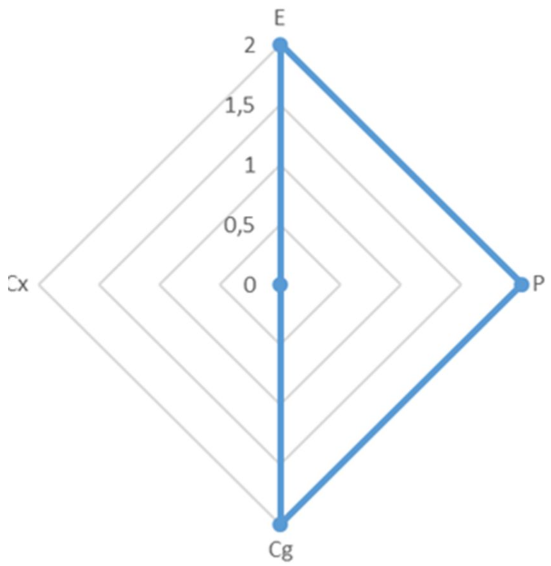

Figure 1. Score by dimension. E: Epistemic, P: Pedagogical, Cg: Cognitive, Cx: Contextual.

The post-hoc test with Bonferroni correction ($p < 0,01$) displayed significant differences between the contextual dimension and the others (contextual vs epistemic, $p = 0.001$; contextual vs. pedagogical, $p = 0.001$; contextual vs cognitive, $p = 0.001$). The other dimensions were not significant (epistemic vs pedagogical, $p = 0.236$; epistemic vs cognitive, $p = 0.138$; pedagogical vs cognitive, $p = 0.542$).

These results show up that the contextual dimension is the least considered by the teachers when they have to comment about how they include visual representations in their teaching practices. In a similar way, this could be thought about the cognitive dimension (a major sample of date is required to confirm this idea).

In sum, from this particular group of university teachers, an important underbalance of the different representational surveillance dimensions was detected. Epistemic and pedagogical dimensions were the most considered by the teachers. The cognitive one was in a minor consideration, and contextual dimension was almost ignored by the majority of the participants.

CONCLUSION AND PERSPECTIVES

This work exposes a significant contribution in two complementary coordinates. The first one is the enlargement of the knowledge about the science teaching practices related to visual representations and their foremost aspects that require to be surveilled during science teaching and learning. Secondly, it offers a comprehensible tool to access to the teachers' knowledge and other valuable information. Both of them constitute a relevant resource to achieve teachers' professional development, mainly at university level where pedagogical teachers training is an indisputable requirement of these uncertain days.

Although all the participants were university teachers of scientific and technological courses of studies, the poor consideration given by them to the contextual dimension is at least disturbed. Even more taking into account that visual representations are also essential not only in the professional development of the future university graduates but also in the daily life of all the citizens.

The new methodological strategy to analyse the representational surveillance in science teaching yielded an evidence of its utility. Visual representations are seen in the core of the scientific knowledge construction as a crucial feature of the graphicacy settings. In addition, it would be added as a significant resource to review the educative work with visual representations in science teaching planning and practices in spaces of teacher education.

The noticeable results of this study could be considered as a milestone in future research with a large number and diversity of participants. Besides, it is a contribution in order to rethink teaching practices from STEM approach or other holistic points of view.

Finally, considering the high relevance of visual representations, this work opens an attractive line of research that recognises the central role of the teachers in the supervision of learning environments, as individuals, and mainly, as a collective group.

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PHYSICAL SCIENCES TEACHERS' BELIEFS ABOUT THE UNIT FACTOR METHOD FOR SOLVING STOICHIOMETRY CALCULATIONS: THE SOUTH AFRICAN CASE

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South African Physical Sciences (SA PS) teachers have difficulty recognising when it is appropriate to apply proportion in stoichiometry calculations. A possible solution is encouragement of use of a generic proportion method, the unit factor method, through professional development opportunities. According to the Theory of Planned Behaviour (TPB), uptake behaviour is affected by relevant beliefs. Therefore, measuring teachers' beliefs regarding the unit factor method, and determining biographical factors which affect these beliefs, may help inform teacher educators of the likelihood of the unit factor method being received favourably by various groups of teachers. To this end, a 14-item Likert-scale questionnaire was administered to 159 SA PS teachers immediately after they had attended a two-day stoichiometry professional development workshop which introduced them to the unit factor method. The questionnaire was designed to measure the three constructs of beliefs according to TPB, in relation to teaching learners to use the unit factor method to solve stoichiometry calculation questions. Data were also collected using an open-response item and biographical questions. Furthermore, a count of the number of written calculation questions (/4) for which the unit factor method was used, was obtained for each participant. The quantitative data were analysed using descriptive and inferential statistics. Inductive content analysis was performed on the qualitative data. Although the unit factor method was hardly used at the start of the professional development intervention, by its end the teachers, irrespective of qualification, experience level and the context in which they taught, tended to be favourably disposed to its use. However, a two-day intervention appears to have been too short for many of the teachers to gain enough confidence with the method for likely realisation of professed intentions regarding uptake of the method.

Keywords: In-service Teacher Education, Teacher professional development, Values in Science Education

INTRODUCTION

Proportionality is the central concept of stoichiometry, which forms a large part of chemistry curricula around the world, including the chemistry component of the South African Physical Sciences (SA PS) curriculum (DBE, 2011). It is therefore essential to empower Physical Sciences teachers to be able to use and teach proportion. This is particularly true for those who have difficulty with proportion, which includes most SA PS teachers (Selvaratnam 2011). The unit factor method, also called the factor label method or dimensional analysis (DeMeo 2008), is a generic proportion method which can provide effective support to people who find proportional reasoning difficult (Gabel and Sherwood 1983). In this method the question's given value is multiplied by a conversion factor which is the proportional relationship between given and required variables and which is, in effect, unity, since its numerator and denominator are equivalent. The given and required units guide the process, reducing cognitive load (DeMeo 2008) and increasing the likelihood of correct execution of calculations involving proportion (Gabel and Sherwood 1983). Currently, SA PS teachers tend to underutilise proportion, to the detriment of their stoichiometry solution success, possibly partly due to an overemphasis on formulae (Stott 2021). Use of a generic proportion method such as the unit factor method might help direct these teachers' focus towards, and develop competence in, proportion, since the method is inherently proportional and it can be applied to any proportion-related topic, thus potentially replacing multiple narrowly applicable formulae.

PROBLEM STATEMENT

Despite these potential advantages of the unit factor method for improving teachers' stoichiometry subject matter knowledge and teaching competence, it is not clear that SA PS teachers would choose to adopt the method for their own stoichiometry calculations and in their stoichiometry teaching. According to the Theory of Planned Behaviour (TPB), beliefs affect intentions, which affect behaviour (Ajzen 2011). Therefore, understanding SA PS teachers' beliefs regarding the value of using and teaching use of, the unit factor method for stoichiometry calculations, their intentions to use the method, and the biographical factors affecting these, would provide insight into the likelihood of various groups of teachers adopting this method in their teaching. Such insight would be valuable for directing teacher education initiatives.

Consequently, this study's aim is investigation of the beliefs and intentions of South African Physical Sciences teachers regarding use of the unit factor method for solving reaction-based stoichiometry questions, at the end of a two-day professional development workshop at which the teachers were exposed to this method. The research is guided by the questions: (1) What beliefs and intentions did these teachers profess regarding the unit factor method? (2) How were these professed beliefs related to the teachers' teaching experience, educational background and the socioeconomic status of the school at which they taught? (3) How were these professed beliefs and intentions related to the extents to which the teachers used the unit factor method in the post-test, and what does this indicate about the validity of these professed beliefs and intentions?

BACKGROUND LITERATURE

The three constructs of the TPB are attitude beliefs, subjective norms and perceptions of behavioural control (Ajzen 2011). In terms of SA PS teachers' likelihood of embracing the unit factor method in their stoichiometry teaching, the following is a brief review of literature relevant to each of these constructs. Teachers in developing world contexts, such as South Africa, tend to be particularly constrained by their attitude beliefs regarding what will earn higher marks in examinations (Makhechane and Qhobela 2019). Particularly relevant to such attitude beliefs, as well as to perceptions of what significant others may expect of teachers, i.e., subjective norms, is a perception that current examination marking practices tend to disadvantage use of the unit factor method (Stott 2021). Relevant to both attitude beliefs and perceptions of behavioural control is the finding that people with high mathematical anxiety levels tend to find stoichiometry in general (Ralph and Lewis 2018), and the unit factor method in particular, (Gabel and Sherwood 1983) difficult. This is particularly relevant since a high proportion of SA learners (Reddy, Visser, Winnaar, Arends, Juan, Prinsloo, and Isdale 2016) and even SA PS teachers (Selvaratnam 2011) display low levels of mathematical competence. Furthermore, successful use of the unit factor method requires an understanding of stoichiometrically equivalent values, which SA PS teachers, particularly those without Bachelor of Science (BSc) degrees and who teach learners of lower socioeconomic status, tend both to be poor at, and to show little progress in developing across at least a short (two-day) professional development intervention (Stott 2020).

METHOD

This is a pragmatically conducted mixed-methods survey study guided by the framework for integrated methodologies (FraIM) (Plowright 2011). Data were collected from South African Physical Sciences teachers who attended a two-day stoichiometry professional development workshop at which I taught them how to use the unit factor method to solve stoichiometry calculation questions. I held eight of these workshops throughout the Free State province of South Africa, between November 2017 and March 2018. The Physical Sciences subject advisors extended an open invitation to the teachers in their area to attend, with the incentive that they would receive teaching resources and earn continuous professional development points. A total of 220 teachers attended these workshops. However, the sample relevant to this study is a sub-group of this (n = 159), since only teachers who completed all the data sources relevant to the analyses conducted here and provided informed written consent for their data to be included in this study, are included. Although this convenience sample cannot be claimed to be representative of the population of South African Physical Sciences teachers, there were no externally imposed biases to inclusion in the sample. Characteristics of the sample are given in Table 47 to enable readers to judge the generalisability of claims made to the broader population. Before data collection commenced, ethical clearance was awarded by the University of the Free State (UFS-HSD2017/1520).

Table 47: Characteristics of the sample.

Socioeconomic status of the learners taught	Possess a Bachelor of Science (BSc) degree	Stoichiometry teaching experience category	N
High (teach at a quintile 5 school) n = 15 (9%)	No (n = 8)	Inexperienced*	5
		Moderately experienced**	3
		Experienced***	0
	Yes (n = 7)	Inexperienced	2
		Moderately experienced	1
		Experienced	4
Low (teach at quintile 1-4 schools) n =144 (91%)	No (n = 94)	Inexperienced	48
		Moderately experienced	19
		Experienced	27
	Yes (n = 50)	Inexperienced	26
		Moderately experienced	14
		Experienced	10

Years' experience teaching stoichiometry: *0-3 **3>10 ***10 or more

Within the pragmatic paradigm, validity is determined by warrantability, which is affected by internal consistency and logic (Plowright 2011). Consistent with this, a questionnaire was designed specifically for this study, informed by relevant literature, the theoretical framework used in this study (TPB), and the research questions. This questionnaire was used to measure the teachers' beliefs regarding use of the unit factor method for stoichiometry calculations and was administered at the end of the two-day workshop. This questionnaire consisted of: 14 Likert scale items (see Table 48) with a 5-scale level of agreement for each (see the key to Figure 33 for the wording of these levels); an open response item; four questions regarding qualifications, teaching experience, and school. As indicated in the last column in Table 48, three of the Likert scale items refer to prior usage and intentions for future usage, of the unit factor method, six questions measure various aspects regarding relevant attitude beliefs, two regarding subjective norms and three regarding perceptions of behavioural control.

Table 48: The statements given in the 5-scale Likert questionnaire items, the code used to refer to each, and the category each question falls into.

Question	Statement	Code	Category
1	I have used the unit factor method **in the past** to help me **solve problems myself**.	Prior personal use	Prior use
2	I have used the unit factor method **in the past in my teaching**.	Prior teaching use	
3	I plan to use the unit factor method **in the future** in my **teaching**.	Future planned use	Future planned use
4	Using the unit factor method has / will **improv(ed) my teaching.**	Improve teaching	Attitude beliefs
5	The unit factor method makes stoichiometry **easier.**	Ease learning	
6	The unit factor method makes learners learn stoichiometry **better.**	Learning improvement	
7	There are **better ways** to teach stoichiometry than the unit factor method. (Reversed item)	The best way to teach	
8	Using the unit factor method in stoichiometry teaching **saves time.**	Time saver	
9	If learners use the unit factor method in **exams,** they will get **higher** marks.	Mark raise	
10	My **subject advisor/principal/head of department/learners' parents** will **encourage** me to use the unit factor method in my teaching.	Adult encouragement	Subjective norms
11	My **learners will want** me to use the unit factor method in my teaching.	Learners will want	
12	I **know** how to use the unit factor method to **solve** stoichiometry problems **myself**. I feel confident to do this.	Confidence self	Perceived behavioural control
13	I know how to **get learners to use** the unit factor method to **solve** stoichiometry problems **myself**. I feel confident to do this.	Confidence teach	
14	My learners are **too slow and weak** to learn the unit factor method in the **time** available. (Reversed item)	Learners not too slow and weak	

The two-day intervention consisted of roughly four hour-long periods of interactive direct instruction, interspersed with four two-hour-long periods of individual written work using a structured workbook and supported by small-group discussion. These activities were focused on developing an understanding of the mole concept and proportion, and application of these within the unit factor method. The participants answered stoichiometry pre- and post- tests at the start and end of the intervention, respectively. Relevant to the third research question, the number of questions (/4) for which each teacher used the unit factor method, was recorded for each participant for the four calculation questions in the post-test. These questions were similar to those reported on in Stott (2021), i.e. to the pre-test calculation questions.

The following data-transforming techniques were used during data analysis: (1) the reverse-score (6 minus score) was used for the reversed items (questions 7 and 14); (2) averages (/5) were calculated for each of the three belief components of the Theory of Planned Behaviour, with the question responses included in each of these indicated in Table 48; (3) a Belief Index (/55) was calculated from a sum of all except the first three (prior-use and intended future use) Likert-scale responses.

To answer the first research question, the Likert scale questionnaire responses were analysed using descriptive statistics and the open response questionnaire responses were categorised according to emerging themes. To answer the second research question, relationships were sought between the Likert scale questionnaire responses and the biographical data. This was done in a pragmatic and iterative manner, using correlation, t-test and ANOVA statistics and using pivot tables and graphs to group and represent the data in various ways to search for patterns. To answer the third research question, correlations were sought between the count (/4) of questions for which the unit factor method was used in the post-test and: (a) the Belief Index (/55); (b) the response to question 3 (/5), referred to as the Intentions Index.

RESULTS AND DISCUSSION

Professed beliefs and intentions regarding the unit factor method

Figure 33 shows the numbers of participants who indicated each of the five levels of agreement offered for each of the statements given in This is a pragmatically conducted mixed-methods survey study guided by the framework for integrated methodologies (FraIM) (Plowright 2011). Data were collected from South African Physical Sciences teachers who attended a two-day stoichiometry professional development workshop at which I taught them how to use the unit factor method to solve stoichiometry calculation questions. I held eight of these workshops throughout the Free State province of South Africa, between November 2017 and March 2018. The Physical Sciences subject advisors extended an open invitation to the teachers in their area to attend, with the incentive that they would receive teaching resources and earn continuous professional development points. A total of 220 teachers attended these workshops. However, the sample relevant to this study is a sub-group of this (n = 159), since only teachers who completed all the data sources relevant to the analyses conducted here and provided informed written consent for their data to be included in this study, are included. Although this convenience sample cannot be claimed to be representative of the population of South African Physical Sciences teachers, there were no externally imposed biases to inclusion in the sample. Characteristics of the sample are given in Table 47 to enable readers to judge the generalisability of claims made to the broader population. Before data collection commenced, ethical clearance was awarded by the University of the Free State (UFS-HSD2017/1520).

Table 47 Note that the reversed scores are plotted here for the two reversed items (7 and 14), which is why the captions for these items are worded positively, rather than in their original negative form. The first two columns show very low levels of prior use of the unit factor method, in stark contrast to DeMeo's (2008) finding that the unit factor method (dimensional analysis) was used by 90% of his sample of high school and university chemistry teachers mainly from the United States of America. Besides these first two columns, the general impression given by Figure 33 is high extents of moderate, strong and very strong, agreement with favourable statements about the teachers' intention to use the unit factor method in the future and the method's usefulness for performing, and teaching, stoichiometry calculations. This corresponds to the finding that only two of the 94 answers to the open response items displayed any negativity towards the unit factor method. These two both referred to national marking practices which would likely penalise use of the unit factor method: "Learners get marks for using formulae and substitutions. Not sure if they'll get marks with the unit factor method."; "I am worried about the memorandum discussion that might not recognise the unit factor method. A guideline in terms of mark allocation would be required so that it can be included in exams." See Stott (2021, p. 454) for suggestions for such guidelines.

The teachers' responses to the attitude belief items of the questionnaire (Columns 4 to 9 in Figure 33), while generally positive, are somewhat erratic, possibly undermining reliability to some extent. The following themes emerged, regarding attitude beliefs, from the open-ended responses regarding the unit factor method: (1) poses initial difficulty (4 comments); (2) improves stoichiometry understanding and generic problem solving (7 comments); (3) makes stoichiometry easier (15 comments); (4) will improve learner performance in stoichiometry (15 comments). It is possible that incorporation of games (e.g. Saitta et al., 2011) and heuristics (e.g. Krieger, 1997) in teacher-education workshops such as these, may help overcome the initial difficulty reported, e.g. "The first time when this method was introduced, I felt like it was difficult, but now I am so excited because after this workshop I realise that this is the easiest method and it saves time." The following comments suggest resolution of the apparent contradiction between this comment, regarding the unit factor method saving time, and the many (33) comments about the method taking a long time to learn: "I think in spending more time on the unit factor method it will save time later in other topics as well"; "Method very much good, could help in handling any problem that requires conversion. I love it and impressed about it." These comments suggest that the generic nature of the unit factor method makes it a versatile time-saver once it has been mastered.

The perceptions of behavioural control dimension (see the last three columns in Figure 33) was the least favourable, on average, of the three TPB dimensions. This corresponds to the finding that 33 of the 94 open-response items referred to the need for more time to practice using the method than was provided in this two-day workshop. For example: "The unit factor method used during the workshop is easy, but one needs time to go back and practice it so that I can master it to be able to teach my learners"; "Very fruitful, but needs more time than these two days".

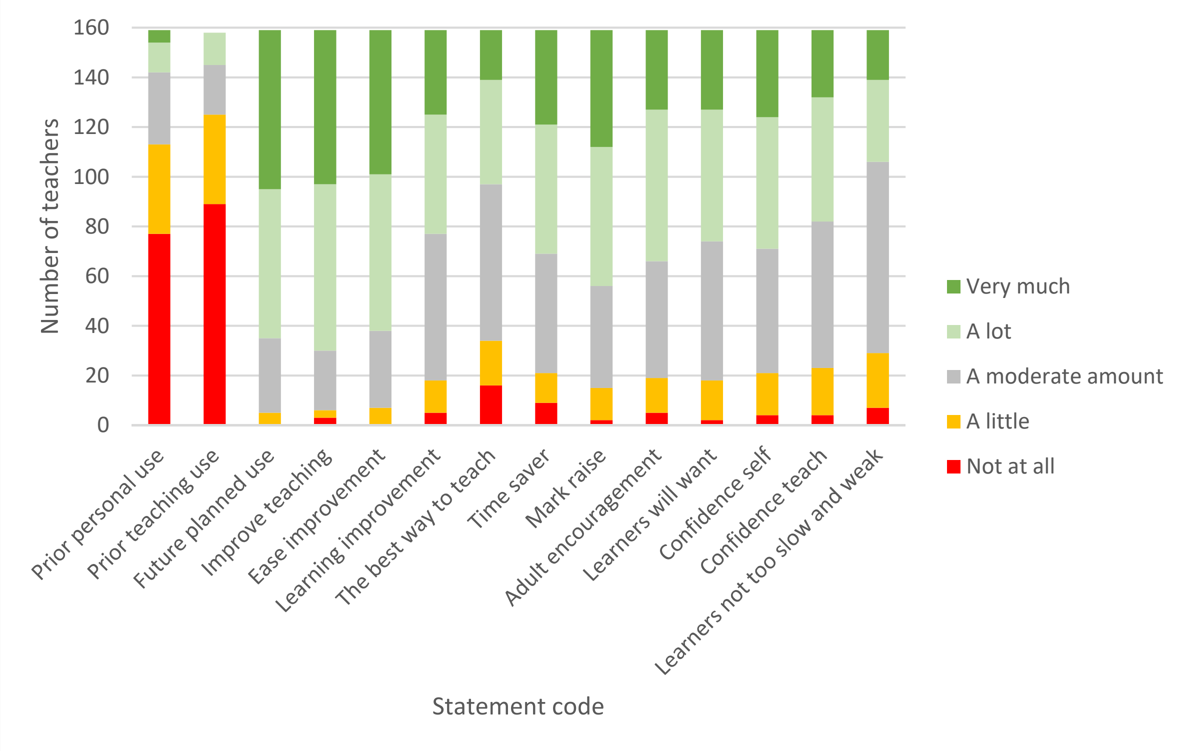

Figure 33: The number of teachers who indicated each of the provided Likert-scale levels of agreement to each of the questionnaire statements about usage, intentions, and beliefs regarding the unit factor method. See Table 2 for the full statement that corresponds to each statement code.

As shown in the final column in Figure 1, the final statement, about learners being too slow and weak to learn the unit factor method effectively, provided considerable concern. However, this concern may apply to stoichiometry, rather than only to the unit factor method. No relevant open-ended comments were made to clarify this. Stoichiometry is known to be particularly difficult for learners with low mathematics competence (Ralph and Lewis 2019), which South African learners, generally, are known to be (Reddy, Visser, Winnaar, Arends, Juan, Prinsloo, Isdale, et al. 2016). Furthermore, since many South African Physical Sciences are also known to have low mathematics competence (Selvaratnam 2011), it is unsurprising that 33 of the teachers remarked that a two-day workshop was not long enough for them to develop confidence in the unit factor method. Perhaps any method would have received the same criticism. Further research would be needed to determine the validity of this speculation.

Relationship between professed beliefs and teaching and qualification factors

No statistically significant relationships could be found between the beliefs the teachers professed towards the unit factor method and the teaching and qualification factors measured in the questionnaire. Figure 34 shows the average ratings assigned to questions about attitude beliefs, subjective norms and perceived behavioural control, for teachers without (n = 102) and with (n =57) a BSc degree, plotted according to their stoichiometry teaching experience level. Consistent with Figure 33, a general average slight positivity is evident, with all averages being in the range between 3 (*moderately agree*) and 4 (*agree a lot*) out of 5. Also consistent with Figure 34, except for both the experienced groups, attitude beliefs are the highest and perceptions of behavioural control the lowest.

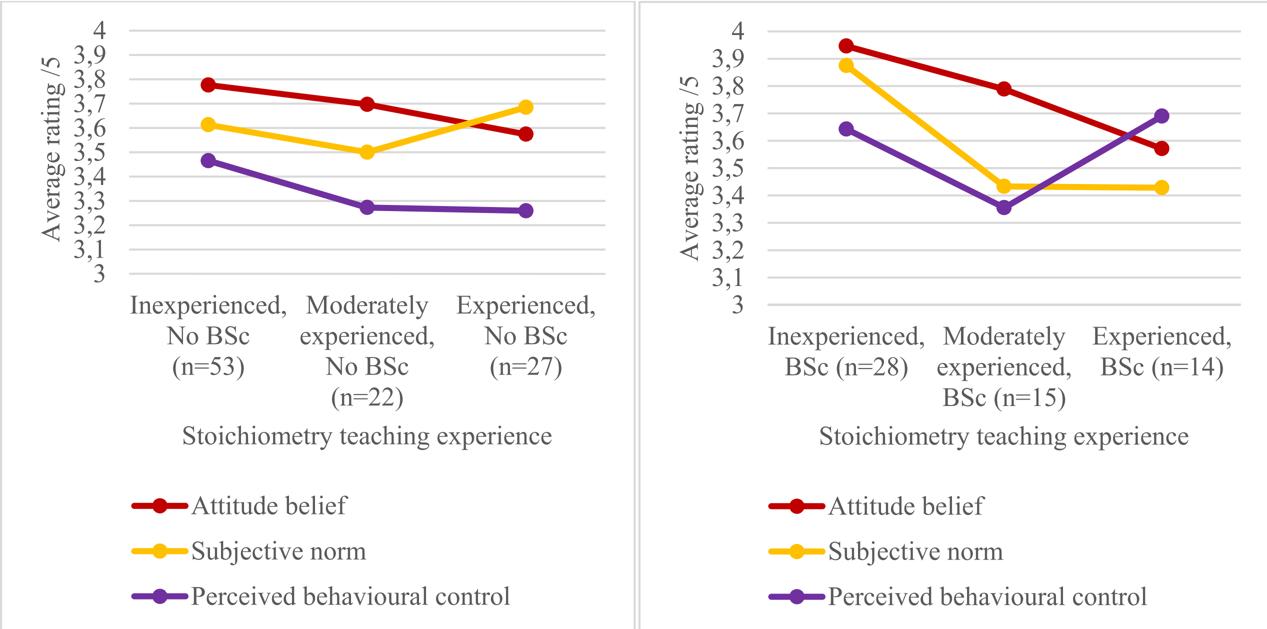

Figure 34: Belief profiles, regarding use of the unit factor method, for teacher groupings according to experience and qualification: Graph a: no BSc, n=102; Graph b: with BSc, n=57.

As shown in Figure 34, on average the teachers who had taught stoichiometry for 3 years or fewer (inexperienced category, n = 81) held the most positive beliefs regarding the unit factor method (M = 41.0/55, SD = 54.3). However, this was not found to be statistically significantly different to the beliefs of those who had taught stoichiometry for 4-9 years (moderately experienced category, n = 37, M = 39.3/55, SD = 42.5) or for 10 years or more (experienced category, n = 41, M = 38.9/55, SD = 40.0), $F(2, 156) = 1.6$, $p = 0.2$. The teachers with a BSc degree (Figure 34b) (M = 40.9/55, SD = 54.9) were more positive, on average, than those without a BSc degree (Figure 34a) (M = 39.6/55, SD = 44.5). However, this was also not found to be statistically significant, $t(157) = -1.2$, $p = 0.2$). The teachers teaching at schools serving learners of low socioeconomic status held more positive beliefs about the method (n = 144, M = 40.1/55, SD = 49.1), on average, than their counterparts (n = 15, M = 38.9/55, SD = 41.8), although this was also statistically insignificant, $t(57) = -0.7$, $p = 0.5$). The small size of the latter group should be noted.

Relationships between professed beliefs and intentions and extent of post-test usage

The third research question refers to the relationship between the teachers' professed beliefs and intentions regarding the unit factor method and the extents to which they chose to use this method in the post-test. The purpose of this research question is to evaluate the validity of the questionnaire based on the TPB's premise that beliefs affect intentions which affect behaviour (Ajzen 2011). The inconsistency of the contexts referred to by the various measures should, however, be noted. The professed beliefs and intentions are related to the teachers' use of the unit factor method in their teaching, whereas the measured behaviour refers to the teachers' own use of the unit factor method in answering a test immediately after the 2-day intervention. So, for example, some teachers with relatively low beliefs about the value of the unit factor method in teaching and learning might have felt that they were expected to use the unit factor method in this test since it followed an intervention focused on this method. This concern is reduced by the fact that the teachers were instructed to use whichever method they wished when answering this test. As a further example of concern, teachers with favourable beliefs regarding use of the unit factor method in the future after additional practice, might have felt safer, under test conditions, to resort to their previously used methods. Nevertheless, it is assumed that although these limitations will weaken any relationships detectable between the measured indices, a valid questionnaire should enable their detection to some degree.

Following from this reasoning, the findings given in Table 49 are taken to suggest that the Belief Rating (/55), obtained from 11 of the questionnaire items, has acceptable validity, whereas the Intention Rating (/5), obtained from a single questionnaire item, likely does not. Table 49 shows that a statistically significant weak positive correlation was found between the beliefs the teachers professed regarding the unit factor method's value in learning and teaching stoichiometry, and the extent to which they used the unit factor method in their own calculations in the post-test. In contrast, the teachers' professed intention to use the unit factor method in their teaching in the future showed no significant correlation to the extent to which they used the method in the post-test.

These findings suggest that this study's detection of: (1) generally positive beliefs towards the unit factor method can be trusted, but (2) high intentions to use the unit factor method in the future should be treated with scepticism. Such scepticism appears to be particularly justified if these teachers are not provided any further support regarding use of the unit factor method, and if SA PS marking guidelines continue to penalise its use.

Table 49: Details of the correlation analysis between professed beliefs and intentions regarding use of the unit factor method and the extent of its use in the post-test

Variable	**Index**	**Index calculation**	**Correlation between index and number of questions for which the unit factor method was used in the post-test (/4)**	**Remarks**
Beliefs regarding the value of the unit factor method in stoichiometry teaching and learning	Belief Index (/55)	Sum of responses to questions 4-14, with 7 and 14 reversed	$r(157) = 0.20, p < 0.01$	Significant, weak positive correlation
Intention for future use of the unit factor method	Intention Index (/5)	Response to question 3	$r(157) = 0.12, p = 0.13$	No significant correlation

CONCLUSION

The following assertions are given, in answer to the research questions: (1) The teachers professed positive beliefs regarding, and intentions for future use of, the unit factor method, despite their very limited prior use of this method; The relatively low measured perceptions of behavioural control partly arose from the intervention being too short to provide a considerable number of the teachers with enough time to practice the method sufficiently to attain the confidence needed to teach it; (2) The teachers' professed beliefs regarding the unit factor method were not significantly related to their teaching experience, whether they possessed a BSc degree, or the socioeconomic status of the learners they taught; (3) The lack of significant correlation between the teachers' professed intentions to use the unit factor method in their teaching and their own use of the method in the post-test undermines the likelihood that the teachers' generally positive professions of intentions to use the unit factor method in their classes will translate into reality; Based on the Theory of Planned Behaviour's premise that beliefs affect behaviour, the presence of significant correlation between the teachers' professed beliefs regarding the use of the unit factor method in teaching and learning, and their own use of the method in the post-test, lends support to the validity of the questionnaire items used to measure these professed beliefs, and therefore also to the validity of the finding of general positivity towards the unit factor method.

Based on these assertions, the following recommendations are made regarding Physical Sciences teachers, at least in South Africa, and possibly in other developing world contexts too: (1) teachers should be given access to professional development interventions, of longer than 2-day duration, which focus on the unit factor method and its application of the mole concept and proportional reasoning; (2) examination marking guidelines should not penalise use of the unit factor method.

Many teachers in the developed world consider the unit factor method the most likely to help learners obtain the correct answer (DeMeo, 2008). Indeed, some authorities even decry the method for enabling attainment of the correct answer without conceptual understanding (DeMeo, 2008). Whether or not this accusation is justified, it is ironic that in a context, such as South Africa, in which even teachers struggle to obtain the correct answer to stoichiometry calculation questions (Stott, 2011), the unit factor method should be underutilised and penalised. This research is significant in suggesting that this underutilisation is not explainable, and this penalisation is not justified, by teacher beliefs.

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QUANTUM TECHNOLOGIES: A PROJECT FOR TEACHER PROFESSIONAL DEVELOPMENT

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We present some results on an ongoing project for teacher professional development whose purpose is to enhance physics teachers' knowledge, awareness, and drive to educational innovation along the lines of the "second quantum revolution". The project started with an initial course whose focus was not only on physical content, but on developing in teachers a professional commitment to the common goal of curriculum innovation and is now in the phase of developing into a community of practice. Although centered on quantum computation, the course opened a much wider perspective on a longitudinal thread which touches several areas of physics, mathematics, logic, and information science. Seen from a teachers' perspective, such thread gives the possibility of exploring, throughout the curriculum, various crucial intersections in which the discourse on computation and the discourse on physics get closer and overlap, to the point of becoming essentially identical with the development of quantum computation. Adopting this perspective as a general guide, teachers can develop examples of educational design not necessarily directly related to quantum mechanics, but covering disparate areas of physics and mathematics, such as propositional logic, classical algorithms, thermodynamics, circuit theory.

Keywords: Teacher professional development, Community of practice, Culture and education

INTRODUCTION

The Strategic Agenda of the European Quantum Flagship (2020) expresses a strong urge for a change in physics education which leads teachers and students, also at the level of secondary school, to perceive "*the paradigm shift from quantum theory as a theory of microscopic matter to quantum theory as a framework for technological applications and information processing*", which is what is meant with the expression "second quantum revolution". The goal is clearly ambitious given that in most European educational systems quantum physics is a recent addition to the physics curriculum, often only a few selected topics are covered (Stadermann et al., 2019) and, in general, more research is needed to develop strategies to help students overcome learning difficulties at secondary school level (Krijtenburg-Lewerissa et al., 2017). Given such limitations, an attempt to encourage teachers to a plain and simple extension of the physics curriculum to include quantum information and computation topics would probably not be appropriate. Thus, our approach was instead to attempt, by means of an initial course providing common grounds and motivation, the formation of a community of practice (Wenger, 1998) motivated to longitudinal and inter-disciplinary curriculum innovation towards the objectives of the Quantum Flagship. To this aim, the initial course stimulates teachers to a high-level reorganization of the physics content (Van Heuleven, 1991) grouping different topics in the physics and mathematics curriculum under the common perspective of representing instances of overlap and interplay between the discourse of physics and the problem of computation. In this way, we thought teachers could be motivated to introduce topics of quantum information and computation, not as one further subject of the physics curriculum, but as the culmination point of a longitudinal and interdisciplinary path which they could have developed through the course of several years.

RESEARCH QUESTIONS

Our final goal is the construction of a community of practice (Wenger, 1998) whose common goal is to perform curriculum innovation towards topics related to the second quantum revolution. In this view, the aim of the initial course is on one hand to provide a first nucleus of shared knowledge about quantum information and computation topics to the attending teachers, on the other hand to provide hints about the ways through which the task could be performed, i.e., elements of curriculum innovation and inter-disciplinary connections distributed longitudinally along the five years curriculum. This shared content is meant to be elaborated by the teachers and researchers within the community of practice into several different types of educational intervention, distributed along the curriculum, also depending on the classes each of the participant teachers currently works in. A central aim of the course is to have teachers develop some degree of personal commitment to the objectives of curriculum innovation. As will become clear in the next section, the initial course has a quite wide span, both in the interdisciplinary sense (physics, mathematics, logic and information science) and in the longitudinal direction, touching subjects from different physics years. As mentioned in the Introduction, this is meant to stimulate a new organization of physics content by which teachers could identify and expand into educational interventions the possible concepts and areas related to an interplay and overlap between the language of physics and the language of computation. Overall, our project is aimed to provide at least a partial response to the following research questions:

1. Do the contents and themes of the second quantum revolution appear sufficiently fruitful to teachers to develop a personal commitment to longitudinal, interdisciplinary educational innovation directed towards themes of quantum information and computation?
2. What are the most appropriate environment and methods for building a distributed, online community of practice of teachers revolving around the themes of the second quantum revolution?

RECONSTRUCTION OF CONTENTS

From the point of view of content reconstruction, our course aims at presenting topics related to the second quantum revolution as the apex of a long progression in the interplay between physics, mathematics and logic revolving around the problem of computation. The course starts discussing the pioneering works of Bennett on the thermodynamics of computation (Bennett, 1982), those of Toffoli and Fredkin on reversible logic (Fredkin and Toffoli, 1982), and the intuitions concerning the possibility of simulating physical systems using computers expressed by R. Feynman (1982). These works play a significant role in bringing the problem of computation even closer to the realm of physics and pave the way for a reflection on the possibility of using quantum mechanics to encode and manipulate information in a profoundly different and innovative way. By using two-level systems – thus in fact adopting a spin first approach well established in PER but moving from the computational side of the problem (Dür and Heusler, 2014) - we can generalize the concept of the classic bit to the quantum bit - qubit - and study some logical operators that act on them. The generalization allows us to establish a correspondence between Boolean functions, describing classical connectives, and unitary operators describing the evolution of a system in quantum physics. All the objects involved in the formalism used also have a simple circuital representation that is a distinctive feature of approaching quantum mechanics from the side of quantum computation but may also open the way for a longitudinal reflection on the different uses of "circuit representation" in physics. At this point the course has three months pause in which the first cornerstones of a community of practice are laid: creation of a dedicated online discussion forum for the participant teachers, assignation of individual and group tasks. In the second part of the course, Bell entangled states are introduced through the newly developed circuital language. These states are sufficient to study some pioneering quantum protocols, crucial in current quantum technological applications, explaining the most significant aspects of entanglement: dense-coding, quantum teleportation, quantum cryptography (López-Incera et al., 2020).

STRUCTURE OF THE INITIAL COURSE

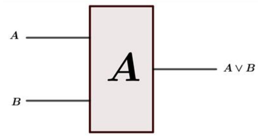
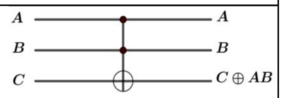
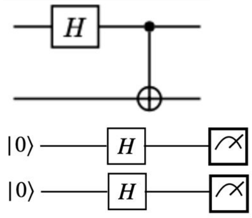
The Educational path has a total duration of about 20 hours and is structured according to the following steps summarized in table 1: 1) introduction to physics problem of classical computation; 2) building the quantum logical language and the origin of quantum algorithms; 3) introduction to entanglement and development of quantum protocols.

Table 1. Structure of the educational path.

Introduction	Building	Development
Physics problem of computation	**QP with Stern-Gerlach device**	**Entanglement**
	From bit to qubit – Quantum circuits	**Bell's inequalities No-cloning theorem**
	Quantum algorithms	**Quantum protocols (Dense coding, quantum teleportation)**
		Cryptography

The first four meetings took place in October and November; the other four in February and March. The key idea around which the entire course moves is the one that best expressed R. Feynman about the simulation of physical systems (Feynman, 1982): "What kind of computer are we going to use to simulate physics?" and even before that "what kind of physics are we going to imitate?". The route we explore with teachers, is that if we want to imitate quantum physics, the natural choice is to renounce both classical logic and classical probability. To understand this fundamental aspect, we have first described using the language of set theory the basic structure of classical physics, and then shown how propositional logic and probability can be constructed as theories concerning subsets of the set S of possible states of classical physics (Isham, 2001).

Table 2. From classical to quantum computation.

	Information coding (preparation)	**Logic gate (transformation)**	**Decoding of information (measurement)**	**Circuital representation**
Classical logic	**Bit 0, 1**	**Boolean functions** $f:\{0,1\}^n \longrightarrow \{0,1\}^m$ $Not, And, Or...$	**Confirms the value of the bit on which it acts. We obtain a bit of classical information**	
Reversible classical logic	**Bit 0,1**	**Invertible Boolean functions** $f:\{0,1\}^{n+m} \longrightarrow \{0,1\}^{n+m}$ $Toffoli, Fredkin$	**Confirms the value of the bit on which it acts. We obtain a bit of classical information**	
Classical computation	**Classical state (potential)**	**Diodes, transistor**	**Measurement instrument (circuit element) of the potential**	
Quantum logic	**Qubit** $\|\psi\rangle = \alpha\|0\rangle + \beta\|1\rangle$ $\|\alpha\|^2 + \|\beta\|^2 = 1$ $\alpha, \beta \in C$	**Unitary operators** $X, Or, And, H, Z...$	**It randomly chooses one of the two eigenvalues associated with the basis qubit states. We get a bit of classical information**	
Quantum computation	**Quantum state** **Spin** $\|\uparrow\rangle, \|\downarrow\rangle$ **Polarization** $\|V\rangle, \|H\rangle$	**Different experimental realizations**	**Measurement devices (intrinsically probabilistic)**	

By using two-level systems, we can then generalize the concept of the classic bit to quantum bit - a qubit - and study some logical operators that act on them (See Table 2). The generalization allows us to establish a correspondence between Boolean functions, describing classical connectives, and unitary operators describing the evolution of a system in quantum physics. All the objects involved in the formalism used also have a simple circuital representation (Coecke & al., 2016), which may be seen as one of the distinctive features of our approach. The possibility of working on new and strongly decontextualized symbolic representations allows the development of an autonomous and complete language that we believe can be of great interest and help for the more in-depth exploration characterizing the second part of the educational path.

The probabilistic interpretation of qubits makes it possible to introduce composite systems and the tensor product fairly and introduce multi-qubit logic gates. The action of logic gates has been described both in Dirac notation and with matrices. An in-depth understanding of the correspondence between circuit element, the Dirac and the matrix formalism, and the physical systems that implement them, is an essential part of learning and grasping the concepts introduced.

The formalism introduced and the corresponding diagrammatic representations made it possible to develop in the following lessons quantum algorithms and protocols that show the deep characteristics of quantum physics, in particular the role of superposition, interference, compound systems and entanglement.

CONTEXT AND DATA COLLECTION

The course was organized in the context of the Italian PLS-Piano Lauree Scentifiche (Plan for Science Degrees) and the education section of the Quantum Flagship. We divided the twenty hours planned in two parts: first 10 hours in October and November; the second part in February and March. Due to the restrictions imposed in response to the COVID-19 pandemic, all lessons, although initially planned as a traditional classroom course, were performed in synchronous distance learning. Interaction between teachers was limited, and the means of delivery were, approximately, 80% frontal lesson, 10% full group discussion, 10% teachers performing individual activities such as exercises or answering questions, which were discussed immediately afterwards. The course was attended by around 30 teachers in the first part and 17 in the second. Asynchronous discussion was performed using both generally available tools (Google drive, forms etc.) and a dedicated online forum set up on the servers of the University of Pavia.

Within the initial course, we collected data by several means:

- 23 pre-questionnaires completed, touching both disciplinary aspects and items related to personal engagement and involvement
- Sheets with solutions to problems and exercises produced by teachers during the course, and answers to on-the-fly clicker type questions given during one lesson of the course
- 14 post-questionnaires completed, touching both disciplinary aspects and items related to personal engagement and involvement
- Semi-structured interviews with four volunteering teachers

In this work we will analyze only the 14 post-questionnaires competed and the semi-structured interviews.

DATA ANALYSIS

Post-course questionnaires

As shown from Figure 1 in general teachers displayed a strong appreciation for the topics covered, particularly on the second part about the entanglement which using the logic gate formalism can be treated in a formally rigorous and conceptually meaningful way. Regarding the first research question, we can note positive answers about having dealt with the course topics and the importance they would have for the students; on the other hand, one can note a significant scepticism about the possibility of introducing them into the curriculum also in a longitudinal and multidisciplinary perspective (See Figures 2 and 3).

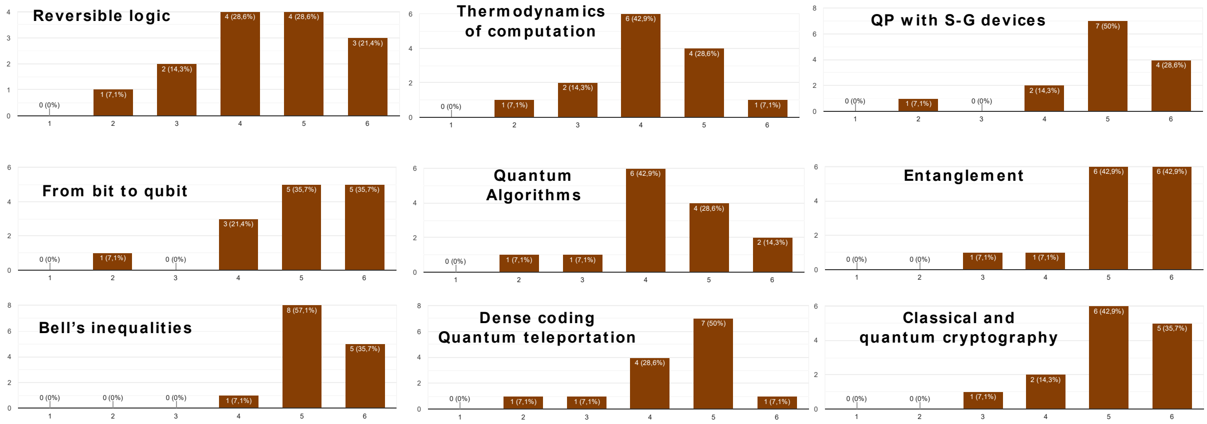
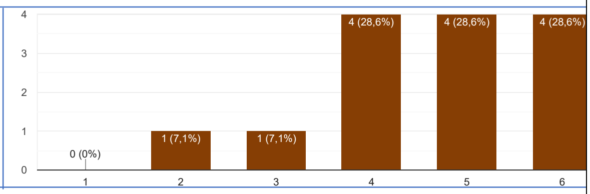


Figure 1. Interest level about topics introduced.

How beneficial do you think it is for your professional development to have studied quantum technology issues in depth during the course?



How much do you think it would be theoretically beneficial for your students' cultural development to introduce some themes - dealt with during the course - related to quantum technologies?

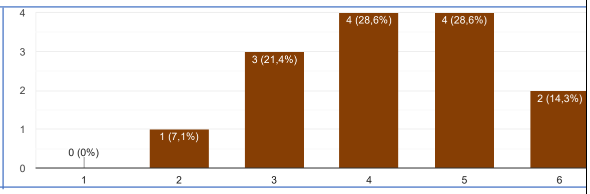
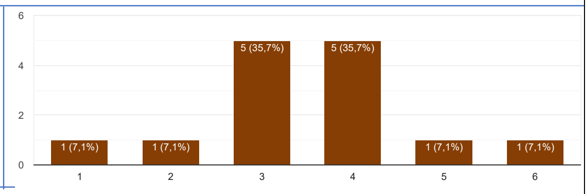


Figure 2. Teachers' and students' beneficial about the studies in quantum technologies.

How do you think it would be feasible to introduce some quantum technology issues to your students?



How practicable do you think the idea of a multidisciplinary (physics, mathematics, computer science) and longitudinal (developed along the entire five-year cycle) path based on the physical aspects of computation is?

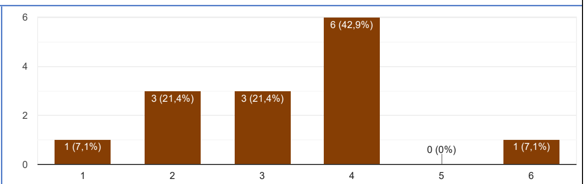


Figure 3. Propensity to introduce the topics of the second quantum revolution into the curriculum and from the perspective of a longitudinal and multidisciplinary approach.

It is also extremely interesting that teachers found the circuit language introduced able to relate phenomenon, mathematical formalism and syntactic representation (See Figure 4).

Regarding the second research question (What are the most appropriate environment and methods for building a distributed, online community of practice of teachers revolving around the themes of the second quantum revolution?), although the teachers greatly appreciated the materials prepared and shared (lecture recordings and slides) and found the lessons as well structured and interesting as they had hoped at the beginning (See Figure 5), they struggled to create a shared community of practice during the course, and teacher-to-teacher or collective online communication did not happen to any significant extent, notwithstanding the instruments we provided the group with (community forum, google drive folders).

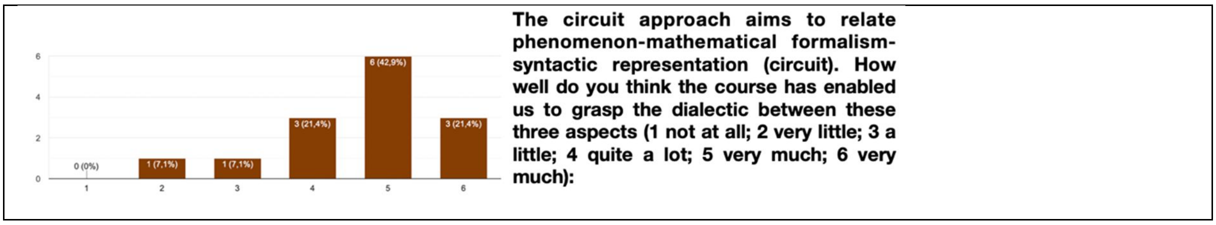


Figure 4 The importance of the circuital representation.

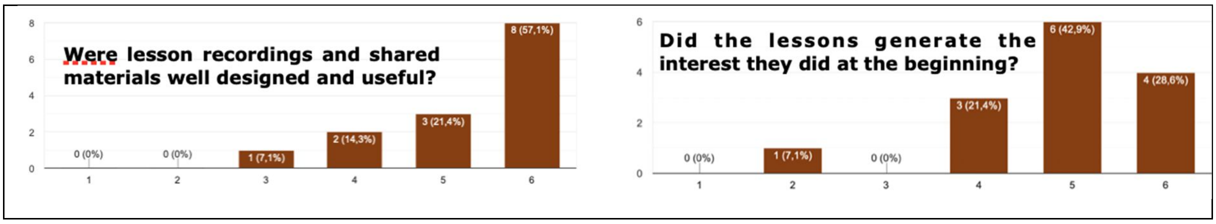


Figure 5 Quality of shared materials and level of satisfaction with respect to expectations.

Semi-structured interviews

We created a matrix for mapping interview questions onto research questions (Castillo, 2016). The interview protocol, after introductory questions, was divided into four parts:

- specific questions about the topics treated;
- teacher opinions on didactic feasibility, multidisciplinary and cultural impact;
- questions about the formalism used and circuital language;
- teacher evaluation of lessons and materials.

Thus, for each section, part of the interview protocol is linked to a research question. The transcription of interviews was used for analysis and comparison guided by the matrix previously created. An *a priori* coding scheme (Otero & al., 2009) is developed also considering the course goals and two of our corollary hypotheses which we intended to verify: 1) that the topics covered would have been interesting especially for mathematics graduates; 2) that the possibility of introducing such topics before the final year would have made them more practically usable in teaching.

Concerning the first part of the course, the introduction to the physics problem of computation, all teachers bring up the issue that mathematical logic it is not taught in great depth in school these days, and is only linked to set theory and propositional calculus, often in passing, in the first year. Teachers after the course believe it would be appropriate to expand the weight of the topic, but this seems not easy in a school context that seems to progressively dismiss its relevance. The cultural importance of introducing non-classical logic is recognized. The strong link proposed between logic and the thermodynamics of computation has caused surprise and difficulty, in particular to the two teachers with a degree in mathematics. All teachers acknowledge the effectiveness of the introduction to QP through the Stern-Gerlach device, but some would prefer to use polarization because it is a topic already known to students. The formalism used for the introduction to quantum computation is considered suitable for high school students if appropriately trained, and it is seen to be very promising especially by the two mathematics graduates. The abstractness of language, however, raises the problem of immediate physical interpretation. This aspect is even more evident in the study of the two proposed algorithms, whose computational aspect seem, in part because of their complexity, to be prevailing on its physical aspects.

Concerning the second and third parts of the course, more directly linked to the development of the language of quantum computation and communication, the interviewees generally agree on the high cultural value of the proposal, and the importance of a multidisciplinary approach for the education of future scientists. However, they recognize the introduction of these topics into the traditional curriculum as problematic, unless some of the content is deeply revised from the early years. The possibility of introducing topics linked to very recent technological developments is viewed as a likely source of students' engagement. Particular importance was attached to the cultural impact of the course, and that the two teachers with a degree in mathematics, in their free final remarks, stressed the great impact that the topics covered had had on their desire to study and explore QP and on a new vision of the world arising from it.

Development of a community of practice

As mentioned above, communication between teachers and in full group was judged insufficient by us during the course. However, and despite the moderate inclination to build multidisciplinary and longitudinal pathways expressed in the final questionnaire, 7 teachers asked to continue to deepen the introduced topics in view of an experimentation with their classes. They asked to go into some aspects in greater depth and are currently engaged in planning teaching sequences which also cover topics that are addressed before the final year.

Follow-up course, co-design and research action projects

At the end of the course, we organised five more meetings meant for teachers who expressed at least an initial interest in experimenting some of the topics treated in school. It was clear that they still needed to go more in depth in the topics treated and, above all, to focus on an educational reconstruction adapted to classroom work. In the first two meetings an introduction to quantum physics with a two state approach based on polarisation instead than on spin was presented, as most teachers had expressed in questionnaires and interviews that they preferred this approach, and it seemed at least equally suitable for an introduction to quantum technologies. The next three meetings concerned the introduction of a possible educational reconstruction for students using materials based on the course on quantum technologies for self-selected fourth- and fifth-year high school students which we held in Pavia in the same period (Sutrini et al, 2021). At the end of these additional 10 hours of meetings, we started work on co-design of customised teaching-learning paths with the 7 teachers willing to prosecute on this route. Experimentations carried on by each teacher will be focused on one or more of the following topics: thermodynamics of computation; the relationship between logic, physics and computation (presented as a multidisciplinary sequence); from classical to quantum cryptography; from classical to quantum search algorithms; entanglement and quantum teleportation protocol

The work we are doing with teachers shows the need for a different approach to some of the fundamental themes of mathematics and physics that students encounter well before the fifth year: propositional logic and the role it can play in the experimental work of a physicist; the concept of probability; the concept of physical system and state; the microscopic approach to the second principle of thermodynamics (Malgieri et al., 2019); the concept of information and its importance in physics. Some of these considerations arise from the research work in physics education that the University of Pavia has been carrying out for years, and they fit into the teachers' teaching practice without constraining it, as teachers are encouraged to take inspiration from it in order to enhance and expand it in the most fruitful way possible.

In this final phase of teacher professional development, we also oversaw a significant increase of socialization, communication and participation within the small group, with teachers with similar interests and aims actively exchanging ideas and materials for design. Our intention is that, at the end of the design and implementation of these teaching sequences, a first nucleus of community of practice can be established that can contribute actively to future project to teacher professional development.

CONCLUSIONS

We have presented in detail a teacher professional development project focused on quantum technologies, but presented within a broad cultural and interdisciplinary perspective which is now ongoing for over one year. To summarize the partial answers we provided to our research questions, we may say that:

- Based on questionnaire and interview answers, the proposed approach is considered engaging and personally enriching by teachers, but they still hold doubts on the practical feasibility in class. The percentage of teachers going all the way from the initial enrolment in the course to the co-design of an educational experimentation was about 25%, similar or slightly better than in our previous experiences of in-service teacher formation on modern physics (e.g., Malgieri et al., 2014) and it must be considered that in the case of the present course all activities were held in distance learning.
- Correspondingly, encouragement to use online socialization tools, prompt requests of comments and sharing of offline work did not seem effective in stimulating an appropriate level of communication, cooperation and sharing within a group of teacher which was not, in its majority, actually motivated to bring the proposed topics to the classroom. The degree of participation expected for a community of practice was only approached within the smaller group of teachers involved in deepening of the topics and co-design. Or hope is that, in future repetitions of the course which are bound to start this spring, the sharing of classroom experiences of these teachers can be inspirational

for the new teachers enrolled, and that the small group we are currently working with can form the seed of an actual community of practice.

Among the other relevant outcomes of the project, we mention the fact that teacher feedback prompted us to change the initial approach to basic QP from a two state approach based on spin to one based on polarisation. This was among the factors which helped us design a (we believe) better and more physically grounded educational reconstruction of quantum computation and communication for secondary school, on which we will report in forthcoming works.

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Part 15 / Strand 15

Early Years Science Education

***Editors**: Bodil Sundberg & Christina Siry*

Part 15. Early Years Science Education

Emergent science, science pedagogy and learning in the early years, cognitive resources for science learning, early years science and technology curriculum, innovative teaching practices in the early years, children's learning, preschool science, early years teacher education in science.

Part 15: Early Years Science Education

Editors: *Christina Siry & Bodil Sundberg*

Introduction

Strand 15 of ESERA is dedicated to science education in the early childhood years, and the 2021 conference featured 6 accepted paper presentations and one invited symposium. Authors that chose to share their research in Strand 15 represented Australia, Finland, France, Germany, Greece, and Spain. Session themes from the 2021 conference reflect several key trends in the field, including the role of digital technologies and play-based learning and early childhood teachers' inquiry-based practices. From the presentation sessions, there were three papers submitted for inclusion in these e-proceedings that also met the technical, editorial requirements. These are reproduced in the following sections; two paper presentations and one symposium.

The symposium was organized by the Early Childhood SIG coordinators on *Early Years Science SIG Nature of Science Invited Symposium*, which highlighted key results from three different research projects related to the Nature of Science (NOS) in the early years. The symposium introduced NOS pedagogy for the early years through four diverse foci. In the first part on "Bush kinders: pedagogically promoting the nature of science", Coral Campbell and Chris Speldewinde presented research data of teachers in bush kinders in Australia and examined their pedagogical approaches to highlight how NOS pedagogy could be expanded. The second part on "NOS For Young Children: the ATLAS project" by Fanny Seroglou, from Greece, explored different approaches to teaching NOS using creativity and art, including animations, children's books, theatrical play, e-books, online activities and Slowmation. The third part on "making elements of scientificity explicit for Kindergarten Teachers" by Estelle Blanquet and Éric Picholle from France presents a new tool for introducing Nature of Science at the pre-school level focusing on criteria of scientificity and examining in-service teachers' reflections on the potential impact on their practice. Lastly, a contribution by Lena Hansson, Lotta Leden and Suzanne Thulin, from Sweden, explores the ways in which "Nature of Science can be introduced through children's books". Collaboration between researchers and early childhood education teachers was used to introduce NOS in the early years through book-talks connected to trade books (narratives as well as expository books).

Papers were submitted by groups of researchers from Spain, that present intervention studies at the early childhood levels, each exploring complex science concepts with young children. In the paper *Working Thermal Conductivity in The Early Childhood Classroom*, Esther Paños, María-Antonia López-Luengo, Cristina Gil and Cristina Vallés elaborate experiences in the physical phenomenon of thermal conductivity through a structured intervention that involved four activities related to thermal conductivity, as they also emphasize the role of material resources. The first author of this presentation also submitted a second paper that is included herein, examining young children's biology-related conceptual understandings. In this contribution, titled, *Biology in the Early Childhood Classrooms: Plants also Die*, Esther Paños, José-Luis Gómez and José-Reyes Ruiz-Gallardo introduce the topic of living and non-living beings. The authors elaborate on an intervention for teaching the concept of death in plants in the early years and investigate children's responses in a post-test and a delayed post-test, drawing implications for teaching practice.

In organizing this contribution from Strand 15 to the ESERA 2021 conference e-proceedings, we note that all three groups of authors emphasize young children's capacities for understanding scientific concepts and for reasoning scientifically. It is evident that students at the early childhood levels benefit from opportunities to investigate phenomena close to their lives, supporting establishing links between children's everyday experiences and the focus of learning in the classroom. The papers featured herein demonstrate a commitment within the ESERA community to exploring the complexities of early childhood science teaching and learning. We hope you will consider submitting to Strand 15 in the future, and enjoy reading the papers.

EARLY YEARS SCIENCE SIG NATURE OF SCIENCE INVITED SYMPOSIUM

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Significant research world-wide has shown that a young child's successful learning in science depends on his teacher's grasp of the nature of science as well as on his pedagogical knowledge. However, there is much confusion about what constitutes science at kindergarten level. Yet, the nature of science (NOS) is poorly understood by many teachers and, without a strong guiding framework, early childhood teachers may miss opportunities to lead young children to an understanding of the nature of science. But how might the nature of science be expressed in such a context? The symposium explored various aspects of the nature of science. This article will deal with the main ideas resulting from three different research projects, selected in order to introduce the key aspects of NOS pedagogy in the early years while emphasizing the variety of possible approaches to early years science, namely:

Part 1 - Bush kinders: pedagogically promoting the nature of science (Coral Campbell & Chris Speldewinde). This part provides research data around the pedagogy of teachers as they work in bush kinders. Teacher pedagogy is interrogated for its promotion of the nature of science and discussion highlights ways that this could be further developed.

Part 2 - NOS For Young Children: the ATLAS project (Fanny Seroglou). This part presents a number of different approaches to teaching NOS using activities for children that involve creativity and art, including the creation of animations, children's books, theatrical play, ebooks, online activities and slowmation

Part 3 - Making elements of scientificity explicit for Kindergarten Teachers (Estelle Blanquet & Éric Picholle). This part reports on the development of a new tool for introducing NOS in pre-school. Trialled with a large group of early childhood teachers, the study shows that they considered the work on the presented elements of scientificity useful for their pupils and were receptive to the introduction of these elements to their classroom practice.

Furthermore, an additional presentation by Lena Hansson, Lotta Leden and Suzanne Thulin (Kristianstad University, Kristianstad, Sweden) dealt with the introduction of the nature of science through children books. The idea of this project, performed in collaboration between researchers and early childhood education (ECE) teachers, was to introduce NOS in the ECE setting through using book-talks connected to trade books (narratives as well as expository books). The empirical data reported consisted of audio recordings of book-talks (N=152) with children aged 2-6 led by five teachers, audio recordings of focus groups and workshops (N=9) with the teachers, documentation of children's drawings as well as of artefacts used by the preschool teachers. The results showed that discussions about a variety of NOS issues are possible in an ECE context. It also showed that attention can be directed towards NOS during book talks regardless of genre or if the books contain explicit NOS references or not. However, book-talks connected to books without explicit NOS references require that the teacher finds *other ways to direct attention towards NOS. The teachers involved in this project managed to do this with only a short introduction to NOS. The authors concluded that book-talks have great potential as an approach to introducing NOS to the youngest children. The results further showed that the teachers experienced that the NOS book-talks had spin-off effects such as increased curiosity, new questions, and engagement in investigations among the children. These results pointed to the potential for NOS teaching to contribute to empowerment and agency for the children, and positions NOS as an important part of science in ECE that values democracy and social justice as central.*

Keywords: nature of science, early childhood education, teaching practices

PART 1. BUSH KINDERS: PEDAGOGICALLY PROMOTING THE NATURE OF SCIENCE

The Scandinavian and European approaches to teaching in forest schools have been influential in the development of Australian nature or bush kindergartens, often known as bush kinders (Christiansen et al. 2018). This type of early years' outdoor learning gained momentum, predominantly stemming from one pilot bush kinder that began in 2011 in a major metropolitan city. Since then, bush kinder programs have rapidly increased in their number and popularity. As bush kinders in Australia continue to proliferate, the research into bush kindershas found that there are a range of pedagogical approaches that guides teachers' practice with nature pedagogy. Important to this in Australia is the Early Years Learning Framework (EYLF) document (DEEWR, 2009) which provides a broad perspective on the benefits that learning in the outdoors has for children.

Bush kinder approaches and structures are emergent, depending on factors such as context, staffing and policy development. As this study illustrates, guidance provided to educators and bush kinder teaching approaches are not necessarily a focus in initial teacher education courses. This has the potential to leave a deficit in teacher understandings of how science learning can be enabled and enhanced in nature-based surroundings. Professional learning specifically for bush kinders is only just developing, suggesting that experienced teachers are reliant on their own knowledge and experience of teaching in the outdoors (Campbell & Speldewinde 2018). This is important because the bush kinder context is one that presents a range of challenges that differ from the traditional classroom environment. Limited teacher education in this area provides teachers with a predicament as they determine their pedagogical approach without the backing of empirical research. This creates the dilemma of what is appropriate pedagogically for bush kinders, particularly as elements of the nature of science such as;

- children's capacity to observe what is occurring around them in nature;
- children's ability to develop understandings of science through their inquiry and exploration;
- children's opportunities to hypothesise, theorise and validate science and;
- children's capacity to imagine and be creative with science in nature

The fieldwork led to consider the research questions:

- Do bush kinders, through the interactions that take place between teachers and children, facilitate learners' transition from being novices in their understanding of the science in nature to becoming experts?
- Do bush kinders facilitate children's understandings of the nature of science?

The fieldwork observations associated with this research project drew attention to the different pedagogical approaches used by the teachers we observed. The ethnographic research method drawn on for this study (Speldewinde, Kilderry & Campbell 2021), is one that allows for an emergent research design, drawing on the work from Stan and Humberstone (2011). This presentation examines those different pedagogical approaches in bush kinders using an ethnographic lens of how pedagogy translates into practice in this early years learning context. Ethnography was valuable here because it enabled us to observe bush kinder teacher behaviour as it occurred (Aubrey et al. 2000, p. 121). Ethnography also allowed to consider the potential and opportunities for bush kinder teaching as the analysis were not limited to one ongoing event, but rather many events occurring simultaneously. As this was the case, a number of ethnographic methods were employed to gather data, which included listening, watching, and participating. 'Being with people as they conducted their everyday duties' both regularly and fleetingly (Forsey 2010, p. 569) lent itself to considering ethnography as an appropriate methodology.

Design of the project

The study discussed in this part used ethnography (Green & Bloome, 2004) which is suited to research in bush kinder settings as the field site is open and requires the researcher to be mobile (Speldewinde, Kilderry & Campbell, 2021). The methodological toolkit used in the study applied a range of research methods including participant observation of teachers and children, and listening to conversations between teachers, between children and between children and teacher. At times, the researchers were drawn into these conversations as participant observers (Speldewinde, Kilderry & Campbell, 2021). They also were able to conduct semi-structured interviews, informal discussions, and capture images using photographic and video capture of play and teaching moments. The range of data allowed them to interrogate the teacher pedagogy. They regularly visited the site over two distinct periods of fieldwork, firstly in 2015 then again in 2017. These weekly visits took place over a two to three hour duration for three different five-week blocks in both 2015 and 2017. These data collection visits allowed to engage with the teachers and to understand what was happening over time. It gave a broader understanding of events, rather than a one-off snapshot of the site and teachers.

The fieldwork associated with this research project took place at three bush kinder sites in the Sandy Shore Shire (pseudonym) of south-eastern Australia, selected due to their close proximity to the researchers' University and each other. Chatlock bush kinder, was characterised by its limited area for play. Wickelsham bush kinder, was an open rectangular paddock with a strand of large cypress trees. Sunrise bush kinder was larger and had a mix of grassed areas, large trees suitable for climbing, exploring and hiding.

This short presentation focuses on three of the five teachers observed at the four sites. The teachers' pedagogy is considered using Edwards' (2017, p.4) Pedagogical Play Framework that consists of open-ended, modelled and purposefully-framed play (all being of equal pedagogical value). Play-based learning is considered the 'cornerstone of early childhood education provision' (Edwards 2017, p.4) and was influential in this analysis, guiding the researchers in their thinking of bush kinder pedagogies as they had observed some intentional teaching in some sites but not all.

Results

The researchers observed significant science experiences around physical, chemical and biological sciences, as well as skill development. For example, children grouped various objects such as twigs or gumnuts – classifying using attributes, they built with rocks, demonstrating persistence, and frequently they were balancing on tree branches, experiencing friction and force. When running and colliding they were involved in momentum and force. Ethically appropriate behaviour was observed as the children were careful in their handling and in awareness of small animal needs. Children observed and commented on changes to the environment due to weather and seasons. Teachers highlighted a biological concept or process to draw children's attention to science related ideas in the physical environment where the natural phenomenon was the catalyst for a child's play.

Teachers were observed being successful in their endeavours in the bush kinder, each with a very different approach to children's learning and teaching. Even though each approach was beneficial for children's learning and teaching, the researchers were left to ponder whether there should there be a specific pedagogical approach that facilitates children's understandings of the nature of science in a bush kinder? Although they do not consider this is necessary at this point in time, they do acknowledge that it would be beneficial for teachers to better understand the contextual limitations and possibilities afforded when teaching science in nature with preschool children.

Conclusion

Findings suggest that the bush kinder environment acts as an enabler for children to experience and improve their understanding of a range of science ideas, and the nature of science. However, there is an impact in the scope of children's learning based on the educator scaffolding. It is argued here that bush kinder, through the interactions that take place between teachers and children, facilitates learners to transition from being novices in their understanding of the science in nature to becoming experts. To date, research observations indicate that there is no particular way to adopt a pedagogical approach when it comes to teaching in bush kinders. What is important is for teachers to be cognisant of their practice. They need to adjust their practice from their everyday, regular kindergarten pedagogy to a different pedagogy more suited to the outdoor context. Teachers also need to understand the affordances that outdoor nature spaces provide for early years learning while being aware that children's learning can be dependent upon what a teacher is aiming to achieve through being in an outdoor bush kinder context.

Going forward, the opportunity exists for further research particularly as bush and nature kindergartens are proliferating. The variations between sites and teachers offers the prospects for further insights into pedagogical approaches. Because of this relatively new context, the impact on children's affinity with science has the potential to be further explored.

PART 2. NOS FOR YOUNG CHILDREN: the ATLAS project

Is it ever too early to introduce a child to the NOS perspective? From the very first time we speak to young children about science we should use the NOS context. Learning of and about science is a dual mode of approaching science knowledge that provides both appreciation of science concepts and an understanding of what science is and how it works, the latter being a pre-requisite for the former. A variety of NOS teaching applications are presented with a series of examples, while in all cases NOS is taught to young children using activities that involve creativity and art. These NOS teaching applications have been carried out by the ATLAS research group in Greece and follow the GNOSIS research model in their structure, while attempting to bridge education and entertainment for young children towards a science edutainment.

NOS Activities for young children: the edutainment approach

Science learning is one of the information exchange activities of our society and has to follow the multimodality and flexibility in communication and interaction characterizing all parts of our lives. If it doesn't evolve and adapt then it might gradually lose touch with its audience (Seroglou et al., 2019). Narratives in NOS edutainment sculpt and structure information through multimodal learning inputs into easily understood representations of abstract science concepts and theories guiding young learners' comprehension. NOS narratives that educate and entertain contribute to the understanding of abstract concepts and phenomena of science as they re-contextualize the traditional science content supporting a new image of science. Abstract science concepts, phenomena and theories as well as NOS aspects acquire form, image and sound (Seroglou et al. 2019; Avraamidou & Osborne, 2009; Brock et al., 2002). Children and teachers who take part in edutainment activities with NOS narratives co-operate with each other, talk about science and learn in a friendly and effective way.

With a series of examples, a variety of NOS teaching applications are presented, while in all cases NOS is taught to young children using activities that involve creativity and art:

a) Animations about science with NOS inputs have been developed by researchers using 4 young children as cartoon heroes that jump in and out of paintings and discuss about viruses.

b) Children books about science and NOS have been published to promote science teaching in the classroom and science learning for young readers in their time of leisure.

c) A theatrical play for children about climate change has been staged with interactive activities for the children.

d) E-books about science and NOS with on-line activities have been developed.

e) Slowmation (i.e., slow animation) movies have been developed by kindergarten teachers and/or young children presenting science in NOS context.

NOS edutainment approaches have a dynamic role not only in the classroom instead of the formal curricula, but also in parents' creative time with their children at home, in children's free time as leisure activities, on stage as a performance for children and adults, on-line for e-learning and m-learning learning activities for children. Science concepts and theories, nature of science aspects, values and attitudes fostered by science, contents and contexts of science, interrelations of science and society are re-contextualized in the developed stories, the on-stage performances, the classroom and on-line activities while children get both educated and entertained.

Discussion

The above NOS teaching applications have been carried out by the ATLAS research group in Greece and follow the GNOSIS research model in their structure, that emphasizes seven aspects of NOS teaching and learning: a) the nature of science contents, b) the nature of science contexts, c) the synthetic nature of science as a product, d) the nature of the evolution and methodologies of science, e) the nature of interrelations of science and society, f) the nature of attitudes expressed through science, g) the nature of values fostered by science. The attempt to bridge education and entertainment for young children towards a science edutainment is a huge but inspiring challenge for pupils and teachers, as well as a new milestone for science education researchers and curriculum developers. At the same time, the detailed study of the learner's interaction with the NOS edutainment approach provides critical information for the design of educational material and its use in formal, non-formal and informal learning environments. The encouraging results during the evaluation of the ATLAS case studies bring forward demanding questions on how to transform science teaching and learning to creative NOS edutainment that would support science learning and inspire all children to learn science.

PART 3. MAKING ELEMENTS OF SCIENTIFICITY EXPLICIT FOR KINDERGARTEN TEACHERS

Some countries encourage the teaching of NoS at every level, including Kindergarten. For instance, in the USA, the chosen approach of the NGSS (2013) is to define specific categories and to adapt the content of each category to the considered level in a top-down approach. Most Science Education researchers use a similar top-down approach when they propose frameworks for Kindergarten level (Lederman & al., 2013; Akerson & Donelli, 2009). Oppositely, some countries don't mention NoS, or even fail to mention science at all in their curriculum for Kindergarten pupils. In France, merely a very short section of the curriculum is dedicated to the "exploration of the living world, objects and matter "; French pupils are expected at the end of Kindergarten to '*recognize the main stages in the development of an animal or a plant and know the essential needs of some of them, locate and name the different parts of the human body, on oneself or on a representation, choose, use and know how to designate tools and materials adapted to a situation, to specific technical actions, build constructions, use digital objects, begin to adopt a responsible attitude in terms of respect for the them and the protection of living things*' (MEN, 2020). No further mention of science teaching can be found in the K1-

K3 curriculum either, nor is there any explicit mention of NoS at the upper level (K4-5) of primary school curriculum. A somewhat related section reads: "Practicing scientific and technological procedures" at K4-5 level and proposes a short list of items that pupils should master at the end of elementary school: '*formulate a question or a simple scientific or technological problem; propose one or more hypotheses to answer a question or a problem; propose simple experiments to test a hypothesis; interpret a result, draw a conclusion; formalize a part of its research in written or oral form*'. Considering the vagueness of the French curriculum about NoS, the rather minimal time dedicated to science in the initial training or teachers (which is supposed to allow them to teach both at Kindergarten and elementary school levels) and their lack of previous knowledge, it is not very surprising that French Kindergarten teachers tend to present a rather limited understanding both of how science work and of how to teach it.

Previous studies (Blanquet & Picholle, 2017) developed a bottom-up tool based on an explicit set of criteria of scientificity (table 1) to provide a guideline to primary school teachers adapted to the French context but also to a wider public. This set doesn't need to be considered as a whole in school; to the contrary, arbitrary subsets of 2 to 7 criteria appear far more suitable to actual inquiries, allowing both some elbow room for the teacher to adapt his choice of subset to his own pedagogical priorities, and an evolution of the number of criteria with the age of the pupils, which gets more and more ambitious as their understanding of NoS grows. The formulation of the criteria doesn't change with the age of the pupils (instead of the formulation of the categories in the NGSS Standards for instance, 2013).

Table 1. List of the full set of 22 criteria of scientificity.

Scientific Method	Observation/Experiment	Discourse&Representations	Argumentation &Theorisation
Primacy of testing Awareness Exploitation of the spectrum of generality Integrity Transmission	**Opportunity Repeatability Replicability Robustness Completeness and Economy of documentation**	**Lexical Coherence Symbolic Coherence Internal Non-contradiction External Non-contradiction Non vacuity Relativity**	**Logical Coherence Non scolasticity Univocity (of a law) Robustness (of a law) Economy (of a law)**

A subset of 5 criteria most likely to be accessible to Kindergarten children was identified — namely, primacy of testing; reproducibility of an experiment (including repeatability and replicability); its robustness (i.e. a minor modification of the conditions of an experiment does not change dramatically its result); exploitation of the spectrum of generality (i.e. navigation between specific and general formulations); awareness (i.e. navigation between the real world and its representations). Do Kindergarten teachers consider this new tool useful for their practice? If so, how would they apply it? Among these criteria, which are consider by early-years teachers the easiest to implement in their classes?

Methods

Data collection Procedure: The data was collected as part of an in-service training program (duration: 3 to 6 hours) from a total of 87 kindergarten teachers separated in two groups, A (62) and B (25). The training courses focused on the teaching of science in kindergarten through an investigative process. Participants were told that the courses included a new approach based on scientific elements and that they would be asked to express honestly and anonymously at the end of the training their opinion on its interest in their practice. During these two training sessions, teachers were invited to quickly experience different educational sequences based on children's books (Blanquet, 2010). Then, they analyzed the issues in terms of content and scientific approach, with the trainer naming the various elements of scientificity explicitly worked with them (and their students potentially) during these sequences. The previously identified most likely five elements were included in the training of group A. Three somewhat more sophisticated elements — namely, lexical coherence, completeness and economy of documentation — were introduced as part of a longer training (6h) with very experienced teachers (group B). The two groups were asked to answer the open question "*Do these criteria seem useful to you for your practice? If so, in what way?*" They were also asked at the end of the training to rank the elements of scientificity presented from the easiest to the least easy according to them to set up in their class. Group A was being invited to classify all the elements of scientificity presented and to add free comments, group B left free to classify all or part of the elements of scientificity presented.

Analysis of data: It was possible to distribute the participants' open answers into four wide categories, in which 90% of the answers spontaneously fell: elements used as a frame of reference, preparation of sequences, regulation of the implementation, step back and evaluation of their practice. Certain elements could then associated to reveal subgroups of criteria selected selectively by the participants.

Results

1. Open question: almost all respondents (86 out of 87) consider that the elements presented are useful for their classroom practice. A single teacher considered them 'complicated for little ones except maybe for exceptional children'. Among the 86 teachers who found the presented elements useful, 34 did not provide examples of possible use. The practical uses envisaged by the 52 remaining teachers fell into four main categories: elements used as a frame of reference (n = 35), preparation of sequences (n = 20), regulation of implementation (n = 21), review and evaluation of their personal practice (n = 13). 44 of the 62 teachers who were offered to leave a comment took up the suggestion. All feedbacks turned out to be positive and focussed mainly on the pleasure and interest of working with children's albums to work on the experimental approach. Six comments related to the elements of scientificity: one teacher was a little worried not to have understood them well, three cited the importance or the interest of hindsight in connection with the work on the albums, including one who would henceforth test reproducibility and robustness with her students; and lastly a teacher who had previously participated to the same training indicated that she greatly enjoyed the additions made, namely *'the importance* of the different elements of scientificity.

2. Classification of the different elements: in Group A, 60 teachers (out of 62) actually ranked the criteria. Reproducibility turned out to be by far the easiest element of scientificity to implement, in the teachers' opinion (75% of the answers, rank 1 or 2), together with the primacy of testing (76% of the answers, rank 1 or 2) and well above the robustness test, followed by awareness and exploitation of the spectrum of generality. In group B, the 25 teachers classified

the elements of scientificity. They ranked an average of 4,3 items, with one teacher ranking only one and five ranking them all. Reproducibility was cited and ranked in first or second position by almost all teachers in group B, as is the primacy of testing.

Analysis, conclusion, implications and perspectives

The results obtained in the two groups appeared convergent. The test of reproducibility appears to be the element of scientificity most accessible to teachers, closely followed the primacy of testing, far ahead of the robustness test and awareness. The outright omission of economy and completeness in group B suggests that these elements are overwhelmingly perceived as too complex for kindergarten students. Providing teachers with a large number of abstract or sophisticated elements also seemed to focus their responses on the elements that are probably most familiar to them and for which they can easily consider implementation in their class (for example, try to know and verify that all students find the same result). The Kindergarten teachers participating to the study very widely considered that work on the elements of scientificity was useful to their pupils (86/87). The data collected therefore seemed to indicate that teachers were receptive to the introduction of elements of scientificity in their classroom practice despite a limited training time (3 to 6 hours). Providing explicit set of elements of scientificity to Kindergarten teachers could be an useful solution to develop the teaching of scientific inquiry by teachers, especially when the curriculum doesn't provide explicite information, the duration of training is as short as 3 hours and the teachers lack of knowledge about epistemology. A study in progress will assess, on the one hand, the appropriation by kindergarten teachers of the elements of scientificity presented and their implementation in classrooms; and, on the other hand, the effect of such teaching on the understanding in particular of the reproducibility by pupils from 3 to 6 years old with a longitudinal study. In conclusion, providing Kindergarten teachers with an explicit framework for the teaching of the Nature of Science appears as a powerful and easy to implement tool to help them form a positive self-image as legitimate early-years science educators, despite a too often rather minimal grasp of scientific issues.

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WORKING THERMAL CONDUCTIVITY IN THE EARLY CHILDHOOD CLASSROOM

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The science teaching and learning process should begin at the initial education levels, offering students experiences connected to their natural world. However, little science is accomplished in pre-primary education, especially when it comes to curricular content on physics. This research describes an intervention in early childhood education classrooms where six-year-olds work on a scientific phenomenon, thermal conductivity. Participants are 127 children aged 5-6. Data collection was right after and one year from the intervention. Results revealed that students could transfer what they have learned to other everyday contexts after the intervention –although they exhibited far more difficulties a year later. There were no gender differences found in the first posttest, although females solved the activity better one year later. Thus, more vast interventions should be considered to facilitate the inclusion of science as regular curricular content.

Keywords: early childhood education, science, thermal conductivity

INTRODUCTION

The early childhood education classroom offers a suitable environment to begin the science teaching-learning process; however, the scientific literature indicates that there is little authentic science intervention during this stage (Kinzie et al., 2014; Saçkes, Trundle, Bell, & O'Connell, 2011) –in which numerical, linguistic, and socializing skills are given preference (Nayfeld, Brenneman, & Gelman, 2011; Worth, 2010). Although the scarcity of research in this initial education level makes it difficult to define a clear pattern, some works show that preschool teachers, both in training and in practice, perceive science teaching as less critical than other domains, and they feel less confident managing science activities in the classroom (Torquati, Cutler, Gilkerson, & Sarver, 2013). Additionally, early childhood educators usually approach science through activities detached from reality and more tied to art or fiction than to science as such (Patrick & Mantzicopoulos, 2015).

Each school, particularly at the initial levels, should offer students multiple and varied science experiences connected to learners' real world. Such fact relies upon that the purpose of science training at schools must be for students to develop dexterities allowing pupils to understand their world's surroundings (García-Carmona, Criado, & Cañal, 2014). In this sense, solely an early approach to science might make students progressively develop scientific thinking permitting them to make truly informed decisions in the future. With these ideas in mind, this research exemplifies how a science experience on a physical phenomenon is implemented in some early childhood classrooms, evaluating how learners relate and transfer the learned to daily-life situations.

THEORETICAL FRAMEWORK

Pupils' first contacts with science are a determining factor in the relationship that students themselves establish with this discipline, and it can guide them to continue studying it in the future (Osborne & Dillon, 2008). Early science experiences are closely related to subsequent interests (Jones, Corin, Andre, Childers, & Stevens, 2017). Despite the limited number of studies in pre-elementary education, in general, there are no gender dissimilarities in the preference of learners for science (Paños & Ruiz-Gallardo, 2021) –although these disparities appear later on vocation choices (OECD, 2016). Hence, early education years may have a minimizing effect on those future differences.

When science interventions are meticulously planned to be implemented in the early childhood classroom, the designed activities must satisfy and prompt the targeted students' intrinsic curiosity. The reason is that such curiosity stands as an essential component of scientific inquiry (Jirout & Zimmerman, 2015). The designed instruction should also act as an activator of students' minds to develop their scientific competence early and in advance (Gómez-Motilla & Ruiz-Gallardo, 2016).

Although there is a particular debate about the suitability of including science at an early age, and opposite to traditionally believed, the truth is that children can understand scientific concepts and reason scientifically as they own more complex cognitive abilities (Eshach & Fried, 2005). At this age stage, students can establish cause-effect relationships and employ scientific thinking as a guide for their learning (Greenfield et al., 2009). Therefore, it is essential to work on nearby phenomena contextualized in the students' most immediate environment (Rubio, 2017). It will be just by this means when learners establish significant links between the learning generated in the classroom and other situations in their daily lives.

When teaching science, the goal should not just focus on children's learning but also on transferring the acquired knowledge to different settings or situations (Haskell, 2000). Moreover, the methodological approaches used in the classroom must be supported by purposefully structured activities considering the relevance of the teacher's guide and assuming the positive effect of this guidance on query activities and learning outcomes (Lazonder & Harmsen, 2016). Research reveals that these activities generate better results in science than others in which teachers opt for methodologies more based on free exploration for pupils' wisdom (Hadzigeorgiou, 2002; Hong & Diamond, 2012).

Apart from the above mentioned, it is also important to consider material resources when working with and on science in the classroom –because classroom resources play an essential role in the cognitive development of students and act as the mediating or catalyzing element between pupils' learning and the environment surrounding them (Ameijeiras, 2008). In this sense, the exploration and manipulation of the learning materials from the environment can offer infants rich opportunities to learn science, as shown by other research, for example, on buoyancy (Paños, Martínez, & Ruiz-Gallardo, 2021) or about the states of matter (Cruz-Guzmán, García-Carmona, & Criado, 2017).

Although science curricula in the early years increasingly emphasize the importance of students understanding the natural world and the phenomena that take place in it (French, 2004; Gelman

& Brenneman, 2004), little science is done in children's classrooms (as described in the initial sections of this paper). Additionally, educators teaching in early childhood and elementary education present more difficulties implementing physics activities and, contrarily, feel more comfortable working on biology or Earth science content (Harlen & Holroyd, 1997; Worth, 2010; Yilmaz-Tuzun, 2008). Yet, there is still scarce research on physics content in the early years of education (Hadzigeorgiou, 2015). Examples of phenomena on which research has been carried out in the early childhood period include magnetism (Christidou, Kazela, Kakana & Valakosta, 2009; Van Hook & Huziak-Clark, 2007) or floating and sinking (Hsin & Wu, 2011; Paños et al., 2021; Tang, Yaw & Woei, 2017), among others.

Considering the importance for childhood-staged children to know the world surrounding them and the scarcity of real science experiences in the classrooms (especially those linked to physics), the goal of this research is to carry out an intervention to work on the thermal conductivity phenomenon and to evaluate the ability of children to transfer the learning to real situations in two stages: just after the intervention and one year later. Through the activities, the intention is to make children explore and manipulate different kinds of materials and ascertain some of their properties, as their ability to conduct heat. In general, it is difficult for youngsters to understand thermal conductivity, a phenomenon that they justify, not by the property of the material, but by the action of the air that surrounds it (Ravanis, 2003).

METHOD

The research consists of a quasi-experimental study with an intervention –posttest– delayed posttest design, involving 127 children (64 girls) from 6 classrooms pertaining the third level of early childhood education (students aged 5-6), in the city of Albacete (Spain). In the delayed posttest 27 students participate as a group of control.

Procedure

The intervention consisted of the following activities:

- *Activity 1.* Classifying common objects. The activity begins in the assembly, with the whole group. A set of nine everyday items from the environment is shown to children –where three of these objects are made of metal, three of wood, and three of plastic. Students are asked different criteria to classify the materials. The teacher leads the dialogue so that the classification is reached according to the material from which everyday items/objects are made of. Through the use of questions, the participation of the whole group is encouraged.
- *Activity 2.* Looking for objects in the classroom. In small groups, children have to identify three things in the classroom made of each of the materials mentioned in Activity 1.
- *Activity 3.* The whole group is proposed to carry out an experiment. The researcher shows three types of rods (metal, wood, and plastic) that the students can manipulate. There is also a container that the researcher fills with hot water, into which she inserts all the rods. Through questions such as 'What will happen to the rods? Why do they get hot? Are they all just as hot?', the researcher guides the learning process. After that, students are asked to make predictions about whether some type of rod will be

hotter or will all be the same. Students make their predictions individually and go on to check the result of them (figure 1). When they check it out, they are asked to say nothing to the rest of their peers until everyone has finished. Once all have finished, the results are shared and discussed in the assembly.

- *Activity 4.* Finally, students are asked to touch objects of these materials in the classroom, especially those near the window, to perceive the studied phenomena.

Notwithstanding two evaluations were implemented, an evaluation is carried out right after the intervention (posttest-1). Both evaluations were designed to verify if the students could relate the activities carried out in the classroom with other situations of their daily lives (being at home or in a playground), and the assessments were done through an individual interview. Besides, to check if the learning in students was retained over time and, thus, not obliterated, a delayed posttest was performed a year later.

Figure 1. Children manipulating the rods.

Posttest-1: students were given a template with two inquiries: Which material do you think a radiator is made of to be able to conduct and transmit heat? Which material is the handle of the pan made of, so that you do not burn yourself when you pick it up? (to facilitate their identification, a drawing of each of these objects was included). They had to choose between these options: metal, plastic, or wood in the first question; and metal or plastic in the second one (figure 2).

Posttest-2: children were shown two images of a playground, containing one them a wooden swing and the other a metal one. Then they were told and asked the following: Imagine that it is a sunny day of summer, in which of these swings would you play? Why? The answer options were as follows: in the metal one, in the wooden one, in either of the two. They also have a picture of a saucepan with a boiling stew, and the question is: Imagine that you have to turn a stew that is boiling, what spoon would you use? Why? The options were: a metal one, or a wooden one.

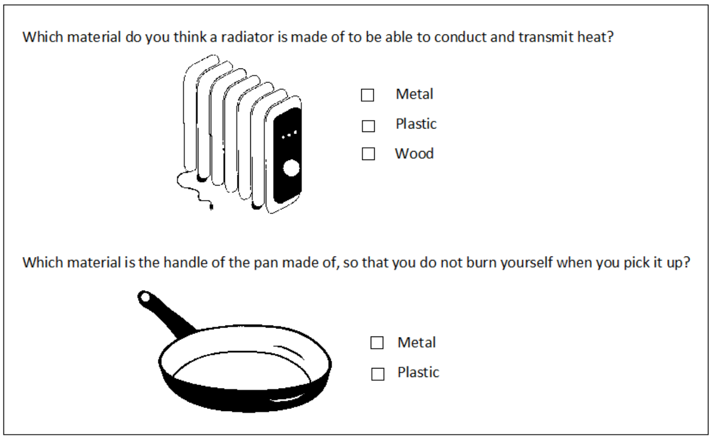

Figure 2. Template employed in the Posttest-1.

Data analysis

The contrast between groups (experimental vs control and boys vs girls) is carried out using contingency tables and the chi-square ($\chi2$) test. This information is complemented with descriptive statistics.

RESULTS AND DISCUSSION

In the posttest-1, 75.59% of the participants correctly solved the two questions raised (table 1). Results reflect that addressing a physical scientific phenomenon with 5-6-year-old students favors their understanding, as Hadzigeorgiou (2002) also points out when working on mechanical stability. Children were able to transfer what they had previously learned about the property of thermal conductivity of materials to other contexts related to their daily life. The use of standard material resources from the environment may have favored these results. There are no statistically significant differences concerning gender, a fact that seems to fit with the trend identified in the scientific literature.

It is noteworthy that only 33.86% of the students answered the two questions correctly in the posttest-2, that is, one year later (table 1). Correct answers employ reasoning like ‘metal gets very hot and you burn’, ‘wood does not heat as much as metal’, ‘iron burns’, or ‘the heat rises through the metal spoon and you get burned.’ Students who do not correctly solve the activity mostly argue that the wooden one can break, burn, or even melt in the case of the spoon. Regarding the swings, 27.56% of participants selected the metal one, justifying it mainly because it was more robust or more rigid, and 16.54% chose both swings.

Although there are no statistically significant differences between the resolution of posttest 1 and 2 by the experimental group, the percentage of students who correctly solve the evaluation one year later is much lower than the previous year, which shows that the positive effects of the intervention have diminished over time, as other studies point (Kang, Duncan, Clements, Sarama, & Bailey, 2019).

When contrasting participants by gender in the delayed posttest, statistically significant differences appear between boys and girls –being the latter the ones that best solved the activity (table 1). Despite such differences, and considering the absence of differences in posttest-1 and the fact that this is a punctual activity, results cannot be generalized.

Significant differences do also appear when contrasting data with the control group, which corroborates the intervention's positive effect (table 1).

Table 1. Correct answers in the evaluation activities. Group contrast.

	Posttest-1			Posttest-2		
	Boys	Girls	Total	Boys	Girls	Total
EG[1] (n = 127)	34.65	40.94	75.59	11.03	22.83	33.86
CG[2] (n = 27)	-	-	-	7.41	0	7.41
Gender differences posttest-1 (EG) = .135				χ^2 (1) = 2.240 / p		
Gender differences posttest-2 (EG) =.006				χ^2 (1) = 7.558 / p		
Posttest-1 and posttest-2 contrast (EG) .829				χ^2 (1) = .047 / p =		
EG/CG contrast = .006				χ^2 (1) = 7.532 / p		

[1]Experimental group. [2]Control group.

CONCLUSIONS

Through the structured intervention, early childhood education students can learn about the scientific phenomenon of thermal conductivity. Also, they can transfer what they have previously learned to other contexts connected to their daily lives. However, participants have more difficulties with it one year after the intervention. This difficulty suggests that long-term interventions would be advisable to address this topic. The more satisfactory results obtained by females in the second posttest –although considered, as previously described, with caution– can be a stimulus to reverse current gender differences in the job market, where women are underrepresented in scientific departments, especially those of physical sciences (Funk & Parker, 2018).

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BIOLOGY IN THE EARLY CHILDHOOD CLASSROOMS: PLANTS also DIE

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Biology contents usually begin to be addressed in pre-compulsory education, and the early childhood education classroom remains a suitable environment to work on science. Thus, this research describes a task where early childhood students must transfer the meaning of death to living beings. Because of its abstractness, this biological concept is difficult for pupils to understand –particularly in the case of plants. Concerning the sample, participants are 114 children aged 5 to 6. Children are assessed twice after the intervention: once the activity ends and the year afterwards. Results reveal that most students do not consider grass as a living being that might die. Learners also struggle to relate the concept of death to trees. These difficulties disappear when children are 6 to 7, so results imply that teaching the concept of death in plants during this age stage might help them form the concept quickly and accurately. No gender differences are found in the results of the two tests.

Keywords: early childhood education, living beings, death

INTRODUCTION

Children's innate curiosity and their need to discover and understand the world in which they live and the phenomena taking place in it make them connected to science from an early age (Spektor-Levy, Baruch, & Mevarech, 2013). The early years of infants' lives undoubtedly involve a continuous learning process in which, through observation, exploration, asking questions, et cetera, they try to make sense of the environment around them (Trundle, 2015). At the commencement of pre-primary school enrolment, children already possess considerable knowledge about the natural world due to their previous experiences; hence, schools' immediate challenge is adapting these initial ideas to the scientific knowledge (Duschl, Schweingruber, & Shouse, 2007).

The early childhood education classroom reveals itself as a favourable environment for initiating the science teaching-learning process. Here, the students will satisfy their needs to manipulate and explore the settings where they will find answers to their first intuitions and interpretations concerning such natural environments. To this end, the role of teachers is vital, generating motivation and myriad opportunities to acquire scientific concepts and procedures and offering children multiple and diverse material resources that stimulate learning. These early experiences will lay the foundation for future learning, and play an essential role in developing positive attitudes toward science (Bruce, Bruce, Conrad, & Huang, 1997).

Although, in general, the scientific literature reflects that little science is done in early childhood levels (Kinzie et al., 2014; Saçkes, Trundle, Bell, & O'Connell, 2011), real science activities can be planned to bring students closer to the natural world around them. Thus, for teachers, when planning and designing the instruction, it is necessary to consider that structured activities prompt in children a more in-depth learning and better results in science than those in which free exploration is used as a teaching resource (Hadzigeorgiou, 2002; Hong & Diamond, 2012; Paños, Martínez, & Ruiz-Gallardo, 2021).

Concerning the information above, this paper presents some classroom experiences to work on a biological sequence about living and non-living beings –a common topic in early childhood education progressively deepened within throughout the school years.

THEORETICAL FRAMEWORK

Notwithstanding that scarce science is accomplished from early childhood education levels, it is yet known that pre-primary education teachers prefer teaching biology content (Worth, 2010) –unveiling the differences between living and non-living beings as one of the most common topics considered from the science curricula (Akerson, Weiland, & Khadija, 2015). Remarkably, teaching the referenced matter is usually performed from a zoocentric perspective, and teachers give less value to botanical contents (Balas & Momsen, 2014). Thus, when children are asked to name plants and animals, they tend not to name plants as often as they reference animals (Patrick & Tunnicliffe, 2011). This omissive fact is interconnected to a phenomenon already identified and conceptualised in the scientific literature as plant blindness –which means the inability to notice the presence of plants or value their importance, considering them inferior to animals (García-Berlanga, 2019; Wandersee & Schussler, 1999).

Students begin to have an adequate biological conception about living beings during early childhood education; however, this is still not complete and precise (Dargett & Witherington, 2011). They cannot give accurate definitions of living beings, limiting themselves to offering examples to describe them (Garrido, García-Barros, & Martínez, 2002). Generally, early childhood students keep anthropomorphic ideas about animals and plants, a state that disappears during the early primary education years. To reduce this conceptions owned by children, authors suggest using scientific texts in the classroom (Petrova, Siderova, Stefanova, & Nikolova, 2010). Likewise, when making distinctions between living and non-living beings at the beginning of the early childhood education span, students tend to rely on the physical movement of the entities for its classification as living or non-living things –although they progressively acquire a more precise mental image of this topic as they progress towards the upcoming primary education stage (Villarroel, Antón, Zuazagoitia, & Nuño, 2017).

Apropos of research by Nguyen and Gelman (2002), children begin to consider plants as biological entities when they are between 4 to 6; however, although they relate the concept of death with living beings, they face more difficulty understanding the same concerning plants. Such fact could be attributed to the absence of salient features of the entities, such as plants' lack of motion or sounds. This lack of movement or sound would make it difficult for infant students to consider them as beings that might die, as it happens to the rest of living beings. Nguyen and Gelman (2002) also identified that, when they are 6 years old, children can understand all of the components of plants death: universality, inevitability, finality, and causality.

In sum, the concept of death in living beings and its biological characteristics can be a suitable topic for pupils during their first learning and education years. Considering the difficulties that 5-6-year-olds have to understand that plants, as living beings, sooner or later will die, this research goal is to present a structured activity to explain the idea of death as something inherent to all living things. This research also aims to evaluate the acquisition of the studied concept considering the gender variable throughout two evaluations: one after the intervention and another one year later.

METHOD

Design and sample

The research design is quasi-experimental, with an intervention, a posttest, and a delayed posttest implemented one year after the intervention. The sample consisted of 114 participants encompassing 55 males and 59 females. Participants were chosen from five third-level classrooms of early childhood education schools (pupils aged 5 to 6) at Albacete, in the Autonomous Region of Castilla-La Mancha, Spain. In the delayed posttest, 27 infants were assigned to the control group.

Procedure

The intervention implemented in each of the early childhood education classrooms develops and is structured as follows:

Stage I. The researcher shows four common objects (e.g., a toy truck, a book, a box, a toy animal) and four living-beings (silkworms, a plant with flowers, a plant without flowers and a terrarium with ants), and classify them into two groups (living/non-living beings). Then she asks students, '–Why have I classified them this way?'

Stage II. Once the children have the two groups identified (living/non-living beings), the researcher asks the students for more in-depth information on the topic. The information encompasses some characteristics of living beings, especially those that differentiate them from non-living things. As the students identify and mention such differences, the researcher notes down the students' answers on a piece of cardboard and the blackboard (Figure 1).

Stage III. If during Stage II of the training process the students have not the concept of death mentioned, the researcher reformulate new queries To say, '–What would happen to silkworms if we don't give them mulberry leaves to eat?' and '–What would happen if we don't water the plants?'

Stage IV. Having Stages I, II, and II accomplished, the researcher explains participants two main characteristics of death: universality (all living things, humans, plants, animals, and others die) and inevitability (death is an unavoidable fact) (Nguyen & Gelman, 2002).

Figure 1. Researcher and students during the intervention.

Data collection

After the activity, students are individually assessed with the sole purpose of identifying if they have the biological conception of death acquired (Posttest-1). Such assessment includes inanimate objects, animals, and different types of plants. Considering Nguyen and Gelman (2002) research results, the chosen plants are a flower (because of its fragility) and a tree (because children can consider it as something sturdy and challenging). Since it is something so familiar that sometimes it is not paid attention to, the grass was added to the activity. Hence, in a template with the eight pictures displayed in figure 2 (butterfly, kite, spider, sunflower, grass, fork, mobile phone and tree), children were asked to circle those pictures whose images include things that one day was –predestined– to die. Individually, students took the same evaluation a year after (Delayed Posttest).

Figure 2. Data collection template.

Data analysis

The contrast between groups (experimental *vs* control and boys *vs* girls) was carried out using contingency tables and the chi-square (χ^2) test. This contrasting information is complemented with descriptive statistics.

RESULTS AND DISCUSSION

Posttest-1

In none of the classrooms involved, the idea of death arose spontaneously as a common characteristic of living beings during the intervention. Children predominantly mentioned biological features such as growth, breath, movement, and reproduction –the most salient and visually perceptible animal characteristics. The use of questions helped students identify that they might die. The specific questions asked to students did also help them identify the lack of food (in the case of worms) or the lack of water (when talking about plants) as factors that would cause living beings to die. Therefore, it is evident how asking questions (especially using open-ended queries) in the context of science teaching in early childhood education can guide children in learning scientific concepts (Hamel, Joo, Hong, & Burton, 2021).

Just after carrying out the activity with the children to work on the concept of death in living beings, and deepen in the aspects of universality and inevitability, only 39.47% of them correctly solved the proposed task, which means to select the butterfly, the spider, the sunflower, the tree and the grass (see table 1). Except for seven succeeding in the task accomplished, the rest of the unsuccessful students did not identify the grass as something that would die. The vast majority of students also exhibited difficulty acknowledging that trees might die as well (38% of those who failed); this same characteristic was far less remarkable in the case of sunflowers (only 13% of those who failed).

This first posttest clearly shows the difficulties children have to assimilate that plants, such as grass and trees, are living beings and, consequently, they will die one day. The trees' physiology, their static appearance, and the fact that they are usually long-lived, as mentioned by Nguyen and Gelman (2002), might cause these results. And we note it down as 'might' because these results contradict other studies pointing out that it is less complicated for children to conceptualise grass as a living thing than it is for them to conceptualise trees (Villarroel & Infante, 2014).

Table 1. Results from Posttest-1 and Delayed Posttest (correct answers in percentages).

	Posttest-1			Delayed Posttest		
	Males	Females	Total	Males	Femal es	Total
Experimental (n = 114)	17.54	21.93	39.47	27.19	33.34	60.53
Control (n = 27)	-	-	-	40.74	14.81	55.55

Delayed Posttest

One year after the intervention and Posttest-1, the Delayed Posttest is implemented. Having the Delayed Posttest accomplished and the answers scrutinised, it was observed that most of the students correctly identified all the images representing something that will die (60.53%). Furthermore, the results dissimilarities between the immediate and delayed posttests in the experimental group revealed statistically significant differences (χ^2 (1) = 7.029 / p = .008). It was observed that, in the delayed posttest, most children aged 6-7 had considered all of the plants (including grass) as 'things' that will die. Therefore, it seems that the age variable and the not participation in the activity determined that they understand the studied phenomenon. This aspect is also corroborated when verifying that there are no statistically significant differences in the activity resolution between the group that participated in the previous year and the control group (χ^2 (1) = .224 / p = .636).

Gender

Regarding gender, there are no statistically significant differences either in the Posttest-1 (χ^2 (1) = .430 / p = .512) or the Delayed Posttest (χ^2 (1) = .771 / p = .380). These results are congruent with the research carried out by Villarroel et al. (2017), where the authors did not find differences in the way females and males aged 4 to 7 classify different entities in living or non-living beings. However, research opposes gender disparities in science, technology, engineering, and mathematics (STEM) fields pinpointed in scientific literature, although these studies usually focus on older students (Wang & Degol, 2013).

CONCLUSIONS

In conclusion, although children aged 5-6 comprehend living beings and the characteristics differentiating such entities from non-living beings, they display difficulties relating the concept of death with plants. Also, the intervention factor of carrying out an activity with students aged 5-6 does not prompt in them the extrapolation of the idea of death to some plants (mostly grass and trees). However, having gone by a year –once they are in the first level of primary education– the results displayed are far better, and most students consider plants as beings that one day will die.

The results, as mentioned earlier, may well have implications when planning science activities or instruction in the early age-stage education levels. Displayed results might be a referent for instructional designers, teachers, and practitioners to focus on the particular features of plants as living beings and pay special attention to those characteristics that learners cannot perceive through the senses (as it happens in the case of animals). These results can also serve future research as the stimulus to welcome more activities related to plants to mitigate what is yet known as plant blindness in the initial educational levels.

The lack of gender differences when solving the activity suggests that these disparities may arise at higher educational levels.

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Part 16 / Strand 16

Science in the Primary School

Editors: *Anna Spyrtou & Federico Corni*

Part 16. Science in the Primary School

Procedural skills in science, science investigations, science teaching and learning sequences.

STRAND 16 - Science in the Primary School

Strand Chairs: *Anna Spyrtou & Federico Corni*

INTRODUCTION

Four papers were included in Strand 16, Science in the Primary School. All the studies come from the European Union (two from Greece, one from Italy and one from Germany). The common thread running across all of the submissions is how various teaching methods might aid in the learning of modern science content in the sense that it is not typically included in the primary school curriculum (the conductivity of electricity in water), crosscutting concepts (proportionality) as well as topics that rarely represented in current research for primary school (modelling-based learning about chemical phenomena). In addition, a study addressed primary school teachers' and students' preconceptions about contemporary Science (Nanoscience).

Eleni-Maria Valkanou and Ioannis Starakis (Greece) investigated if k5 students can construct the scientifically accepted explanation for the electrical conductivity of water. The researchers implemented a teaching intervention within a constructivist learning context to confront the students' alternative idea that electrical conductivity in all materials is due to free electrons within them. The students conducted experiments to determine that the water's electrical conductivity is due to the presence of dissolved salts in the water. For example, they tested if tap water is electrically conductive and if the addition of a quantity of salt affects the electrical conductivity of water. Based on analysis of video recordings of the teaching intervention as well as students' responses in written questionnaires, the authors conclude that students can build the scientifically accepted explanation, meaning they attribute electrical conductivity to the existence of dilute salts in water.

Francesco Cuomo, Emilio Balzano, Anna Merinio and Marco Serpico (Italy) conducted a design-based study to explore how hands-on, inquiry-based activities can promote the development of proportional thinking in the first grades of primary school. Instead of the common approach of proportionality in schools based on word problems, the researchers designed authentic activities based on physical quantities e.g., measuring volumes and masses. The researchers, based on qualitative analysis of video and audio recordings of the interventions, field notes as well as photographs, concluded that students could identify proportional relationships in the quantities they measured and were able to make predictions by applying proportional reasoning. The authors' interpretation of this finding is that students' engagement with natural phenomena, in which proportional relationships emerge in an authentic context from measurements of physical quantities conducted by the children themselves, significantly impacts the learning process.

Julia Elsner, Claudia Tenberge and Sabine Fechner (Germany) studied to what extent chemical phenomena that are considered to be difficult to be learned are suitable for modelling-based learning in primary education. The researchers implemented a teaching intervention regarding the state of matter, the solubility of salt in water and the burning process of a candle. The data collection was based on videos of the teaching experiment as well as the students' drawings (models). The authors argue that the results show that modelling-based learning about chemical phenomena is partly possible in primary school since the models that the students built corresponded to a few aspects of the scientific concept, they showed a low explanatory process and the conceptual change was hardly achieved. They propose that it is necessary the modelling-based learning to be supported by scaffolds.

Giorgos Peikos, Leonidas Manou and Anna Spyrtou (Greece) examined the Primary Teachers' and Primary Students' preconceptions about Nanoscience content i.e., the lotus effect, through the lens of the conceptual change. The researchers, based on participants' answers to a written questionnaire, conducted a qualitative analysis and found four categories of preconceptions that both Primary Teachers and Primary Students shared. It is worth mentioning that most of the participants explained the phenomenon as a Direct Process, e.g. providing explanations based on perceptual-based agents. The authors argue that this finding indicates that instructional materials for Primary Teachers and Primary Students should be designed to help them explain the lotus effect as an Emergent Process, i.e. based on a collective interaction of non-perceptual agents.

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AN APPROACH TO TEACHING THE CONDUCTIVITY OF ELECTRICITY IN WATER IN PRIMARY EDUCATION

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The purpose of this research was to study the extent to which k5 students can construct the scientifically accepted explanation for the electrical conductivity of water. In this context, the learning pathways of 24 k5 students in a Greek primary school were documented during the teaching of the phenomenon in question. The intervention focused on confronting the students' alternative idea that electrical conductivity in all materials is due to the existence of free electrons within them. The data was drawn from two sources: an analysis of the video recordings of the conversations which took place during the intervention, and the responses provided by the students in two written questionnaires, one completed before and the other after the intervention. The results showed that the students in question are able to attribute the electrical conductivity of water to the presence of solute salts within it.

Keywords: Primary School, Science Education, Video Analysis

INTRODUCTION

A host of research studies—and teaching interventions, too—have been conducted at every level of education over the past four decades with a focus on students' ideas about concepts relating to electricity (Duit, 2009). The phenomenon of the electrical conductivity of solids and liquids has generally been investigated in secondary and higher education (De Posada, 1997; Othman et al., 2008; Sanger & Greenbowe, 1997).

It has been found that students at these levels tend to attribute the electrical conductivity of liquids to free electrons. This perception seems to be influenced by the students' prior knowledge about the electrical conductivity of metals (Othman et al., 2008). In their study of undergraduate Chemistry students in a university in the American Midwest, Sanger and Greenbowe (1997) found that students who had mastered the concept of a closed electrical circuit often had the idea that the presence of free electrons can ensure current flow in a closed circuit, part of which is an electrolyte solution. A number of students thus thought that in an electrical circuit of this sort, free electrons in the wires can flow through the salt bridge formed by the ions in the electrolyte solution to complete the circuit. Secondary school students appear to express similar alternative ideas. A study conducted by Othman et al. (2008) with students in a Singapore secondary school found that students attributed the electrical conductivity in ionic solutions to the free electrons which, as they saw it, were released into the water when the ionic compound is dissolved in water.

The research goal

This pilot study set out to investigate the extent to which k5 students are in a position to construct the scientifically accepted explanation for the electrical conductivity of water. To this end, we designed and implemented a teaching intervention which would allow us to record the learning pathways of k5 students during the teaching of the given phenomenon, to study the difficulties they encountered on their way to reaching their conclusion, and possible ways in which these difficulties could be overcome. The research question we designed our research to answer was: *"Can k5 students attribute the electrical conductivity of water to the presence of dilute salts within it?"*.

METHODOLOGY

The teaching intervention was implemented in a typical class in a public elementary school in Greece over three teaching hours on separate days and within a constructivist learning context. In a constructivist context, the students actively 'construct' knowledge as they strive to understand the world. The students' prior knowledge plays an important role in this process, as new information is evaluated against what they already know (Duit & Treagust, 1998). The students performed the experiments and recorded their findings in groups. Each group announced its conclusions to the whole class; the students were encouraged to discuss what they were doing and exchange views in relation to the questions they had been set throughout the teaching session.

In previous lessons in which they were taught the first units in the chapter on Electricity, the students seemed both to have reached the scientifically accepted model for electric current in an electric circuit, and to have adopted the scientifically accepted explanation for electrical conductivity in solids.

Research tools

The teachings sessions were recorded on video and subsequently transcribed verbatim, along with instances of non-verbal communication between the students. In parallel, the students completed two written questionnaires, one before and one a month after the teaching. Specifically, both questionnaires contained the question: *"Do you think water is a conductor or an insulator of electric current? Justify your answer, stating why you believe water to be a conductor or an insulator of electric current"*.

Participants

In all, 24 students (10 boys and 14 girls) from a k5 class in a primary school in Galatsi took part. Galatsi is a municipality in the Attica Region, Greece. One of the 24 students was sick and missed the post-test.

Data collection and analysis

In view of the exploratory nature of the research, qualitative content analysis methods were used (Erickson, 2012).

The data were collected using two different procedures:

(1) analysis of the recorded teaching sessions

The recordings were transcribed verbatim, then divided into the steps which are described below in the teaching intervention. The following were recorded for each step in the learning intervention: (a) the ideas which the students expressed in response to key questions put to them during the teaching sessions, (b) the arguments they used to support these ideas, to comment on the views of other members of the class, or to interpret the data from the experiments they performed, (c) the difficulties they encountered at every step of the teaching process, (d) the procedures which, in some cases, helped them overcome these difficulties, and (e) their conceptual framework at the end of the intervention.

(2) questionnaires completed by the students before and after the teaching (pre-/ post-tests)

The first questionnaire was administered before the start of the intervention, the second a month after the final session. The question the students were asked sought to explore their ideas about the electrical conductivity of water and, at a second level, to gain insights into their interpretations of the phenomenon. The students' responses to the questionnaires were then recorded and categorized. The goal was to capture the original ideas which the students held before the intervention (through the pre-test), and to record the evolution of these ideas (through the post-test).

These two methods of data collection contributed to the triangulation of the data, since they were categorized and combined in order to capture any conceptual development on the part of the students and to record their learning processes.

The structure of the intervention for teaching the electric conductivity of water

The main learning objective of our intervention was that:

"The students should determine experimentally that the electrical conductivity of water is due to the presence of dissolved salts in the water".

The basic steps of the teaching intervention were as follows:

Step 1

In Step 1 the students were asked: a) to express their initial ideas on whether tap water is electrically conductive, b) subsequently, to determine experimentally that tap water does indeed conduct electric current (*Experiment 1, fig.1*), and c) to interpret this experimental realization.

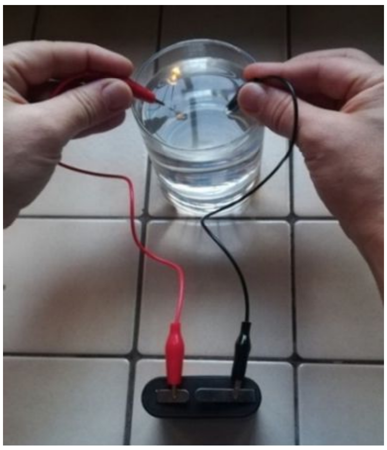

Figure 1. Experiment 1.

To perform the Experiment 1, the equipment used was: (1) a 4.5V battery, (2) double-ended crocodile clip wires, (3) an LED bulb and (4) a glass with tap water in it. The student groups were asked to set up an electrical circuit including a glass of water, and to record their observations on the brightness of the bulb.

A low-voltage LED bulb was chosen for this experiment and those that followed. The technical characteristics of this type of lamp mean that the potential difference which develops at the ends of the wires in the tap water will, with this type of battery, light the bulb. For the same thing to happen with a conventional incandescent light bulb, salt would have to be added to the tap water in the glass. At this step in the teaching, the core learning objective was for students to determine experimentally that tap water conducts electricity. If we chose incandescent bulb, students would not have been observed the conductivity of the water without adding further salt, which is not the case with the LED lamp. The choice of the particular type of lightbulb therefore enhanced the teaching process in this step.

Step 2

In Step 2, the students were asked: a) to express their ideas on the impact of the addition of a quantity of salt might have on the electrical conductivity of water, b) to determine experimentally that adding salt enhances the electric conductivity of water (*Experiment 2, fig.2*), c) to interpret this experimental realization, d) to determine experimentally that salt, as a solid body, is an insulator of electric current (*Experiment 3, fig.3*) and e) to interpret afresh the results of 2nd experiment.

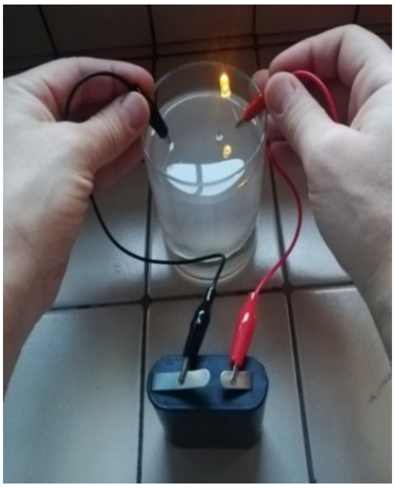

Figure 2. Experiment 2.

Figure 3. Experiment 3.

To perform Experiment 2, the following were used: (1) a 4.5V battery, (2) double-ended crocodile clip wires, (3) an LED bulb, (4) a glass with tap water in it, and (5) salt. Each group was given salt and asked to add a spoonful to the glass of tap water used in the previous step, then to conduct the experiment again, recording their observations on the brightness of the bulb.

To perform Experiment 3, the following were used: (1) a 4.5V battery, (2) double-ended crocodile clip wires, (3) an LED bulb and (4) salt. If the students had expressed the view that salt in its solid form is a conductor of electricity, they were asked to perform the experiment again, this time completing the circuit with grains of salt.

Step 3

In Step 3, the students were asked: a) to express their ideas on the electrical conductivity of water which does not contain salts, b) to determine experimentally that water without salts does not conduct electricity (*Experiment 4, fig.4*), and c) to interpret this experimental observation.

Figure 4. Experiment 4.

To perform Experiment 4, the equipment used was: (1) a 4.5V battery, (2) double-ended crocodile clip wires, (3) an LED bulb, (4) a glass with double distilled water in it. Each group of students was asked to carry out the experiment with double distilled water and to record their observations.

It is worth noting that the water used in this experiment was double distilled water intended for pharmaceutical use. The electric conductivity of this type of water is such that the potential difference which develops at the ends of the wires immersed in the water will not light the LED bulb with this type of battery. At this step in the intervention, our goal was for the students to determine that the double distilled water does not conduct electricity. Choosing this type of water therefore reinforced the teaching in this step.

RESULTS

Results from the analysis of the classroom recordings

Step 1

At first, students were invited to express their ideas on the electrical conductivity of tap water and to interpret these views. Initially, the majority thought that water was an electrical insulator. They expressed the idea that a body had to have free electrons in order to conduct electric current, and that this was not the case with water:

> *Myrto: I want to clarify that water is transparent and the electrons are not visible. I mean, they would be visible, essentially. And because we drink a lot of water, generally speaking, it wouldn't be good for us.*
>
> *Teacher (T): So are there free electrons in the water or not?*

Myrto: I don't think there are, because they'd show up and the water is clear.

T.: So what do you think the water is?

Myrto: An insulator.

The performing of the first experiment with tap water seems to have been a turning point in the teaching. The students' observations from the experiment helped them to determine that tap water conducts electricity, and thus to move away from the view they held beforehand. All the students considered water to be a conductor of electric current. However, the majority of them seemed to adopt a scientifically incorrect explanation for the electrical conductivity of water. Specifically, having completed the experiment with tap water, the students attributed the electrical conductivity of this water to the free electrons they argued it contained. The electrical knowledge they constructed during the teaching of the section on "Conductors and Insulators" mentioned above seems to have contributed to their adopting this view at this point in the teaching:

T.: So what did you notice during the experiment?

Konstantinos: That it lit up.

T.: Why do you think that happened?

Konstantinos: Because water has free electrons.

T.: Does everyone else agree? (We hear almost everyone shout "yes")

How many of you agree with Konstantinos' view that the water contains free electrons and that's why the bulb lit up? (22 children raise their hands)

Maria: I have to say now that it has electrons in it, because if it doesn't then why should it light, with no reason?

Step 2

In the next stage of the teaching, the students were asked to give their views on what might happen if they dissolved some salt in the glass of water used in the experiment in the previous step. The students' answers could be grouped into two tendencies:

(a) the majority expressed the view that the addition of salt would not affect the brightness of the bulb, because the salt neither adds nor subtracts free electrons from the circuit:

Christos: I think it will light up, because salt can't "kill" the electrons.

T.: And do you think it will be the same brightness, more or less?

Christos: The same, since the salt does not contain free electrons.

(b) a significant number of students argued that adding salt would make the water less conductive. So the bulb would either not light at all, or it would shine less brightly, because the salt impedes the movement of the free electrons:

Redion: I don't think it will light, because the salt probably does something to the electrons.

T.: So you don't think it will light at all?

Redion: No, it won't. The salt acts as a fence in front of the free electrons and doesn't let them continue.

The experiment with tap water to which salt has been added seems to have been a key point in the intervention. From their observational data, the students determined that the presence of salts causes the bulb to shine more brightly; this seemed to help the majority of the students to transcend the difficulties they encountered in the previous step. However, it became clear at this point in the teaching that all the students now considered salt to be a conductor of electricity. Specifically, they had the idea that salt adds free electrons to the water:

Christos: I think it shone more brightly with the salt, because it's like the salt added more electrons to the water.

For the students to get past this obstacle, it was decided to perform a variation on the initial experiment in which an amount of salt in its solid form (i.e. not dissolved in water) was inserted into the circuit. This experiment seemed to help the students determine that salt is not a conductor of electricity. When, having completed the experiment, the students were asked to express their views anew on what could have caused the bulb to shine more brightly in the Experiment 2, the majority said the salt only becomes a conductor when it is dissolved or absorbed into a quantity of water.

At this point, it seemed that the students have moved on from their previous view that the water contains free electrons, since they no longer mentioned either their being present in the water or their possible interaction with the salt. This students' conceptual stance seems close to the scientifically accepted view on the electric conductivity of electrolytes:

Nefeli: I still believe that salt is a conductor, but maybe to be a conductor it has to... (She gestures mixing something)... how can I say it... it has to be mixed up with something else, like water, to help the bulb to shine more brightly.

Step 3

When the students were asked to say what they thought would happen if the experiment was conducted with water from which the salts had been removed, they all argued that the bulb would not light up. The majority of the students thought that if the water used in the experiment was free of solute salts, it would be impossible for it to conduct electric current:

Constantine: I think the salts play the role of free electrons in the water without being free electrons, because I believe that if it's just the water without salts, the bulb will not light up, because it will be like it doesn't have any free electrons.

The conducting of the experiment with distilled water, in which the students determine experimentally that the water in question does not conduct electricity, seems to have been a key point in the teaching. When asked to formulate their conclusion with respect to the electrical conductivity of water, almost all the students seemed to have adopted the scientifically accepted model explaining the phenomenon. The majority suggested that only the saline solution can conduct electricity:

Mary: I said that while the salt does nothing on its own and the water does nothing on its own, if we put the two together they will form something like a road, so they can connect and move (makes a circular hand movement) so the bulb will light.

Results from the analysis of the pre and post-test

The results obtained from the analysis of the videotaped dialogues were confirmed when they were compared with the students' responses in the pre- and post-test.

The students' responses to the question they were asked in the pre- and post-test were categorized on the basis of the answer they gave to whether they considered water to be a conductor or insulator of electricity. Table 1 aggregates the results from their responses.

Table 1. Comparing students' answers to the question in the pre- and post-tests.

Do you think water is a conductor or an insulator of electricity?	Pre test		Post test	
	N	%	N	%
Conductor	6	25	21	91,3
Insulator	18	75	2	8,7
Total	N=24		N=23	

In the pre-test, most students (18 out of 24, or 75%) thought that water was an insulator of electricity. Of these students, the most common explanation for why water is an insulator was that it does not have free electrons (11 out of 18, or 61%); the remaining students expressed reasons relating to the nature of water as a material and to the fact that water may cause an electric shock because it traps the current in the cables that are in contact with our hands. The students who thought water was a conductor (6 out of 24, or 25%) mainly said that this was because water can "push" the electrons in the cable.

In the post-test, the majority of students moved on from their previous view, since most (21 out of 23, or 91.3%) argued that water is a conductor of electricity. Of these students, the highest percentage (16 out of 21, or 76%) expressed the scientifically accepted view that the dissolved salts in the water creates the brine which is an electrical conductor. The rest of these students (5 out of 21, or 24%) backed up their response with reference solely to the observational data from the experiments carried out in the various steps of the intervention, without mentioning any particular interpretive framework.

DISCUSSION

The main goal of this study was to investigate the learning pathways of k5 students as they are being taught the electrical conductivity of water. The following seem to have served as major obstacles along the students' learning pathways:

(1) The fact that water is transparent encourages students to think that there can be no free electrons in it. This view seems to be reinforced, too, by the fact they consider free electrons to

be harmful, as they typically say that we cannot drink something that contains free electrons. Based on these views, virtually all the students tend to consider water an electrical insulator.

(2) Having already been taught the electrical conductivity of solids, the students tend to attribute electrical conductivity in general to free electrons. This proved to be an obstacle in the learning path of every student in the sample after they conducted the first experiment in the intervention with tap water. According to the conclusions drawn in the literature, this alternative approach seems to be quite common among secondary school and university students, too (Othman et al., 2008; Sanger & Greenbowe, 1997).

(3) At an initial stage, the students seem to consider that the presence of salts in an aqueous solution cannot have a positive impact on its electrical conductivity, either because they think the salts impede the movement of the free electrons, or because they think the salt cannot add free electrons to the water. Later, however, after they had conducted the experiment with the brine, another major obstacle appeared in the students' learning paths: their tendency to consider salt a conductor of electricity and to claim that its presence in the water added electrons to it.

A few key points which seems to help students to overcome these obstacles are:

(1) The observation that tap water conducts electric current without added salts during the conducting of the Experiment 1. It allowed students to grasp that tap water is a conductor of electricity and to shift conceptually away from their initial view that it is an insulator.

(2) Conducting the experiment with brine seems to help the students to grasp that the presence of salts plays a positive role in the conductivity of the water, and to transcend the previous obstacle: namely, the belief that salts impede the motion of the free electrons. However, because the observational data from this experiment seems to encourage students to believe that salt is a conductor of electricity—since it adds free electrons to the water, which is why the bulb shines more brightly—, conducting a variation of this experiment in which salt is inserted into the circuit in solid form (without water) seems to have been a key point in helping students to realize that salt only becomes a conductor when it is dissolved in water.

(3) Conducting the experiment with double distilled water seems to form another node on the students' learning pathways. The observational data obtained from this experiment seems to help the students to grasp that the water in question does not conduct electricity and is therefore an insulator. However, because there was no opportunity during the implementation of the intervention to explore all students' ideas in depth, we were unable to adequately investigate whether the students still believed that water has free electrons in it, or that their supposed presence in the water affects the movement of the salts, contributing in this way to the electrical conductivity of the water.

CONCLUSIONS

The research shows that k5 students can construct the scientifically accepted explanation for the electrical conductivity of water, meaning they attribute it to the existence of dilute salts in it. The obstacles the students seemed to encounter on the way to the desired conclusion were dealt with satisfactorily by means of the aforementioned didactic intervention. However, this was a pilot study and its results cannot be generalized. At the same time, there were some restrictions. During whole class interactions, it is impossible to give every student the opportunity to express their views on all the issues presented to them. It is also not always possible to explore the views expressed in depth or to interpret them. Consequently, we propose that the intervention be repeated with small groups of 3–4 students employing the "Teaching Experiment" method, in order to study the students' learning pathways in greater depth (Komorek & Duit, 2004).

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LEARNING ABOUT PROPORTIONALITY THROUGH ENGAGEMENT IN HANDS-ON ACTIVITIES IN PRIMARY SCHOOL

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Proportionality is considered one of the basic concepts cross-cutting through science and technology subjects and a cornerstone in the middle school mathematics curriculum. Proportional reasoning is also involved in scientific practices related to mathematizing, analysing and interpreting data, and modeling. Research shows that students of all ages have difficulties understanding the concept of proportionality and learning to reason proportionally. For the early grades of primary schools, some scholars have suggested that this might be related to the way the topic is taught and have shown that children in grades 2-6 are able to develop a concept of proportionality when involved in appropriate learning processes. Literature also suggests that learning is more effective when students are involved in hands-on activities. In a design-based study, we involved children in grades 2-4 in hands-on, inquiry-based activities, to explore if engagement in different phenomenological domains would promote a development of their understanding of proportionality and ability to reason proportionally. By design, we restrained from teaching the children explicitly about proportionality and looked at how children addressed proportional relations as they emerge naturally from the phenomena observed and the actions carried out. We found that children were able to identify proportional regularities in the observed quantities and make predictions of observations based on those regularities, clearly exhibiting proportional reasoning. The activities carried out included, inter alia*, pouring water between recipients of different capacity, measuring volumes and masses of different materials and exploring shadows in daylight.*

Keywords: Primary School, Reasoning, Scientific Practices

INTRODUCTION

Proportionality plays an important role in the way mathematics, science and engineering make sense of and represent the world. The National Research Council (2012) refers to proportionality as one of the seven basic concepts cross-cutting through science and technology subjects. In their extensive review of literature Lesh et al. (1988) point out that proportional thinking should be considered the capstone of elementary school mathematics and the cornerstone of high school mathematics. The National Council of Teachers of Mathematics (2000) lists proportionality among the fundamental mathematical ideas and proposes a specific emphasis on it as an integrative theme in the middle school mathematics curriculum. Proportional thinking is also involved in scientific and engineering practices such as “Using mathematics and computational thinking” and “Analysing and interpreting data” (NRC, 2012). As the simplest and most intuitive non-trivial functional relationship, proportionality also represents a cornerstone in mathematizing, a key component in the practice of modeling (Lesh & Doerr, 2000). Research and practice suggest that understanding and effectively applying proportionality poses serious difficulties for students of all ages and adults alike (Lamon, 2007).

On the one hand, proportional reasoning requires dealing with logical multiplication (Inhelder & Piaget, 1958). Moreover, understanding proportionality involves an ability to deal with a second-order relationship: a relationship between relationships (Piaget & Inhelder, 1975 as cited in Lesh et al., 1988). These difficulties may, however, be related to the way in which students are taught (Vysotskaya et al., 2000). Vygotskaya and collaborators (2000) found that under appropriate learning conditions children in grades 2-6 are perfectly able to develop proportional reasoning and a concept of proportionality. The National Research Council (2012) suggests that “facility with proportionality develops through work in many areas of the curriculum, including ratio and proportion, percent, similarity, scaling, linear equations, slope, relative-frequency histograms, and probability” and that “the understanding of proportionality should also emerge through problem solving and reasoning” (p. 212). In his influential work, Vergnaud (1983) considers proportionality as conceptually tied to multiplication, division, fraction, ratio and linear functions in what he referred to as ‘multiplicative conceptual fields.’ Other scholars suggested that students can develop proportional reasoning by engaging in a number of different small areas of inquiry and gradually extending their competence to larger contexts (Karplus et al., 1983a, 1983b; Lesh et al., 1988; Tourniaire & Pulos, 1985). On the other hand, as Langrall and Swafford (2000) point out, “the emphasis in textbooks is often on developing procedural skills rather than conceptual understanding” (p. 260). These authors suggest, on the contrary, that “instruction with proportional reasoning should begin with situations that can be visualized or modeled” (*Ib.*). In his report based on a large-scale survey from the National Assessment of Educational Progress, Wenglinsky (2000) finds that among the most relevant factors in student achievement in mathematics and science classroom practices matter the most. In particular, “when students are exposed to hands-on learning on a weekly rather than a monthly basis, they prove to be 72% of a grade level ahead in mathematics” (p. 27). The purpose of this study is to explore how hands-on, inquiry-based activities can promote the development of proportional thinking in the first grades of primary school. The main idea is to involve the children in activities in which proportional relations emerge naturally from the phenomena observed and the actions carried out.

RESEARCH SETTING AND METHODS

Our findings emerge from an action-research programme implemented in a primary school in a suburban area of a large city in Italy (ca. 1 million inhabitants). Four classes (ca. 100 children) were involved in the programme over a period of five years. This corresponds to the complete primary school cycle in the Italian education system. In each school year, seven interventions were carried out (ca. 1.5 h) by the researchers with the participation of the class teachers. The interventions were all centred on authentic, phenomenological contexts and we (and the teachers) restrained from direct instruction of proportionality. Our methodological reference is design research, an approach that aims at developing empirically grounded theories through a combined study of both the process of learning and the means that support that process (e.g., Cobb et al. 2003; diSessa & Cobb, 2004). A design research approach implied that we designed and implemented interventions in authentic classroom contexts, whereas the regular presence of the researchers in the classroom over an extended time-frame allowed for a seamless integration of the intervention in the students’ everyday school experience. The iterative nature of the design approach involved a process of cyclic design, evaluation and revision in which interventions were planned according to provisional assessment of learning outcomes. This implies that learning and design can be studied in their mutual interdependence.

The learning process starts with driving questions (How does it work? What happens if...? How can I make X happen? etc.) to which the children, stimulated by laboratory experiences aimed at their emotional and physical involvement, begin to respond on the basis of their perceptions, their personal experiences, and using their own natural language. Starting from phenomena that are closer to everyday experience and whose understanding therefore takes on a more "functional" dimension, the children proceed investigating more complex classes of phenomena by identifying, through analogies, increasingly abstract correlations. In the interaction with the adults, vocabulary and syntax develop from natural language towards scientific, formal language, which also include mathematical expressions. The need to define variables, to identify measurable quantities, to discover the relationships between them emerges from inquiry with the designed educational materials, the related experiences with natural phenomena and the interaction with the adults. Inquiry is here intended in the current perspective involving all scientific practices (NRC, 2012; NGSS Lead States, 2013).

Data collection included video- and audio-recordings of the interventions and field notes. Also, the inscriptions produced by the students were partly photographed and partly collected and scanned. Selected data (focussing on activities related to proportional reasoning) were analysed qualitatively according to a content analysis approach (Hsieh & Shannon, 2005; Lichtman, 2013; Mayring, 2014).

FINDINGS

Children were involved in hands-on inquiries in different phenomenological domains and encouraged to produce enactive, iconic and symbolic representations of their ideas in interaction with their peers, the researchers and the teachers. One of the activities implied comparing different quantities of water by pouring from one recipient into another of different capacity. Children used pipettes to count the drops necessary to fill a spoon, then the spoons necessary to fill a glass and so on up to larger recipients, some of which were graded. When making sense of the numbers collected using tables, children were able to make predictions of the ratios between the recipients, showing that they had detected a pattern of proportionality in the relationships between them. Interestingly, children were also able to intuitively reason with larger numbers than those addressed in class at that stage in the curriculum. In a further step towards a progressively more refined mathematization of the process, children used graded recipients for their inquiries. The design of this intervention was based upon the assumption that the action of pouring water from one container into another while keeping track of the number of actions to be repeated to obtain the goal of filling the larger recipient represents a concrete experience of a relative idea of quantity and of multiplication as a repeated addition of same quantities, as illustrated by the video-recording snapshot in Fig. 1. Compared to other experiences with ratios and rates, like e.g., time and distance, this activity has therefore the advantage of providing children with a direct, visual experience of the variables (quantities of water) and a direct, manual experience of their ratio (number of actions necessary to fill one recipient with the smaller one). The concept of ratio naturally emerges from these actions, when children consider the number of pouring acts necessary to fill one recipient with another.

Figure 1. A 2nd-grade student's symbolic representations of the relationship between a smaller and a larger recipient.

In another activity, children measured volume and weight of different materials (of different density), including water, flower, fine and coarse salt, corn seeds and popcorn, pasta of small and large cuts, and marbles. Starting with water, children soon realized that the operation of measuring the two variables in grams and millilitres yields a special regularity, represented numerically by the identity. Asked to forecast the result of the measuring of the mass after having measured the volume of larger quantities then first experienced, children were could easily produce the correct answer, showing they were able to identify the proportional regularity and apply it to unknowns. We started our activities with water under the assumption that the exercise of dealing with proportional relationships in the special, most intuitive case of the identity (factor of proportionality = 1) would be an effective cognitive precursor to working with more complex relationships. When working with fine salt, for example, children were immediately able to identify the new, less trivial proportional relation. After just one measurement of 200 ml, resulting in 220 grams, one of the students promptly commented on the next measurements in which 400 millilitres yielded 460 grams and 600 yielded 750 grams. "Something is wrong here – he pointed out – For 400 ml it must be 440 g because the double of 200 is 400 and the double of 20 is 40. I mean, it should be double, for 600 ml we should have 660 g." This ability to identify the expected measurement of a variable in terms of a given value of another, related variable in this case is a clear manifestation of proportional reasoning.

In the following trial with marbles (see Fig. 2), when encouraged to look for regularities not only in the rows but also in the columns, the children were both able to identify the proportional relationships in the multiplicative structures between numbers of marbles and related weights (e.g., 5x7=35m, 10x7=35, etc.) and volumes (5x3=15, 10x3=30, etc.) but also the covariance between columns: If the initial number of marbles 5 is multiplied by 5 the related multiplication between masses and volumes 35x5 and 15x5 yields the related results (same raw) of 175 and 75 (the complete table is presented in Fig. 3).

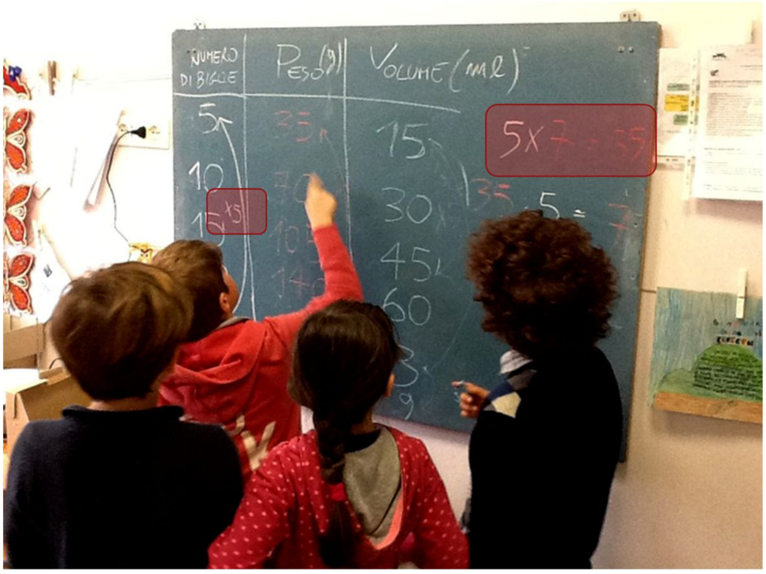

Figure 2. 3rd grade students discussing the multiplicative relationships between weight (second column) and volumes (first column) of different numbers of marbles (first column).

N. of MARBLES	WEIGHT	VOLUME
5	35	15
10	70	30
15	105	45
20	140	60
25	175	75

x5 (N. of MARBLES, 5 to 25); x5 (VOLUME, 15 to 75)

5x7 = 35
10x7=70
5x5=25
35x5=175
15x5=75

Figure 3. Complete Table of numbers of marbles and measurements obtained and examples of proportional relationships identified by the children.

In another activity, the children explored the length of the shadows of different objects (different height) in the sun (i.e., constant distance of the source) at specific times of the day. In this case two, children were able – after a number of measurements of both variables for specific objects – to reason about the possible length of the shadow of a new object, only by measuring its height (at the same time of the day, i.e., position of the sun in the sky). In a follow up discussion at the end of each year, children were able to remember the experiences and apply proportional reasoning to discuss the relationships between the involved quantities.

CONCLUSIONS

Proportional reasoning is both an important difficult competence in all four domains of STEM education and a difficult one to develop for students of all ages. The most common approach to this subject in school is based on word problems, a classical example being Mr. Tall and Mr. Short (cf. Riehl & Steinthorsdottir, 2014) (see also Langrall & Swafford (2000); Lamon, 2020 for a variety of other typologies). This is likely to lead to developing "procedural skills rather than conceptual understanding" (Langrall & Swafford, 2000, p. 206). Also, the study of proportionality is usually first introduced in middle school (Lamon, 2020; NCTM, 2000. Taking an inquiry-based approach and implementing scientific practices (NRC, 2012; NGSS Lead States 2013) we designed a series of activities for primary school children based in natural phenomena which we then conducted in four classes ranging from second to fifth grade over the course of four years. Our research on the outcomes of these activities showed that children in this early age were able to identify proportional relationships in the quantities they measured and successfully make related predictions or commenting on unexpected measurements by applying proportional reasoning. Our interpretation of these results is that the engagement with natural phenomena, in which the proportional relationships emerge in an authentic context from measurements of physical quantities conducted by the children themselves in the framework of their inquiries strongly influences the learning process. Our findings might also represent a starting point for developing and testing learning progressions (NRC, 2012) and teaching sequences (Lijnse, 1995) for the basic cross-cutting concept of proportionality.

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MODELING-BASED LEARNING ABOUT CHEMICAL PHENOMENA IN PRIMARY EDUCATION

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National and international studies demonstrate that students at primary level are able to express their mental models by drawing. These findings illustrate that modeling-based learning in primary school is partly possible. However, a deeper look at the results shows that the drawn models do often not correspond to scientific ideas or are inadequate to explain a phenomenon. Furthermore, most of the current research in primary education is focused on physical phenomena, e.g., the hydrologic cycle. Chemical topics, like solubility, are rarely represented in scientific research on this topic. One assumption to underline this research gap could be that modeling-based learning about chemical phenomena in primary education might be difficult because the chemical process takes place at the submicroscopic level. Because of that, a qualitative study was planned, which aims to clarify to what extent chemical phenomena are suitable for modeling-based learning in primary education. The study was conducted at a German primary school with ten fourth grade students. During the intervention, the students are confronted with two different phenomena: Boiling water in a kettle and dissolving table salt in water. These phenomena are the starting point for the student modeling process during the study. The data is collected through teaching experiments which are videotaped and then transcribed for the analysis. In addition to the teaching experiments, the drawings and the videotaped drawing process are available for the evaluation. The results of the study show that modeling-based learning about chemical phenomena is fruitful in primary education if appropriate interventions are available. The students are able to express their mental models by drawing. However, most of the built models can hardly be used to explain the phenomenon and do not correspond to scientific ideas. Because of that scaffolds are needed for modeling-based learning in primary school. Therefore, a study is following which focuses on support measures in modeling-based learning about solubility.

Keywords: Mental Models, Modeling-based Learning, Primary School

BACKGROUND AND RATIONALE

National and international science standards show that explaining and understanding scientific phenomena is important for science education at school in all grades (GDSU, 2013; National Research Council [NRC], 2012). Following NRC (2012), students should learn to explain phenomena with the help of (self-generated) models. Modeling is one method to achieve this goal in school (Constantinou et al., 2019; NRC, 2012; Nicolaou & Constantinou, 2014).

Forbes et al. (2014) demonstrate in their study that 3rd-grade students are able to draw a model of the hydrologic cycle. In order to analyse the drawn models, Forbes et al. (2014) set three levels of learning performances. These three levels are defined among other things by the explanatory process. The explanatory process describes how the verbalised elements, e.g. the connection between temperature and state of matter, are represented in the drawn models. Although the students are able to express their mental models by drawing, it is noticeable that the drawn models have gaps in their explanatory process. Lange et al. (2014) confirm these results in their study in a 4th grade at a German primary school. This study also illustrates that students at primary level are able to construct and revise the model. However, the built models do not correspond to the scientific models (Lange et al., 2014).

These results are focused on physical phenomena, like the hydrologic cycle. Phenomena of the chemical domain are hardly represented in current research to modeling-based learning in primary school. This could be due to the fact that modeling on a submicroscopic level might be more difficult than on the macroscopic level. Because of that further research of modeling-based learning about chemical phenomena in primary education is needed. The following article is focused on this research gap. Firstly, the theoretical framework of modeling-based learning is presented in more detail. After that, the conducted study and the achieved results are presented and discussed. Finally, an outlook on further research is given.

THEORETICAL FRAMEWORK

In the educational context, modeling plays an important role in order to explain a phenomenon with the help of a model and to gain new conceptual knowledge. Following Clement (1989) the modeling process is "used to develop an explanation for a newly recognized phenomenon" (p. 346). In primary education, students are confronted with those phenomena that are part of the students' living world. One aim of science education in primary school is to take up real-life phenomena as a topic of learning and to gain new insights about the phenomenon during the lesson (GDSU, 2013). For such a knowledge acquisition it is important to perceive the students' initial mental models and to develop them into a scientific mental model, which is described by Vosniadou (1994) as conceptual change. In order to reach a conceptual change, it is necessary that the students actively engage with their mental models, discuss explanations and test and revise their mental models. Only through such an active engagement and a conscious design of the learning setting it is possible to achieve a conceptual change (Gilbert & Justi, 2016; Vosniadou, 1994).

In order to reach a conceptual change, modeling-based learning could be useful. Gilbert and Justi (2016) developed a *Model of Modelling v2* that focuses on the modeling practices and is a complement to the original *'model of modelling' framework* by Justi and Gilbert (2002). Following Gilbert and Justi (2016) modeling is a process, which is dynamic and cyclic. In order to build a model through modeling, the modeler goes through four phases: First, a cognitive representation of a phenomenon – the mental model – is built. This mental model will be expressed in various ways of representation, e.g., in a 2D model by drawing it. Afterwards, the expressed model can be tested in experiments or simulations. Finally, the built model must be evaluated. In this phase, it is necessary to identify the limitations of the model by testing it in different contexts. After identifying the limitations, the model should be revised, which requires a new cycle of the modeling process. During this modeling process, various cognitive processes take place, e.g., analogical reasoning (Gilbert & Justi, 2016).

However, a closer look at the term modeling shows that modeling is used in different ways in scientific discourse. According to the literature review of Constantinou et al. (2019), modeling is described as a skill or, as mentioned above and following NRC (2012), a practice to explain phenomena with the help of models. In the educational context, modeling-based learning is linked to teaching strategies, like described by Louca and Zacharia (2012), or defined as a scientific method to achieve scientific literacy (Constantinou et al., 2019). To summarize these facets of the concept of modeling, Constantinou et al. (2019) develop a framework for modeling-based learning based on the concept of competence according to Weinert (2001). Understanding modeling as a competence combines both practical skills and metacognitive knowledge about models and modeling (Constantinou et al., 2019; Nicolaou & Constantinou, 2014).

In addition to the current research by Forbes et al. (2014) and Lange et al. (2014), the following study will focus on the modeling practices. Therefore, students go through the modeling process in a non-linear and dynamic way to construct a self-generated model, as shown by Gilbert and Justi (2016).

RESEARCH GAP AND RESEARCH QUESTIONS

As mentioned before, modeling-based learning about chemical phenomena is rarely represented in current research. Therefore, it is necessary to identify suitable phenomena as learning contents for modeling-based learning in primary school. Following the national standards for science education in primary school, three different chemical topics are suitable for learning science at primary level: State of matter, solubility of solids in liquids and burning processes (GDSU, 2013; MSB NRW, 2008). The extent to which these phenomena are a suitable learning content for modeling in primary education is the core of the following study. In concrete terms, the following research question can be formulated from this:

To what extent are primary school students in the 4th grade able to model chemical phenomena?

RESEARCH DESIGN AND METHODS

In order to investigate the above research question, the students are confronted with three different phenomena: State of matter, solubility of salt in water and the burning process of a candle. After the presentation of each phenomenon, further experiments are shown to focus on specific aspects of the phenomenon. To discuss the change of state of matter with the students, the boiling of water in a kettle is first presented as a phenomenon. After that, a plate is held over the opening of the kettle during the boiling process. In this short experiment, the students can observe the condensation of water on the plate. In addition to the change of state of matter, the students are confronted with the solubility of salt in water. For this purpose, salt is put into a glass of water so that the students can observe the solution process. To check whether the salt has been dissolved and is still present, the evaporation of the solution is shown. Finally, in order to examine the burning process of a candle more closely, the students are also confronted with the phenomenon in this case. For this, a candle is lighted, which is observed by the students. In order to examine the partial processes of burning, four short experiments are shown. First, the wick is observed more closely and it is investigated whether it also burns without the candle wax. Then the extent to which air plays an essential role in the burning process is examined. For this purpose, a glass is put over the candle. Finally, the products of the burning process are investigated. To do this, a glass is held over the candle in such a way that water and soot becomes visible.

The presented intervention is part of the planned qualitative study. A qualitative study enables to get insights into the personal ideas and thinking process. Common research methods are observation and interviews in order to get such personal insights (Creswell, 2013, 2014). In educational context, qualitative methods, e.g. teaching experiments, are used to investigate learning processes (Schecker et al., 2014). The teaching experiment represent a specific qualitative method in educational context, where "the researcher acts as teachers" (Steffe, 1991, p. 177). The benefits of the teaching experiment are that the researcher can react individually to what the participant says in the situation and make decisions on the spot (Steffe, 1991). Because of this benefit, a teaching experiment is planned for the following study. In order to plan the data collection more precisely, the teaching experiment is pre-structured with questions and stimuli. The pre-structured guide includes the following structure, shown in Table 1:

Table 1. Pre-structured guide of the teaching experiment using the example of the solubility of salt in water.

Teaching experiment	Mental model	Stimuli	Material
Let's take a closer look at salt now. I have taken salt and a glass of water with me. If I put salt in the water, what happens?	The salt dissolves. The salt melts. The salt evaporates. The taste has transferred. Water absorbs the salt. The water becomes salty. The salt is gone or is disappeared.	→ What do you mean by the salt 'dissolves'/ 'melts'/ 'evaporates' / 'is gone'?	Salt, glass, water

As shown in Table 1, the teaching experiment includes little experiments that focus on specific aspects of the phenomenon. While conducting the experiments, questions are asked in order to gain insights into the mental models of the participants. In addition to these questions, possible statements related to the underlying mental models are included in the above pre-structured guide. The statements in this case relate to the literature review by Grüß-Niehaus and Schanze (2011). In their overview, Grüß-Niehaus and Schanze (2011) summarise possible learners' conceptions about solubility. According to these possible answers, the stimuli are planned. This allows the researcher to react to the participant's statements on the spot. In addition to the questions and stimuli, the material for the experiment is also included in this structure to ensure that the study runs smoothly and comparably.

Next to the superordinate structure explained here, the teaching experiment on the three phenomena has the following structure:

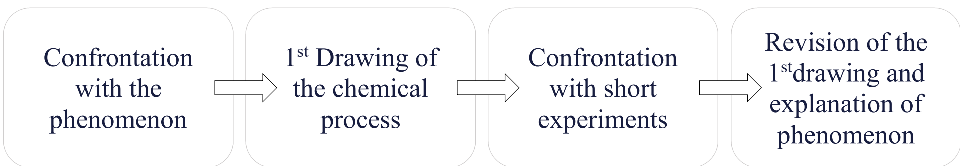

Figure 1. Structure of the teaching experiment.

According to the modeling process by Gilbert and Justi (2016), the students are confronted with the phenomenon in order to create an initial mental model. After that, the students have to draw the chemical process, which represents the expression of the mental model. In order to test their models, the students are confronted with short experiments that focus on certain aspects of the phenomenon. The students are then asked to revise their 1st drawing and explain the phenomenon using the model they drew before.

During the teaching experiment the students have to describe their thinking process by using the think aloud technique. Think aloud is a method to gain insights into the students' thinking process. Meanwhile, the "participants are explicitly instructed to focus on the task while thinking aloud and merely to verbalize their thoughts […] rather than describe or explain them to anyone else" (Ericsson & Simon, 1998, p. 181). In the conducted teaching experiment, this method is explicitly used for the drawing process in order to get a deeper look at the elements represented in the drawings. This protocol of think aloud is also necessary for the correct interpretation of the drawings.

The teaching experiment is videotaped and forms the basis for the analysis. The drawings are analysed with the help of the recorded video-data. The audio-data of the videotaped teaching experiment is transcribed afterwards. This transcription is the basis for the qualitative content analysis according to Mayring (2014). Mayring (2014) defines different types of techniques: Summarising, inductive way of categorisation, explication and structuring by deductive categories. For the study described and data collected, the inductive categorisation and structured content analysis by using deductive categories are useful. According to Mayring (2014), the category system is formed by the theoretical background and literature review. In this study the category system includes studies about possible learners' conceptions, e.g. conceptions about solubility by Grüß-Niehaus and Schanze (2011). Derived from the theory, categories and sub-categories are formed and defined in the coding guidelines. The coding guidelines contain the category, a definition, an anchor example and coding rules, which are presented in Table 2:

Table 2. Coding guidelines using the example of learners' conception of the solubility of salt in water.

Learners‘ conception of solubility (by Grüß-Niehaus & Schanze, 2011)				
Category		**Definition**	**Anchor example**	**Coding rules**
Conditions for solubility *(Why is the salt dissolved?)*	Stirring with a spoon to promote the solution process	Stirring with a spoon promotes the solution process. This also means that without stirring the substance will not dissolve.	B6: Because we have shaken and stirred that. #00:26:12#	The statements listed under the phenomenon solubility are analysed.

With the help of the coding guidelines, the transcribed statements can be clearly assigned to a category. Furthermore, the coding rules are necessary to determine which passages in the transcript should be analysed. In addition to the deductive categories, inductive categories could also be added during the analysis process. This process is necessary because further learners' conceptions might appear that have hardly been applied in literature so far. Moreover, inductive catgeries are useful to describe the explanatory process during the teaching experiment. This is due to the fact that the explanatory process during the modeling process cannot be determined deductively in advance because of the exploratory nature of the study.

SAMPLE

In order to test the planned teaching experiment, a pilot study is conducted with a nine-year-old girl attending the fourth grade of a German primary school. This participant has a high level of scientific knowledge and seems to be interested in scientific experiments. The following main study is conducted in December 2019 at the same primary school that the participant of the pilot study attends. The study involves ten students in the fourth grade who have heterogenous learning levels. The sample includes four boys and six girls at the age of nine to ten. According to the teachers' evaluations, three participants have a low level of scientific knowledge, four students have a medium level and three children have a high level of knowledge. Two of the three students at the highest level took part in an additional course in biology.

RESULTS

Pilot study

The pilot study shows that the planned teaching experiment is well implementable. Only minor improvements to the guide are necessary. The participant is able to draw and revise the mental model of the phenomena. Especially the topics 'state of matter' and 'solubility' show good and detailed results. In comparison, it can be seen that the burning process is presented in less detail. There is no explanation of the underlying chemical process. For this reason, only the two phenomena – state of matter and solubility of salt in water – are dealt with in the following main study.

Main study

State of matter

The change of state of matter takes place on the submicroscopic level and depends on the temperature increase. The connection between change of the state of matter and temperature increase is described by almost all of the students at the beginning of the teaching experiment. Most of the participants describe that the water boils and bubbles appear. However, a deeper look into the students' explanation shows that most of the probands cannot describe what causes the bubbles during the boiling process. Seven out of ten students explain that the bubbles are hot air. This demonstrates that the participants know about the temperature increase in this phenomenon. The connection to the change of state of matter is mostly not recognised. A deeper look at the expressed models shows that the bubbles are represented as blue circles. The temperature is not explicitly shown in the model for the majority of the participants. Only two out of ten students draw the temperature increase during the boiling in the 1st model. The temperature is shown in red lines or red bubbles. One student is not able to explain the connection to the temperature increase.

After the experiment, the students should revise their 1st models with the new insights. Four out of ten students explain after the revision of their models that the boiling process depends on the change of the state of matter. However, only two of the built models represent the connection between state of matter and temperature increase. The other drawn models have gaps in their explanatory process. Furthermore, the analysis shows that the learners' conception that hot air is responsible for the boiling process is deeply embedded. A conceptual change is rarely achieved in this teaching experiment.

Solubility of salt in water

The solubility of salt in water cannot be observed directly because the solution process takes place on a submicroscopic level. Many learners' conception about solubility can be identified in the main study. Five out of ten students explain that dissolving salt in water is due to stirring with a spoon during the solution process. Therefore, the drawn models of those participants show a spoon in the representation. Two out of ten students explain that the taste of the salt is transferred to the water. The drawn models show the term 'salt taste' or a yellow shading representing the salty water. Furthermore, three participants explain that the salt disappeared in water. This conception is represented in the model by drawing and erasing the grains of salt or crossing out the drawn salt. A deeper look at the other explanations shows that some students explain the solubility with animistic properties. One student explains that the salt would hide during the solution process. Three participants explain the solubility like a change of the state of matter. For these students, the salt would melt in water. This process is not expressed in the model. In particular, one model should be highlighted. The student describes the solution process by distributing the grains of salt in water. In her conception, the grains of salt become smaller and divide more and more until they cannot be seen visually:

"And then there are little […] grains of salt. They pop up. And then there are such small particles. So, grains of salt you can no longer see" (B2, #00:28:58#).

For this purpose, the dissolved salt is shown as pink circles that are evenly distributed in the water. This student's drawing comes close to a model on the submicroscopic level.

After confronting the students with the short experiment, the students should revise their 1st drawing. Most of the students add elements of the experiment on the phenomenological level, like the drawing of the experimental setup or a writing about conducting the experiment. The revision of the model does not take place. Furthermore, the built models have gaps in their explanatory process and the models can hardly be used for the explanation of the phenomenon.

All in all, it can be summarised that modeling-based learning in primary school could be fruitful if appropriate interventions are available. This was partially successful in the context of the state of matter, as the models were revised after the interventions and used for explanation. However, most of the models still have gaps in their explanatory process. Furthermore, the built models only correspond to a few aspects of the scientific concept, e.g., the influence of the temperature increase or the fact that the boiling process depends on the state of matter. A similar result is seen regarding the topic of solubility. Here, only one model comes close to a submicroscopic level and can be used for the explanation of the phenomenon. Most of the other models can hardly be used to explain solubility and also show gaps in the explanatory process.

DISCUSSION

The study shows two main results: 1. The built models only correspond to a few aspects of the scientific concept. A conceptual change is hardly to be found in the data presented. The students' alternative concepts are often so well established that a conceptual change does not seem plausible. This problem is also presented by Vosniadou (1994). Conceptual change is an ongoing process and requires a variety of learning situations as well as active engagement. The interventions in the framework of the study are hardly sufficient for this.

2. The built models for both phenomena show a rather low explanatory process. In this context, the models are hardly used for the explanation. This is due to the fact that elements that are necessary for describing the process are inadequately represented. This problem is also evident in the study by Forbes et al. (2014).

From these findings it can be concluded that modeling-based learning about chemical phenomena is partly possible in primary education but should be supported by scaffolds.

OUTLOOK

Based on the presented results, further research on modeling-based learning about chemical phenomena is needed. Therefore, a study is planned to investigate possible support measures for modeling-based learning about solubility.

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COMPARING TEACHERS' AND STUDENTS' PRECONCEPTIONS ABOUT NANOSCIENCE CONTENT: THE CASE OF THE LOTUS EFFECT

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In this study we aimed to identify similarities between Primary Teachers' (PTs) (n=154) and Primary Students' (PSs) (n=347) preconceptions about the lotus effect through the lens of the Conceptual Change. We identified five categories of preconceptions. Four out of five categories were common between the two groups. Most of the participants interpreted the lotus effect based on a perceptual-based agent (e.g., soft/ hard/smooth surface). Therefore, both the PTs and the PSs approached the lotus effect as a Direct Process (has an identifiable agent that causes some outcome in a sequential sort of way). This finding has implications in Science Education. We argue that training courses for PTs and educational interventions for PSs could be designed through a common rationale: to enable the learners to shift their explanations from the Direct towards the Emergent Processes (have neither an identifiable causal agent or agents nor an identifiable sequence of stages), explaining the phenomenon as a result of the collective interaction of agents, e.g., the leaf's micro and nanostructure and the trapped air between the interstitial spaces.

Keywords: Science Education, Primary School, Conceptual Change

INTRODUCTION

Throughout this paper, the term "preconception" is used denoting the explanations of physical phenomena that learners form before any systematic instruction (Vosniadou, 2012). Shifting learners' preconceptions from naive towards more sophisticated ones (i.e., conceptual change) is considered to be the main goal of Science Education. Chi (2008) argues that it is common for students to have preconceptions that contradict scientific concepts (i.e., misconceptions) because their explanations are not classified in the correct Ontological or Lateral Category. For example, students approach the heat based on attributes of Entities mentioning that heat is some kind of hot molecules implying that heat "can be contained" such as the objects. In the case of heat transfer, students seem to estimate that heat is moving from an area to another as a Process. However, they describe heat as a Direct Process (has an identifiable agent that causes some outcome in a sequential sort of way), in the sense that hot molecules are moving from one location to another. This conception of heat contradicts the scientific view according to which heat transfer constitutes an Emergent Process (have neither an identifiable causal agent or agents nor an identifiable sequence of stages) caused by the collisions of molecules (Chi, 2008; Chi, Roscoe, Slotta, Roy, & Chase, 2012).

In this paper, we examine primary teachers' (PTs) and primary students' (PSs) preconceptions about a phenomenon that is studied thoroughly by the research of Nanoscience, namely the lotus effect. Nanoscience comprises a modern field where research is placed at the nanoscale (1-100nm approximately) (Lin, Wu, Cho, & Chen, 2015). A significant area of Nanoscience research is associated with the field of biomimetics, i.e., the research of how the nanoscale affects the behavior of the natural organisms. More specifically, concerning the lotus effect, the lotus leaves present structural multi-scale roughness, having micro-bumps and nano-bumps which are covered with epicuticular wax. Air pockets are formed in the interstitial spaces. Due to the hierarchical structure (micro-bumps, nano-bumps), the droplet has a larger surface area in contact with the air than with the surface of the leaf, resulting in the spherical shape of the water droplet. In addition, when water droplets fall on the lotus leaf's surface, they bead up rolling off the surface and collecting any dirt particles adhered to the leaf (Kim et al., 2018) (Figure 1). Several commercial products have been produced by mimicking the lotus leaf's surface e.g., self-cleaning fabrics (Lin et al., 2015).

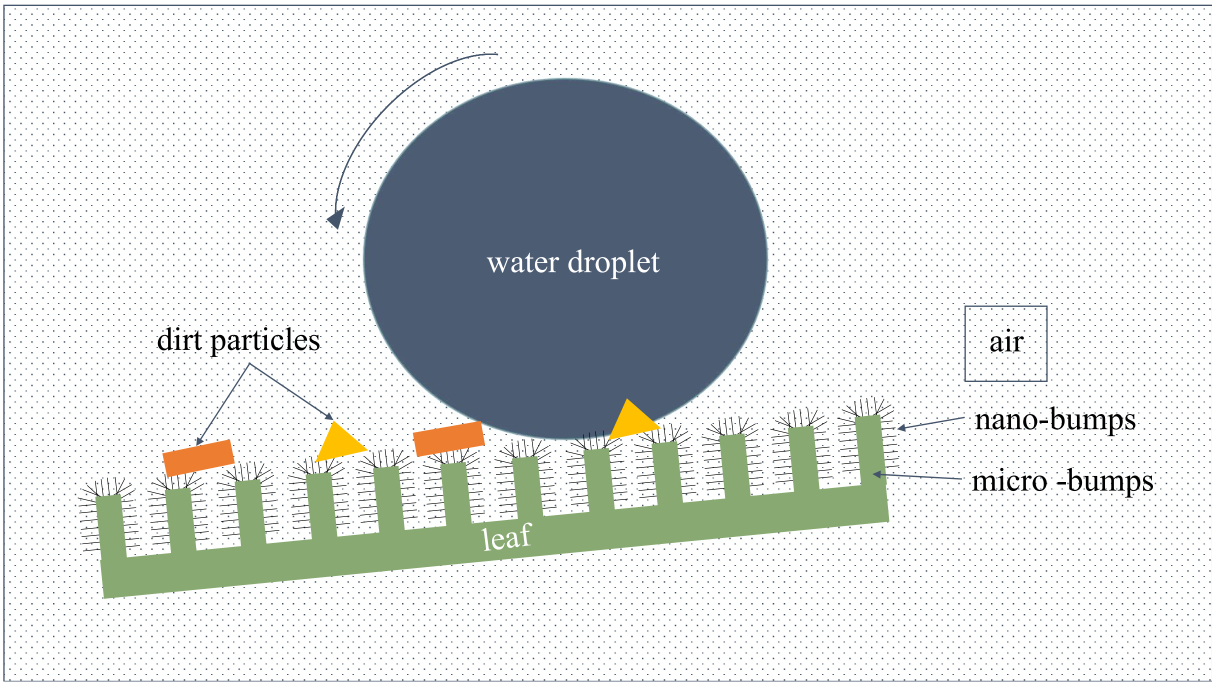


Figure 1: Representation of the lotus effect (based on Manou et al., 2019).

Through the lens of the Ontological Categories the explanation of the lotus effect seems to be an Emergent Process since it is a result of the collective interaction agents, e.g., the leaf's micro and nanostructure and the trapped air between the interstitial spaces (Peikos, Spyrtou, Pnevmatikos, & Papadopoulou, 2020).

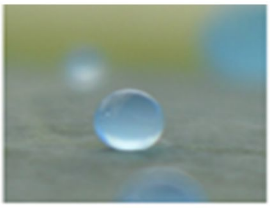
Even though the lotus effect is included in educational approaches in primary schools (Lin et al., 2015; Mandrikas, Michailidi, & Stavrou, 2019), research concerning learners' preconceptions about this modern topic is in its infancy. A recent study concerning PSs' preconceptions about the lotus effect (n=250) revealed that they approach the lotus effect as a Direct Process. Most of the explanations that they provided included a perceptual-based agent as a cause of the effect e.g., "the spherical droplet is formed because the leaf is rough" (Peikos et al., 2020). In the literature it is stated that PTs have misconceptions similar to those of their students about a variety of science concepts, such as the concept of magnetism and gases (Burgoon, Heddle, & Duran, 2011). In the case of the lotus effect, we could not trace any study until today that deals with whether PSs or PTs hold similar or different preconceptions about the lotus effect. This is a literature gap, because if PTs hold the same misconceptions with PSs, they will not be able to identify the misconceptions of their students, and, therefore, they will not be able to address the misconceptions during instruction. In contrast, it is possible to strengthen and even create new misconceptions to their students during a related educational intervention (Burgoon et al., 2011).

In this study we aim to examine whether PTs have preconceptions about lotus effect that are similar or not to those of PSs. Thus, the research question that drives this study is: Which are the similarities between primary teachers' and primary students' preconceptions about the lotus effect?

METHOD

The participants of the study were 154 PTs and 311 PSs of Greece. In a context of a broad area of Nanoscience content, they were asked to complete a written questionnaire. One of the tasks prompted participants to write their explanations about the lotus effect (Table 1) (Peikos et al. 2019, 2020; Manou, Spyrtou, Hatzikraniotis, & Kariotoglou, 2019).

Table 1. The tasks of the questionnaire for the lotus effect.

Lotus effect task for PTS	Lotus effect task for PSs
Assume that you pour the same amount of water on a wooden (A) and on a leaf's surface (B). Describe the differences of the shape of the droplet. By using words or drawing, provide an explanation regarding the different shape of the water droplet.	Two brothers washed some cabbage leaves for the salad and noticed that the water on the leaves beads up forming spherical droplets. Why do you think this happened?
 	 

We conducted a content analysis method, which is considered to be an appropriate research method for analyzing written responses, aiming to create knowledge and understanding about the explanations that the PTs and PSs provided, regarding the mechanism underlying the lotus effect (Elo & Kyngäs, 2008). More specifically, we coded PTs' and PSs' answers based on the inductive coding process. According to this method, the written responses of every PT or PS were analyzed based on Meaning Units (MUs), which can be words or phrases that make sense for the particular research question (Graneheim & Lundman, 2004; Elo & Kyngäs, 2008). For example, one PT wrote:

"On the leaf's surface the water droplet has remained in a more upright position. This is because the surface of the leaf is softer. In addition, the leaf's surface is porous and creates the round shape of the water droplet".

According to this explanation, we may identify two MUs, that are meaningful to the research question:

MU1: "*On the leaf's surface the water droplet has remained in a more upright position* (i.e., in relation to the wooden surface). *This is because the surface of the leaf is softer* (i.e., than the wooden surface)".

MU2: "*The leaf's surface is porous and creates the round shape of the water droplet".*

Subsequently, we assigned an appropriate code to each one of the MUs. The similar codes were aggregated together in order to form the initial categories of preconceptions. For example, the codes "softer surface" and "porous surface" were assigned to both MUs stated above. Both codes formed the category "perceptual-based features of the leaf". The next step was to create more abstract categories by integrating the initial categories through the lens of the conceptual change. For instance, the category "perceptual-based features of the leaf" was classified into the more abstract category "explanation based on perceptual-based agents". The same process was followed for analyzing PSs' responses. Figure 2 represents the inductive coding process that we followed in order to analyze PTs' and PSs' MUs.

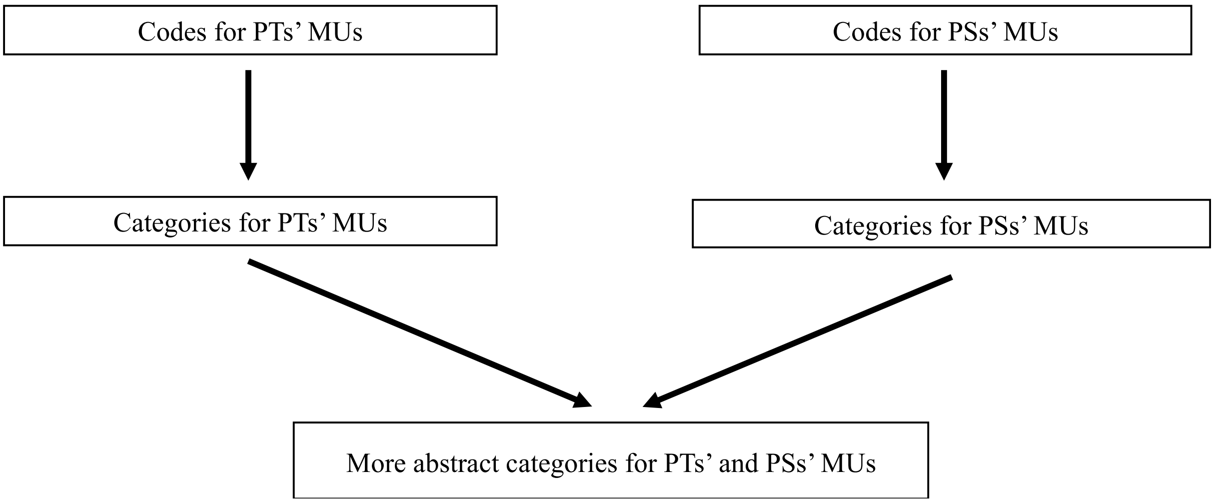


Figure 2. The analysis process.

The three authors of the study, who participated in the coding process, have formed two pairs. The first pair analyzed PSs' written responses and consisted both of the first and third Author. The second pair - consisted of the second and third Author - analyzed together PTs' responses. Each pair worked independently from the other pair. In the final step, the three Authors discussed the similarities and differences between the catagories, until they reached a concsensus.

RESULTS

Five categories of preconceptions were finally formed about the explanation of the lotus effect. We found 167 and 347 MUs within PTs' and PSs' answers respectively. Table 2 presents the percentage of PTs' and PSs' MUs per category.

Table 2. Categories for the preconceptions of the lotus effect: percentages of Meaning Units

Categories	Percentage of PTs' MUs	Percentage of PSs' MUs
C1. Blank or vague answer	28.14%	28.82%
C2. Explanation based on perceptual-based agents (e.g., features of the leaf or the droplet)	59.28%	62.82%
C3. Explanation based on non-visible agents (e.g., cells, molecules) without reference to the leaf's nanostructure	7.18%	7.78%
C4. Explanation including the agent concerning the interactions between the droplet and the leaf (e.g., attractive forces)	4.80%	0%
C5. Explanation including the agent concerning scientific concepts for the lotus effect (e.g., nano bumps, hydrophobicity)	0.60%	0.58%

Explanation based on perceptual-based agents

The largest percentage of the PTs' MUs (59.28%) and PSs' MUs (62.82%) were classified in the category "Explanation based on perceptual-based agents". This means that both groups of the participants interpreted the spherical shape of the droplet based on a perceptual-based agent, associated either with the features of the leaf's surface or with the droplet itself.

Some PSs explained the spherical shape of the water by referring to the leaf's absorbance. For example: *"The cabbage leaf did not absorb water. So, the water droplets were gathered to a spherical shape".*

Other PSs described the initial state of the leaf, namely if it was wet or dry. For instance: *"When the droplets fall on the leaf, its surface gets dry, so the water forms small balls".*

Moreover, a number of PSs referred to agents such as the hardness/smoothness of the leaf's surface. For example:

"The cabbage's leaves are hard, which is what make the droplets spherical".

"Because the cabbage leaf's surface is smooth".

Furthermore, some PSs interpreted the cabbage's shape as an agent that causes the spherical shape of the droplets. For instance: "*When the droplets attach to the cabbage, they take its shape, which is round'.*

Similarly, various perceptual-based agents were found within PTs' MUs. These agents included the hard/soft, the smooth/rough, the porous, the bumpy surface, the thin/the dense, the non-absorbent leaf etc. For example:

"On the leaf's surface the water droplet forms a spherical shape. This is because the leaf's surface is smooth".

"The water droplet is spherical because the leaf's surface does not have many pores, contrary to the wooden surface".

"The leaf is light in weight, so when the drop falls on the leaf, its spherical shape does not change".

Blank or vague answer

The category "Blank or vague answer" is the next with high proportion of MUs for both PTs (28.14%) and PSs (28.82%). For example, some PSs and PTs wrote: "I don't know how to explain it".

Explanation based on non-visible agents without reference to the leaf's nanostructure

The category "Explanation based on non-visible agents without reference to the leaf's nanostructure" comprised 7.18% of PTs' MUs and 7.78% of PSs' MUs. The participants referred to non-visible agents that they think that cause the lotus effect, such as the leaves' cells or molecules.

Typical examples of MUs that were identified in PSs' MUs were:

"The cabbage leaf's cells keep the droplets, making them spherical".

"The water molecules are spherical; this is why water becomes spherical".

Similarly, PTs' non visible agents included mostly the leaf's stomata and molecules. For example:

"The leaf's surface consists of stomata, which prevents droplets from spreading".

"The leaf's surface consists of a thin layer of molecules and, as a result, fewer molecules (than the wooden surface) are in contact with the droplet's surface".

Explanation including the agent about the interactions between the droplet and the leaf

The category "Explanation including the agent concerning the interactions between the droplet and the leaf" was found only in the PTs' MUs (4.80%).

For example: "*In the case of the leaf, the shape of the droplet is spherical because of the leaf's surface. I guess the forces that act on the droplet are very little to zero*".

Explanation including the agent concerning scientific concepts of the lotus effect

It is notable that a low percentage of both PTs' MUs (0.60%) and PSs' MUs (0.58%) included the agent associated with scientific concepts for the lotus effect e.g., invisible bumps, hydrophobicity. For example, one PS mentioned: *"I believe that the cabbage's leaf is covered with small invisible bumps that make the water spherical. This phenomenon is called lotus effect".*

CONCLUSION-DISCUSSION

In this study we aimed to identify similarities between PTs' and PSs' preconceptions about the lotus effect. We found four categories of preconceptions that both groups of participants shared (categories C1, C2, C3, C5). Among them, C2, for both groups, was the category with the highest percentage of MUs. This finding indicated that PTs as well as PSs were based on their senses in order to explain an effect, whose mechanism is not perceived through our perceptual ability. Accordingly, we noted that PTs and PSs referred to the same agents, such as the soft, hard, rough surface. In addition, both of the groups faced major difficulties in providing just a single explanation about the effect (C1 category).

Literature findings suggest that various preconceptions are incommensurate with the scientific conceptions because they are not classified into the correct Ontological or Lateral category (Chi 2008, 2012). We argue that the participants' explanations of the categories C2 and C3 could be classified in the Ontological category of Processes and, more specifically, in the Lateral category, namely the Direct Processes. This means that the participants referred to an identifiable agent, which was either a perceptual-based agent or a non-visible agent. In both cases, through the participants' explanations we can assume that they attribute the effect to a single agent. In contrast, the scientific explanation about the lotus effect can be classified into the Emergent Processes since it is the entire collection of all the agents that cause the effect i.e., the spherical shape of the droplet on the lotus leaf. This finding has implications in the Science Education field. In Figure 3 we propose that training courses for PTs and educational interventions for PSs could be designed through a common rationale: to enable learners to shift their explanations from the Direct towards the Emergent Processes in order to conceptualize a nanoscale phenomenon that is based on multiple agents (Peikos et al., 2020).

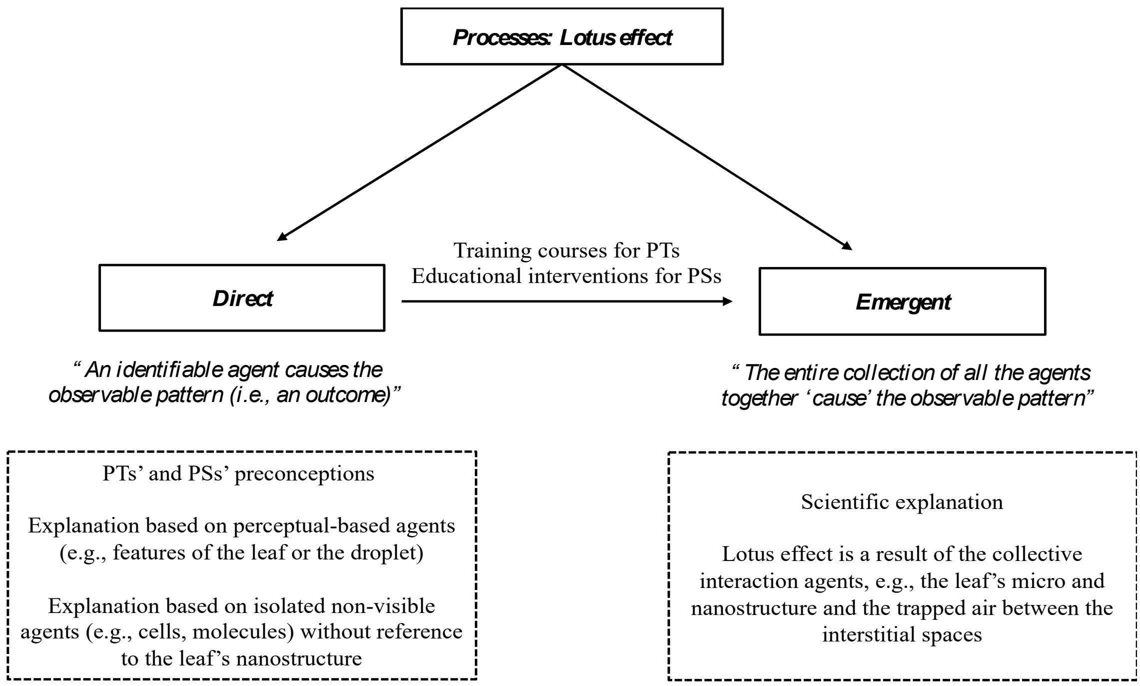


Figure 3. The rationale for designing training courses for PTs and educational interventions for PSs about the concept of the lotus effect (based on Peikos et al., 2020).

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Part 17 / Strand 17

Science Teaching at the University Level

Editors: *Jenaro Guisasola & Paula Heron*

Part 17. Science Teaching at the University Level

University pedagogy. Teaching and learning at the university level.

INTERNATIONALIZATION AND SCIENCE TEACHER EDUCATION IN ACADEMIC PRODUCTIONS IN BRAZIL

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Today's society is increasingly globalized and interconnected by digital technologies. Consequently, it needs a broad education capable of meeting the formative needs of 21st century citizens. This requires that the training of science teachers be up to date and in line with scientific and technological advances. In this perspective, we highlight the internationalization of higher education as a possibility to help these professionals to expand knowledge, intercultural relations, worldview, valorization, and respect among people. Therefore, and this study aimed to investigate the internationalization in science teacher education. For this, we conducted bibliographic research in the thesis/dissertation banks and scientific articles. This resulted in eight productions analyzed in three categories: internationalization in the perspective of comparative study, internationalization by international cooperation, and internationalization of the degree through academic mobility. We verified through this study the relevance of the international cooperation and international academic mobility programs to strengthen and expand the initial and continuing education of teachers. Furthermore, we note a low production and the need for more research in this area, considering the importance and contributions of internationalization in science teacher education and professional development.

Keywords: Teacher education, Internationalization of higher education, Sciences education

INTRODUCTION

Today's society is increasingly globalized and interconnected, with facilities to access diverse information and knowledge from anywhere in the world, to interact and learn from each other, and to exchange intercultural experiences. In this sense, favoring an education capable of developing a more effective, broad education that meets the formative needs of citizens in the 21st century are challenges.

This requires that the science teacher education is updated and connected with the formative, scientific and technological needs of global society. In this context, the internationalization of higher education defined by Knight (2004, p11) as "a process that integrates a global, intercultural and international dimension in the objectives, functions and offer of post-secondary education". The studies related to this process intensified in the 1990 in Brazil due to the possibility of improving the quality of education. Thus, universities seek to internationalize by increasing partnerships and international cooperation between countries. According to (Rodriguez & Massena,2020, p. 20) "the origin and advancement in the area of Science Education in Latin America has been a product of internationalization and cooperation in the higher education".

This internationalization process can occur through three main strategies: international academic mobility, internationalization of the curriculum and internationalization at home. International academic mobility abroad is the main form of internationalization worldwide. One of the best-known mobility programs is the European Action Scheme for the Mobility of *Students* (ERASMUS), the European Union Mobility Program. In Brazil, the largest academic mobility program was Science without Borders, which enabled the insertion of many higher education institution in the global context and accelerated the internationalization process of these institutions (Stallivieri, 2020).

Internationalization of the curriculum is the incorporation of international, intercultural and/or global dimensions into the content of the curriculum, as well as into the learning outcomes, assessment tasks, teaching methods and support services of a program of study" (Leask, 2015, p. 9). And internationalization at home is "the intentional integration of the international and intercultural dimension into the formal and informal curriculum for all students in home learning environments" (Beelen & Jones, 2015, p. 69). And it aims to include people who cannot afford to travel to another country either due to financial or other reasons. With the Covid-19 pandemic, internationalization at home through digital technologies has been the main way to continue with internationalization activities.

The internationalization of higher education is considered important in the training of science teachers, as it can expand knowledge, the worldview, the appreciation, and respect among peoples, such as on intercultural issues. And the teacher is the main responsible for the development of the internationalization of teaching, through the formulation or reformulation of the curriculum, development of teaching and learning strategies, conduct collaborative research with teachers from abroad and publication of scientific articles, receive in the classroom foreign students, among others (Stallivieri, 2016; Postiglione; Altbach, 2013) that help the student to develop intercultural competencies and skills.

However, in Brazil teachers are distant from the broader process of internationalization of teaching, although some actions have been taken (Ramos, 2018). From this perspective, this study aims to investigate the productions on internationalization in science teacher education in Brazil.

METHODOLOGY

The present study is characterized as bibliographic research with a qualitative approach, given that the focus is the process and not only the product (Bogdan & Biklen, 1994). The production of data occurred through a survey conducted in the Brazilian Digital Library of Theses and Dissertations (BDTD), in the theses database of the Coordination for the Improvement of Higher-Level Personnel (CAPES), in the Scielo database and in the Google academic in the last ten years. We used the descriptor: internationalization in science teacher education.

The data were analyzed according to the content analysis (Franco, 2005) which resulted in three categories: Internationalization by international cooperation, Internationalization of undergraduate degree by international mobility and Internationalization by comparative study.

RESULTS AND DISCUSSION

The investigation carried out in the databases of theses/dissertations and scientific articles resulted in eight productions, being two dissertations and six articles described in table 1.

Table 1. Productions related to internationalization and science teacher education.

Theme of productions	Author(s)/ year	Institution/ Scientific journal
The initial training of chemistry teachers and the internationalization of higher education in Brazil	Silva Junior (2017)	University of São Paulo (USP)
Initial training of chemistry teachers from the perspective of inclusive education: a dialogue between the curricular proposals of higher education institutions in the State of São Paulo and *the Teachers College* of Columbia University (USA)	Nascimento (2018)	University of São Paulo (USP)
Professional development and international cooperation for chemistry teachers: Evaluation of the intention of pedagogical change after continuing education in Porto, Portugal	Paiva et al. (2017)	New Chemical Magazine
Reflections on the effects of the transnationalization of curricula and the coloniality of knowledge/power in international cooperation: focus on science education	Cassiani (2018)	Education Sciences Journal
The international training experience in the Paulo Freire Academic Mobility Project for Students of University Teacher Training Programs of the Organization of Ibero-American States for Education, Science and Culture (OEI)	Tonello (2019)	Insignare Scientia Magazine
Repercussions of the International Degree Program on the academic and personal training of a group of chemistry graduates of the Federal University of Viçosa (MG)	Fialho, Santos and Catão (2019)	Education in Punto de Vista
Internationalization of Higher Education in the context of bachelor's degrees in Science Education	De Paula, Mello (2020)	Journal of the Amazon Network of Science and Mathematics – REAMEC
Latin American cooperation for the training of science teachers	Rodriguez and Massena (2020)	Essay Magazine

The dissertations were published in 2017 and 2018 by the Graduate Program of Education of the University of São Paulo (USP), a southeastern region of Brazil where publications in the area of science teaching predominate. Regarding the articles, we found six publications, one in 2017 and 2018, in 2019 and two in 2020. This indicates that the research related to this theme are still recent in Brazil and with few productions.

Internationalization by comparative study

In this category we found two dissertations, Silva Junior (2017) that verified how the initial training of chemistry teachers occurs in six courses from three state universities in São Paulo, taking into account the impacts of the Bologna process, which is an agreement signed by Ministers of Education from several European countries. The analysis showed the impact of international policies on education in Brazil and the similarities between the courses analyzed, indicating a pattern of compatibility and the possibility of academic mobility, as occurs among the countries that are part of the Bologna process (Silva Junior, 2017).

The second dissertation by Nascimento (2018), investigated how the issue of inclusion of students with disabilities is addressed in the initial training of chemistry teachers in the state of São Paulo, comparing with the international proposals of the teacher training program of teachers College at Columbia University in the United States. This evidenced that higher education institutions have not ensured a solid inclusive education for future chemistry teachers in do Brazil. This was also observed in the work of Bozi and Catão (2021) when studying the theme of professional training and experiences of chemistry teachers in the educational inclusion of the deaf and emphasized the urgency of discussions and training on inclusion in the initial and continuing education of chemistry teachers.

These two dissertations approached the internationalization from a comparative study perspective, this type of study seeks to verify the similarities and differences existing in a certain area in the international context, which can lead to the improvement of teacher education and provide cooperation and mobility between countries.

Internationalization by international cooperation

International cooperation is one of the ways to internationalize higher education and teacher training. It is considered an efficient strategy that collaborates to think about the construction a fair/sustainable society (Rodriguez & Massena, 2020).

The articles in this category addressed two Brazilian international cooperation programs: the Professional Development Program for Teachers of the Coordination of Personal Improvement of Higher Education (PDPP/CAPES), and the Program for Teacher Qualification and Portuguese Language Teaching in East Timor (PQLP /CAPES). These cooperation's occurred between Portuguese speaking countries and highlighted the relevance of international cooperation in science teacher training as described below:

> *It is possible to understand that the opportunity to "see and run the world" has been in itself generating gains, namely, at the level of the teachers' socio-professional knowledge (Paiva, et al., 2017).*
>
> *It can provide contact with important knowledge that contributes to citizenship education and peace consolidation (Cassiani, 2018, p.225).*
>
> *The processes of international cooperation in Latin America are fundamental, as they allow participants to build new visions about our reality, to live different academic and personal experiences, as well as to strengthen their regional identity and their professional, cultural, and personal formation (Rodriguez & Massena, 2020, p.22).*

These facts highlight the potential and benefits of internationalization through international cooperation in teacher education. This was also observed by Lopes (2020), when he stated that this type of partnership is already consolidated, and that it is important to invest in training strategies for the development of education professionals. However, we identified some threats and challenges in international cooperation that hinder the realization of this work, according to the excerpts below:

> *The heterogeneity of the participants*, the high risk of communication problems due to language *difficulties, lack of pedagogical resources (Paiva, et al., 2017).*
>
> *[...] the transnationalization of the curriculum, the effects of coloniality through textbooks, which can generate dependence and subalternization by vertically imposing universal, neutral, ahistorical knowledge, and without dialogue* of knowledges (Cassiani, 2018, p. 240).
>
> *[...] Need for articulation of professional training to personal training, approach of initial training courses to the school context, strengthening of the teaching identity and approach of education professionals to the community through contextualization, reflection, and research (Rodriguez & Massena, 2020, p. 22).*

Some of these difficulties have been identified in the context of cooperation in Portugal (Lopes, 2020), such as:

Lack of access to resources in the intervention context, lack of sustained dialogue specifically focused on the preparation of the missions with the institutional partners and as beneficiaries of the training program, lack of preparation of professionals both coordinators and teachers to work the curricula in this context, absence of memory and institutional organization, lack of articulation of work among collaborators (Lopes, 2020, p. 8).

The decontextualization of science teaching with the regional context was also mentioned in one of the studies. In this scenario, providing teacher education bringing science teaching closer to the local reality will favor a greater use and learning of the contents critically. The challenges and threats of cooperation need to be worked on to avoid the opposite effect. Therefore, it is important to monitor, plan, availability of adequate resources, training of coordinators and teachers, dissemination of the cooperation carried out in order to disseminate the information and improve the quality of these activities.

In addition, internationalization through international cooperation was seen as a means of professional teacher development by Brazilian and Portuguese researchers as highlighted by Paiva et al. (2016). This reinforces the magnitude of internationalization actions in science teacher education.

Internationalization of science degree by international academic mobility

In the studies of this category, we note the actions of internationalization of higher education through the international mobility carried out by CAPES, such as the International Graduate Program (PLI). The objective of this program was to improve the quality of initial teacher training in the areas of Portuguese, Arts, Physical Education, Mathematics, Biology, Physics and Chemistry. This was carried out in sandwich format in partnership with countries such as France and Portugal and enabled the acquisition of double diplomas.

This program contributed in the initial training of chemistry teachers in several aspects, such as the motivational favoring the permanence in the course and incentive to studies, construction of critical and reflective knowledge in various themes, mutual respect and human training, opportunities to exchange professional and intercultural experiences, learning differentiated teaching methodology, among others (Fialho, Santos, & Catão, 2019). However, the authors also report some negative points such as the lack of psychological support, the lack of sharing of experiences, the lack of welcome when returning to Brazil, and the focus on undergraduate courses. This needs to be improved in future international mobility programs.

Another international academic mobility program, considered of great relevance in the process of Internationalization of Higher Education in Brazil was the Sciences without Borders, which took place from 2011 to 2017 and provided international experiences to thousands of students, mainly in the areas of technologies, engineering, and exact sciences. The undergraduate courses had a negligible participation because it was not the focus of this program.

The study by Tonello (2019), addressed the experience resulting from his participation as a biology student in the Paulo Freire Academic Mobility project for teacher training of the

Organization of Ibero-American States for Education, Sciences and Culture (OEI) in collaboration with the Federal University of the Southern Border. The exchange took place at a University of Chile, and allowed to attend courses in the pedagogical area, to observe and practice in schools, to immerse and integrate with the academic community, to improve by participating in events and cultural activities. In other words, international mobility contributed in comprehensive way to the initial training and will help the student's future professional performance.

Although these internationalization actions have been carried out, we verified the low participation of students of teacher education courses in this process, and this number is even lower in the training of teachers in the area of Natural Sciences as emphasized in the work of Paula and Mello (2020). In this sense, programs, projects, and other strategies that promote internationalization in undergraduate degrees should be encouraged and expanded in higher education institutions with government support, to overcome disparities and allow the inclusion of science teachers in this process.

CONCLUSION

Through this study, we identified some evidence of internationalization in science teacher education in Brazil based on bibliographic research. We found eight academic productions in the period from 2017 to 2020 that were analyzed in three categories: internationalization from the perspective of comparative study, internationalization and international cooperation and internationalization of undergraduate science education through academic mobility.

We note the relevance of international cooperation programs and international academic mobility to strengthen and expand internationalization in the initial and continuing education for teachers. CAPES played a fundamental role in the implementation and financing of these actions, which enabled the development and advancement of the internationalization of higher education in Brazil.

Nevertheless, the results show a gap regarding internationalization in the production of science teaching, which indicates the need for more research, programs, and strategies aimed at internationalization in the science teacher education, considering the relevance of this process in pre-service, continued, and professional development.

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TRAINING STUDENTS TO MASTER THE MATHEMATICAL PREREQUISITES FOR A UNIVERSITY SCIENCE CURRICULUM

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Most science courses at a university level require a prerequisite in mathematics without which students encounter serious difficulties. In order to support students who do not adequately master these concepts, we looked at the possibility of building a mathematics course that focuses on strengthening the prerequisites for the first-year science courses at university.

This program was designed with three goals in mind: (i) to define the key skills which serve as a basis in mathematics and other scientific disciplines, especially in physics (ii) to identify the prior knowledge in mathematics which are the prerequisites for those skills (iii) to strengthen the level of mastery of each skill.

Four strategies were implemented: (i) working in an interdisciplinary team of science teachers to define the targeted skills and support students in their training, (ii) identifying the connections between those skills, (iii) setting up a training course with activities to strengthen assimilation of certain skills targeted by other disciplines as early as possible and (iv) devoting a significant part of the program to prerequisites already seen in middle and high school but not mastered.

This study shows that to best achieve these goals, the sequencing of the content and teaching organisation differ from that of a classic refresher course in mathematics: it does not follow the traditional structural links between the prerequisites. In addition, devoting time to teaching mathematical prerequisites up to middle high school level appears essential.

Keywords: Higher Education, STEM Education, Pedagogical Content Knowledge

INTRODUCTION

It is well known that science students who enter university find it difficult to succeed because they lack a strong mathematical foundation. Struggling with the management and handling of mathematical tools, they fail at comprehending and manipulating the prescribed scientific concepts taught in class.

Conceptual frame

Students need to build on their own prior mathematical knowledge to succeed in mathematics (Faulkner, Hannigan, Fitzmaurice, 2014). The necessary prerequisites to study a concept are not always obvious to a student, even though they are identified by the teacher (Lehtinen, Hannula-Sormunen, McMullen, Gruber, 2017). The latter therefore develops his teaching according to this sequence of prerequisites. For the students who have gaps in their mathematical knowledge, this progression becomes impossible to follow, especially if those gaps are from a high school or even a middle school level.

Prior mathematical knowledge predicts not only success in mathematics, but also in other experimental sciences. Success in physics was even found to be correlated to students' prior success in mathematics and not to their prior success in physics (Meltzer, 2002). Science courses are based on fundamental mathematical concepts that must be perfectly mastered, so that students can focus on higher level disciplinary concepts (Uhden, Karam, Pietrocola & Pospiech, 2012; Blum & Leiß, 2007). However, the standard evaluation does not require learners to have a complete mastery of the content, since a 50% pass rate is usually all it takes to validate a course and move on to the next. Some students entering their first year at university make errors on middle school notions such as the manipulation of fractions, equations of order one or vector additions. To maximize their chances of success in all scientific fields, they must be able to manipulate the prerequisites quickly and without error in order to focus on what is new in their curriculum. Some universities have developed specific programs to sustain mathematical training aimed at different fields (Jackson, 2020).

In addition to the disciplinary content of the course, we know that some learning techniques are more efficient than others (Dunlosky, Rawson, Marsh, Nathan, Willingham, 2013). Spacing (Karpicke, Roediger, 2008) is one of the most efficient way of learning, and interleaved practice improves mathematics learning (Rohrer, Dedrick, Stershic, 2015). These learning techniques are also easy to implement in a curriculum. In order to support students with difficulties, one can decide to embed these techniques directly in the curriculum, to create a context where students naturally apply them without requiring any methodological competencies.

How does one build a program (i.e., content, order) that helps students mastering the necessary prior knowledge in mathematics when they enter a science curriculum in university?

What should be in such a program? How does one decide in which order to teach the different course concepts?

MATERIAL AND METHODS

The Institut Villebon - Georges Charpak is a public interest group that provides a three-year Bachelor program of Science and Technology. At the beginning of each academic year, about thirty-five students are recruited mainly on the basis of their motivation, giving priority to those who might have had disciplinary shortcomings in high school or obstacles to their success in university studies more related to social criteria. Precisely, out of our 105 students: 45% are women, 60% benefit from social grants, and 30% suffer from various disabilies. The program, which received funding from the French National Research Agency in 2012 through the "Initiative D'Excellence en Formations Innovantes" (Initiatives of Excellence in Innovative Training) program, uses active and personalized teaching methods to promote the success of these students. The teaching we designed was spread out over a semester for 35 students, with three sessions per week (two 1.5-hour sessions and one 2-hour session) and provided by two teachers (one maths teacher, one physics teacher), with a total of 60 teaching hours.

Within the framework of this action-research, the design of an upgrading program in mathematics for science at the university entrance is based on informal interactions between mathematics and physics teachers of the undergraduate program. Additionally, an interdisciplinary approach is taken whereby students are taught by both a mathematics and a physics teacher. The mathematical concepts that are necessary in physics and other scientific disciplines are not necessarily the same as those covered in a mathematics course designed to train mathematicians at a university level (Jackson, 2020): for this reason, an optimization of the program was made. The needs of other science courses have been taken into account in deciding the order in which the course concepts are addressed, either at the semester level or at the whole curriculum level.

In order to pinpoint the mathematical tools that have not been mastered, typical errors were identified thanks to previous student cohorts. Informal discussions with high school teachers and a dozen colleagues teaching science at a university level confirmed these observations. In order to measure the extent of students' initial shortcomings as well as their potential progress, a pre-test was administered to students at the beginning of their undergraduate studies. The initial positioning test consists of 3 middle school level questions, 2 sophomore year high school level questions, 2 junior year high school level questions and 10 senior year high school level questions. Here we present two examples of questions: “Calculate the value of the derivative $\frac{df}{dx}$ at x=1 as the function f is defined for all real x by $f(x) = x^2 - 1$” (Question 1), “We randomly choose 3 cards in a 32 cards game, what is the contrary event to "The three cards are kings"? (Question 2)”. The same test with the same questions was also taken twice by students in January (juste after the end of the course) and in June (at the end of the first year).

The resulting program has been organized in blocks (Figure 1). In order to decide of each block’s position, the teachers have worked within a 4 steps process:

1/ Within the disciplinary context (mathematics): Where are the dependencies between each notion ? What are the notions before and after this block? For example, while “elementary geometry” can be done before or after “introduction to functions”, “derivatives” has to be done before “integration”.

2/ Within the interdisciplinary context: Is this notion critical for physics? If it isn’t, on should postpone it as much as possible.

3/ Can one block of notion be postponed in order to create some spaced repetition and interleaved practice?

4/ Are the notions usually perceived as easy or hard by the student? Is it possible to avoid cumulating hard chapters in a row?

RESULTS/DISCUSSION

The initial positioning test shows the need to consolidate middle and high school learning in mathematics for most students. For example, only 54% of students succeed in Question 1 and 50% in Question 2. Other difficulties such a fraction simplification and vector manipulation have not been evaluated in this test but remain present. For example, 20% of the students think that.

Subsequently, 13 objectives were chosen: 2 based on middle school notions, 3 fully covered in high school, 5 deepening elements of high school and 3 novel notions at the undergrad level for the students.

Transfers were made from one year to the next: concepts that were not used by the other scientific disciplines in first year were postponed until second and third year, while those used in first year were integrated as early as possible into the mathematics program.

The resulting program [Figure 1] is divided in 13 blocks and does not resemble a traditional program: it is based on some middle school and high school notions which are traditionally not readdressed at university level. Additionally, it does not follow the usual sequential teaching path between the prerequisites and allows for feedback on blocks of skills in order to improve their acquisition [Figure 2].

The grading is designed to give students the opportunity to work on the evaluated concepts in depth. If a student makes an error in the validation of this block, they can make several attempts until complete success is achieved. The resulting automation of the task and the understanding of the basics, allow the student to adjust their functioning according to the task.

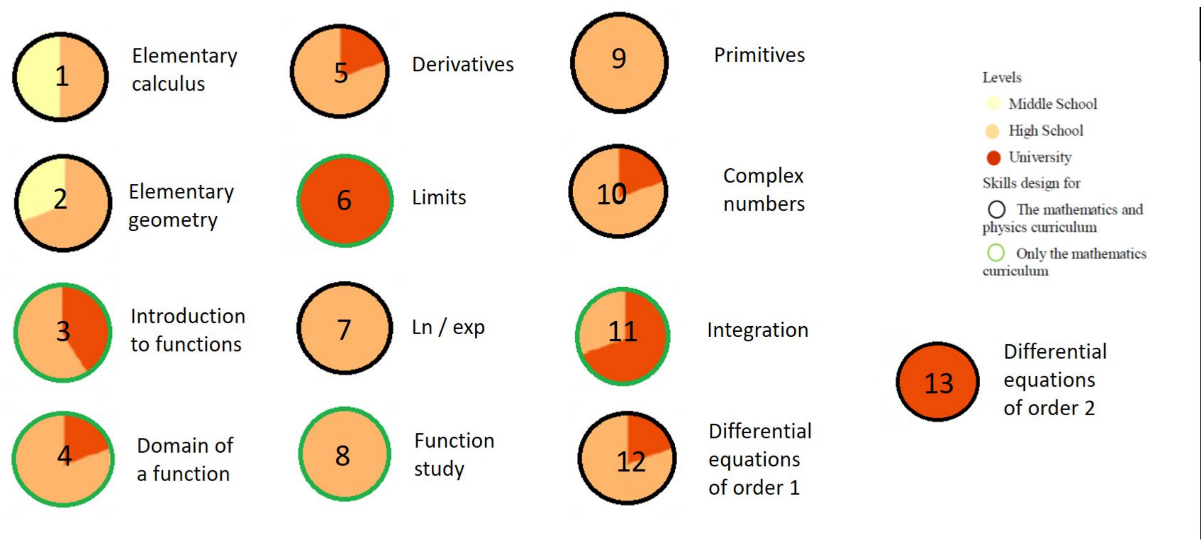

Figure 1. Program of the curriculum. The 13 blocks of skills: the colors indicate the level of the skill levels included in each target (middle school, high school, university level), The skills within a black circle serve as prerequisite for the physics curriculum.

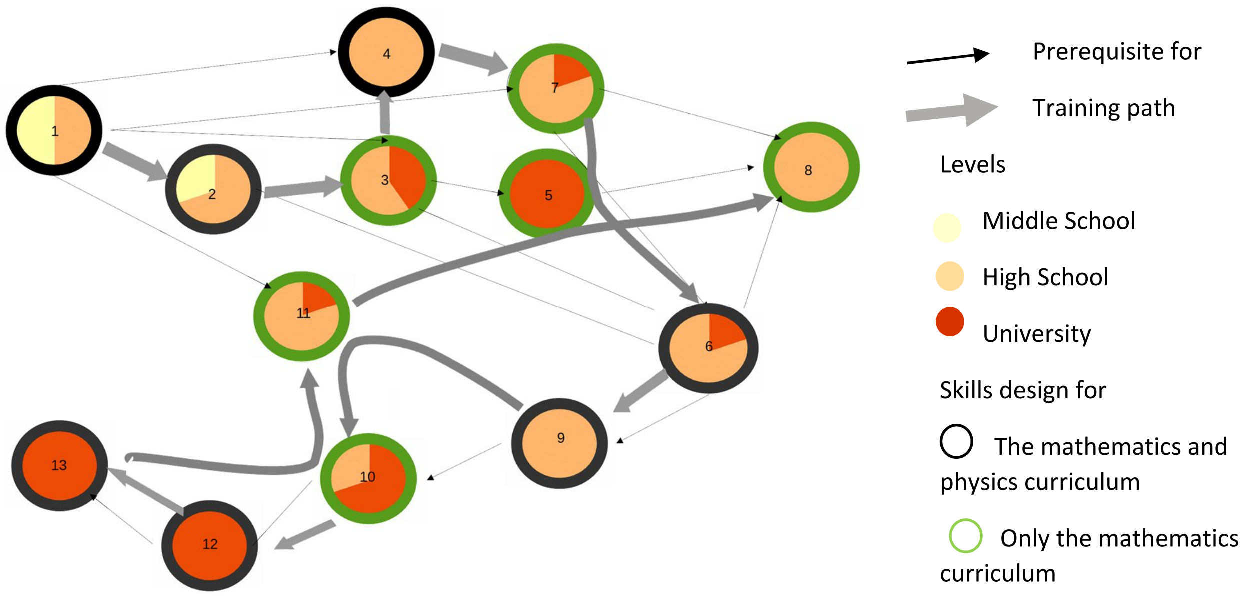

Figure 2. Organisation of the curriculum The 13 blocks of skills: the colors still indicate the level of the skill levels included in each target (middle school, high school, university level), the black thin arrows indicate the prerequisites, the grey thick broken arrow indicates the path of learning offered to the students. The skills within a black circle serve as prerequisite for the physics curriculum.

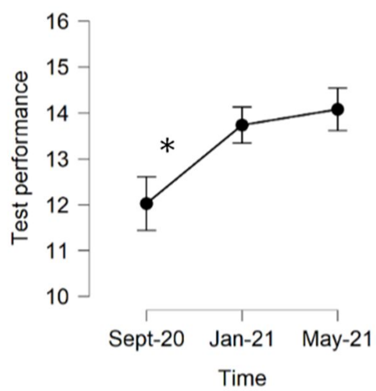

Figure 3. Evolution of the students performance in the positionning test. Significant progress is made during the dedicated semester. No loss 6 months later. No gain either

Regarding the positioning test, we observe a significant increase in the results between the first and the second test taken four months later in January [Figure 3]. This confirms the beneficial effects of the course on student learning.

CONCLUSION

An original refresher course in Mathematics for Science has been developed for students entering university. This course is different from the maths courses generally offered. It is based on our observations of the student's most common shortcomings, includes some notions from the middle school and high school curriculum and insists on the implementation of a great mastery of tools and automation of computational mathematical tasks. Although its effectiveness has not yet been fully tested, preliminary observations show some progress made by students. This program highlights the difficulties of organising the content of remedial courses that we believe is worth continuing to address, both within and outside of our teaching context.

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PROMOTION OF SELF-REGULATED LEARNING IN PEER TUTORIALS – INFLUENCE ON UNIVERSITY STUDENTS' USE OF LEARNING STRATEGIES IN BIOLOGY

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The transition to higher education involves institutional and individual challenges for first-year biology students, for example, modified learning environments. Introductory lectures in biology contain a high density of biological topics. With the complexity of biological content, it is assumed that the use of learning strategies plays a key role in studying biology. Therefore, we implemented peer tutoring for a lecture in biology with integrated learning strategy training. Recent research demonstrates the positive effects of tutorials on the students' use of learning skills. However, there are currently no investigations examining peer learning in the context of studying biology. In our study, we conducted tutor-based learning strategy training for first-year biology students to accompany an introductory biology lecture. In a pretest-posttest design, the influence of the implemented tutorial on the strategy use by 200 biology students ($M_{age} = 20.61 \pm 2.97$ *years; 64.5% female) was examined. A pretest and posttest comparison revealed that the tutor-based course fosters the use of almost all learning strategies (cognitive, metacognitive, and resource-based strategies). However, the biology students reported lower values for the scale elaboration in the posttest. In addition, we found significant differences regarding rehearsal, organisational, and time management strategies depending on how often the tutorials were attended. The tutorial with integrated learning strategy training could contribute to the increased use of learning strategies in biology education at the university level. Regarding challenges in the transition to university, peer learning could address higher periods of self-regulated learning.*

Keywords: self-regulated learning, higher education, peer tutorials

INTRODUCTION

The transition to higher education involves institutional and individual challenges for first-year biology students, for example, modified learning environments (Bosse & Trautwein, 2014; Streblow & Schiefele, 2006). As the university learning context could be described as more self-determined and complex, self-regulated learning and learning strategies play an essential role for university academic success (Bellhäuser, Lösch, Winter & Schmitz, 2016), particularly in biology (Binder, Waldeyer & Schmiemann, 2021; Richardson, Abraham & Bond, 2012; Sebesta & Speth, 2017; Shen, Li & Lee, 2018; Waldeyer, Fleischer, Wirth & Leutner, 2019). However, biology students have limited knowledge and ability to use these learning strategies (Sebesta & Speth, 2017). Therefore, peer tutoring settings with integrated learning strategy training have increasingly been implemented in higher education in recent years (Donker, de Boer, Kostons, Dignath van Ewijk & van der Werf, 2014; Hattie, Biggs & Purdie, 1996). According to Dörrenbach and Perels (2016) and Donker et al. (2014), tutorials with integrated learning strategy training could have a positive impact on students' use of learning strategies. However, to our knowledge, few investigations have implemented and examined peer learning settings in the context of studying biology. For this reason, we developed and conducted tutor-based learning strategy training for first-year biology students to accompany an introductory biology lecture.

THEORETICAL BACKGROUND

Transition from school to university

The transition from school to university involves modified institutional and learning conditions, for example, fewer interactive and structured courses (Bosse & Trautwein, 2014), a higher density of learning content (Bosse & Trautwein, 2014; Streblow & Schiefele, 2006), extensive module exams (Streblow & Schiefele, 2006), and less individual feedback (Bosse & Trautwein, 2014; Streblow & Schiefele, 2006). In the context of studying biology, significant amounts of varied learning content were covered in an introductory biology lecture. The high density and complexity of biology subjects often overwhelm biology students. Thus, the excessive demands on students could lead to an increase in university dropouts (Binder, Sandmann, Sures, Friege, Theyssen & Schmiemann, 2019; Loehr, Almarode, Tai & Sadler, 2012). While the university learning context can be described as more self-determined, it is also associated with a higher level of complexity. Therefore, self-regulated learning plays a vital role in studying any subject, particularly biology (Dresel et al., 2015; Shen et al., 2018).

Learning strategies in biology

Zimmerman and Schunk (2011) point out that learning strategies play an essential role in self-regulated learning. According to a classification by den Elzen-Rump, Wirth, and Leutner (2008), learning strategies can be categorised into *cognitive*, *metacognitive*, and *resource-based strategies*. Cognitive learning strategies can be divided into *rehearsal*, *organisational*, and *elaboration* strategies, whereas metacognitive learning strategies consist of *planning*, *monitoring*, and *regulation* strategies (den Elzen-Rump et al., 2008). Resource-based learning strategies include internal and external resources. While internal resources contain *time management*, *effort,* and *motivational strategies*, the *use of literature* and the *arrangement of the learning setting* are considered part of the external resources (den Elzen-Rump et al., 2008).

In the context of biology, various learning strategies could be relevant (Shen et al., 2018). Regarding the high density of biological content in introductory lectures *rehearsal strategies* (e.g. reviewing graded work) (Sebesta & Speth, 2017) could play an essential role. To plan, monitor, and regulate the learning process, *metacognitive learning strategies* such as self-explanations could be implemented (Sebesta & Speth, 2017). Furthermore, *time management strategies* (e.g. timelines, to-do lists) could be relevant for biology students to structure the extensive learning process over the course of the semester (Sebesta & Speth, 2017; Waldeyer et al., 2019). Considering the high complexity of biological topics (cf. Jördens, Asshoff, Kullmann & Hammann, 2016; Parker et al., 2012), *organisational* and *elaboration strategies* such as mind-maps, tables, and diagrams could be relevant (Fiorella & Mayer, 2016; Shen et al., 2018; Stokhof, de Vries, Bastiaens & Martens, 2020). Using these learning strategies could help understand and link different system levels of biological topics (e.g. ecosystems, organisms, organs, cells, cell organelles; Parker et al., 2012).

Learning strategies and learning success

The importance of learning strategies in the university learning context becomes clear in the relationship between learning strategies and academic success (Binder et al., 2021; Fleischer et al., 2019; Richardson et al., 2012). The results of interdisciplinary empirical studies have shown that *rehearsal strategies* predict success in simple learning approaches (e.g. multiple-choice exams), whereas *organisational* and *elaboration strategies* predict the performance in complex learning approaches (Souvignier & Gold, 2004). Furthermore, *effort* and *motivational regulation strategies* play a crucial role in explaining academic success (DeFreyter, Caers, Vigna & Berings, 2012; Kryshko, Fleischer, Waldeyer, Wirth & Leutner, 2020).

Investigations in the science context have indicated that *resource-based strategies* (time management and effort) have a positive effect on university learning success (Binder et al., 2021; Fleischer et al., 2019; Waldeyer et al., 2019). According to Sebesta and Speth (2017), *rehearsal strategies* (e.g. reviewing graded work) predict the academic achievement of biology students (Sebesta & Speth, 2017). In addition, *metacognitive strategies* have a positive impact on academic success (Sebesta & Speth, 2017). As learning strategies could be described as changeable variables, it could be assumed that learning strategy training can foster and support students' use of learning strategies (Sebesta & Speth, 2017).

Peer tutorials with integrated learning strategy training

Investigations regarding the implementation of learning strategies in higher education have become more important in recent years (Donker et al., 2014; Dörrenbach & Perels, 2016; Gutmann, Geiger & Seufert, 2014; Hattie et al., 1996; van der Beek, Bellhäuser, Karlen & Hertel, 2019). Various studies have indicated positive effects of learning strategy training on the students' application of *cognitive* (Donker et al., 2014; Dörrenbach & Perels, 2016; Gutmann et al., 2014; van der Beek et al., 2019), *metacognitive* (Donker et al., 2014; Gutmann et al., 2014), and *resource-based learning strategies* (Donker et al., 2014; Gutmann et al., 2014). In this case, various elements that are particularly effective in the acquisition of learning strategies became apparent. First, a direct link between the learning strategies and subject-specific content proved to be particularly effective (Masui & de Corte, 2005). Second, effective learning strategy training should be integrated into authentic task contexts (Dignath, Büttner & Langfeldt, 2008). In this way, the relevance of different learning strategies for the students can be shown, and the application of these learning strategies can therefore be promoted (Dignath et al., 2008; Masui & de Corte, 2005).

KEY OBJECTIVES

The university learning context requires a higher degree of self-regulation compared to school (Bellhäuser et al., 2016; Shen et al., 2018). Peer learning settings with integrated learning strategy training could provide effective support for students in addressing various challenges in the introductory phase at the university level (Donker et al., 2014; Dürrenbach & Perels, 2016). However, there are currently no studies assessing the influence of peer tutorials with integrated learning strategy training on the students' use of learning strategies in biology. Therefore, our research question can be formulated as follows:

Does peer tutoring with integrated learning strategy training foster biology students' use of learning strategies?

METHOD

Sample

Two hundred first-year biology students (M_{age} = 20.61 ± 2.97 years) participated in the current study, of which 64.5% were female. According to the participation in the tutorials, the biology students were divided into four study groups. The students who did not take part in the tutorial were divided into group I (*n* = 49). Group II includes biology students who attended the tutorial one to five times (*n* = 46), and those who participated between six and ten times were assigned to group III (*n* = 51). Group IV includes biology students who attended most of the tutorial dates (11 to 15 times) (*n* = 54). No significant differences regarding the sex of the biology students could be found between these four study groups ($\chi^2(3,178) = 2.29$, p = ns).

Test instrument

To investigate the biology students' use of learning strategies, the scales by Baumert, Heyn, and Köller (1992; *Kiel Learning Strategies Inventory*) were applied. The questionnaire consisted of seven subscales and used a five-point rating scale ranging from 0 (*strongly disagree*) to 4 (*strongly agree*). Table 1 below shows the numbers of items with examples for each subscale. To measure the internal consistency of the subscales, Cronbach's alpha was determined. These values were quite satisfactory for the pretest and posttest (Table 1).

Table 1. Sample items, number of subscale items, and Cronbach's alpha (α) values.

Subscale	Number of items	Sample items *When I study biology, …*	Pretest Cronbach's α	Posttest Cronbach's α
Rehearsal	5	… I practice by repeating the material to myself several times.	.82	.78
Organisation	10	… I write brief summaries of the main points.	.84	.79
Elaboration	12	… I try to link the content with previous experiences.	.91	.81
Planning	8	… I write a list of the important content and then learn them.	.78	.76
Monitoring	7	… I observe myself to be sure that I have understood what I have learned correctly.	.79	.74
Regulation	5	… I try to find out what I have not yet understood correctly.	.78	.78
Time management	3	… I determine certain times when I learn.	.64	.61

Test design

We conducted a pretest-posttest design. In the pretest, the students' use of learning strategies was assessed. Afterward, the biology students joined in the introductory lecture. This lecture contained basic biological principles and key concepts, for example in cell biology, biochemistry, and botany. During the semester, the students had also the opportunity to participate in a tutorial guided by biology students in higher semesters. In the posttest at the end of the semester, the scales to investigate the students' use of learning strategies were again applied (Figure 1).

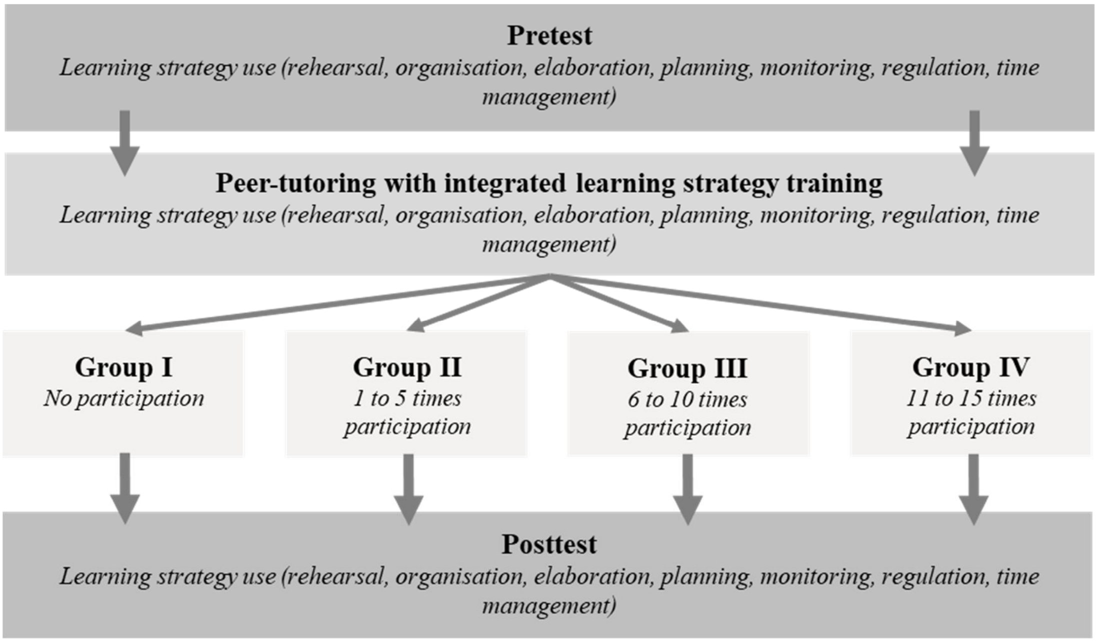

Figure 1. Pretest-posttest design of the current study.

Peer tutoring with an integrated learning strategy training

The weekly tutorials accompanying the introductory lecture lasted about 90 minutes and were guided by biology students in higher semesters. The implemented peer learning setting was divided into three phases.

The first phase of the tutorial included the repetition and presentation of the previous week's lecture content. The biology students were also allowed to address their perceived content-related difficulties and questions. In addition to the repetition of the lecture content, the first-year students were trained in learning strategies in the second phase. The learning strategies discussed in the training were based on the categorisation according to den Elzen-Rump et al. (2008) (*cognitive*, *metacognitive*, and *resource-based strategies*) and were adapted to the special biological topics of the lectures. Organisational strategies (e.g., creating summaries and mind maps) were presented to the biology students as cognitive strategies to use in preparation for the lectures (den Elzen-Rump et al., 2008). Regarding the immediate preparation for an examination, the tutors presented rehearsal strategies in particular (den Elzen-Rump et al., 2008). Metacognitive learning strategies were integrated into the tutorials by addressing planning and monitoring strategies (e.g., self-learning tasks and self-explanations) (den Elzen-Rump et al., 2008). Concerning long- and short-term exam preparation, resource-based strategies (e.g., time management, effort, and motivation management) were also covered in the peer tutorial (den Elzen-Rump et al., 2008). In the final, or practical, third phase, the biology students were permitted to actively work through the learning content in exercises.

RESULTS

In the following section, the results of analysis of variance (ANOVA) with repeated measures are presented.

Cognitive learning strategies

Regarding the students' use of *rehearsal* and *organisational strategies*, we found significant main effects of time with large effect sizes (*rehearsal:* $F(3,196) = 220.95$, $p = .000$, $\eta^2 = .53$; *organisation:* $F(3,196) = 227.84$, $p = .000$, $\eta^2 = .54$). The biology students reported higher values of these learning strategies in the posttest in comparison to the pretest. Furthermore, the ANOVAs with repeated measures revealed significant time *x* group interaction effects with middle effect sizes regarding the use of *rehearsal* and *organisational strategies* (*rehearsal:* $F(3,196) = 3.32$, $p = .021$, $\eta^2 = .05$; *organisation:* $F(3,196) = 2.78$, $p = .034$, $\eta^2 = .05$). Biology students who participated in the tutorial 11 to 15 times (group IV) reported the largest increase in the use of these learning strategies compared to students in groups I – III (Figure 2A and 2B).

Regarding *elaboration strategies*, the ANOVA with repeated measures showed a significant main effect of time with a large effect size ($F(3,196) = 251.70$, $p = .000$, $\eta^2 = .56$). In contrast with the use of rehearsal and organisational strategies, the students showed a lower use of elaboration strategies at the end of the semester (posttest). The ANOVA with repeated measures revealed no significant interaction effect ($F(3,196) = 2.11$, $p =$ ns) (Figure 2C).

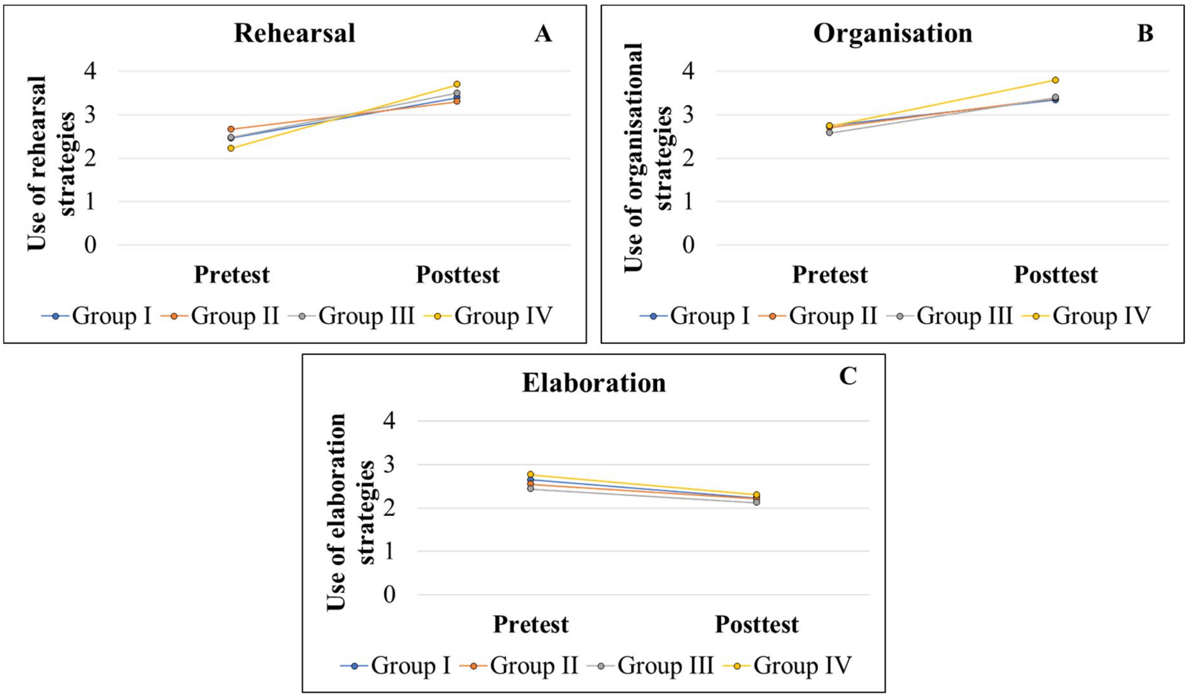

Figure 2. Results of the ANOVAs with repeated measures for *rehearsal* (A), *organisational* (B), and *elaboration* (C) strategies.

Metacognitive learning strategies

Regarding the use of metacognitive learning strategies, the ANOVA with repeated measures showed significant effects of time with large effect sizes. As shown in Figure 3, the biology students' reported a higher application of *planning* ($F(3,196) = 105.49$, $p = .000$, $\eta^2 = .35$), *monitoring* (F(3,196) = 351.78, p = .000, η^2 = .64), *regulation* (F(3,196) = 25.93, p = .000, η^2 = .12) strategies at the end of the semester. However, we found no significant group *x* time interaction effects comparing the use of these learning strategies by the biology students' in group I to IV (*planning*: F(3,196) = 0.34, p = ns; *monitoring*: F(3,196) = 0.91, p = ns; *regulation*: F(3,196) = 1.74, p = ns) (Figure 3A-C).

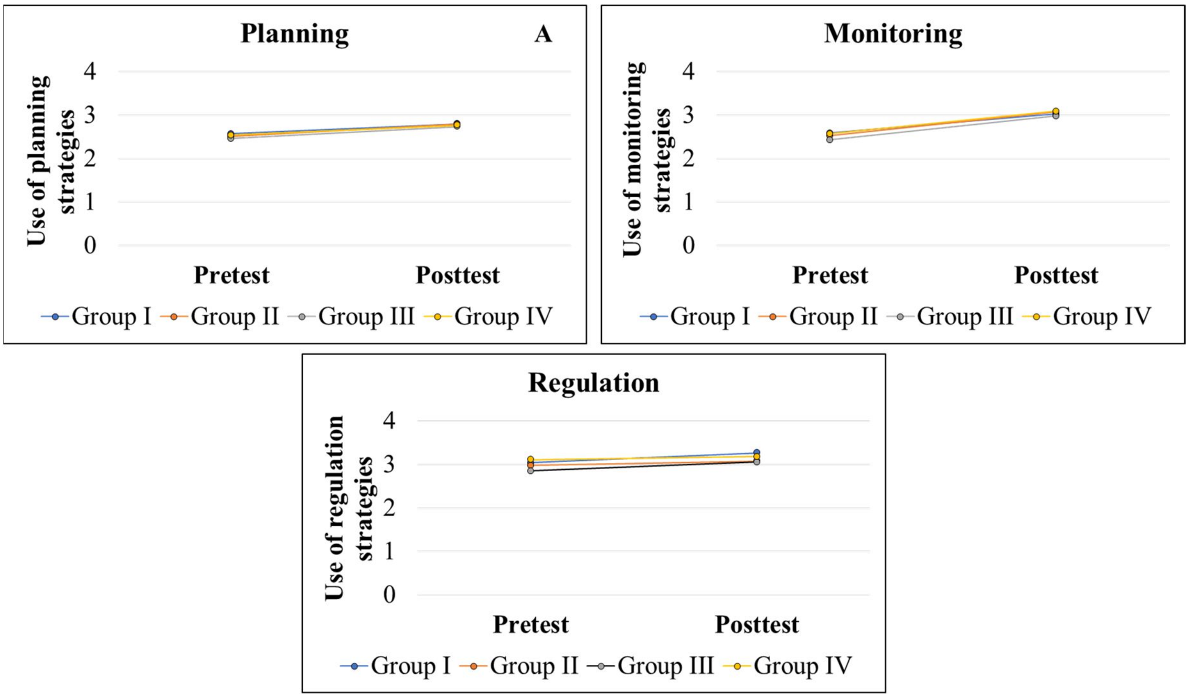

Figure 3. Results of the ANOVAs with repeated measures for *planning* (A), *monitoring* (B), and *regulation* (C) strategies.

Resource-based learning strategies

Regarding biology students' *time management*, the ANOVA with repeated measures revealed a significant main effect of time in a comparison of pretest and posttest with a large effect size (F(3,196) = 321.97, p = .000, η^2 = .62). The biology students reported higher use of time management strategies at the end of the semester. In a comparison of the four study groups, we found significant differences in the scale *time management* (time *x* group interaction effect with a medium effect size: F(3,196) = 23.47, p = .000, η^2 = .11) in favour of the biology students in group IV (Figure 4).

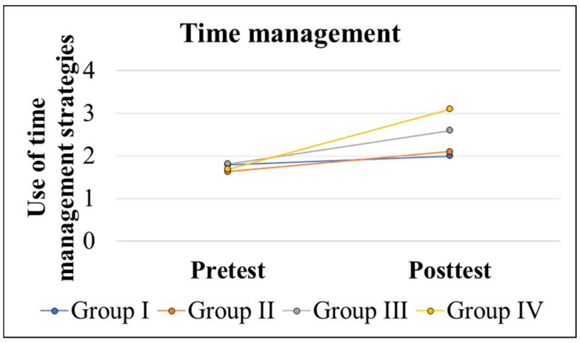

Figure 4. Results of the ANOVA with repeated measures for *time management* strategies.

DISCUSSION AND CONCLUSION

The biology students in all study groups showed higher use of *rehearsal*, *organisational*, *metacognitive*, and *time management strategies* at the end of the semester. The form of examination with a high proportion of reproduction tasks (e.g., multiple-choice) requires the use of rehearsal and organisational strategies (Sebesta & Speth, 2017; Shen et al., 2018; Souvignier & Gold, 2004; Stokhof et al., 2020), which could therefore explain these results. Furthermore, the high density of biological content in the introductory lecture could also explain the higher use of cognitive, metacognitive, and resource-based learning strategies (Richardson et al., 2012; Sebesta & Speth, 2017; Waldeyer et al., 2019). Regarding *elaboration strategies*, the biology students reported lower values in the posttest compared to the pretest. Due to a lack of knowledge about elaboration strategies in the introductory phase in university (Sebesta & Speth, 2017), biology students could overestimate their use of elaboration strategies at the beginning of the semester. The biology students could adequately assess their use of elaboration strategies only by addressing these learning strategies in the learning strategy training. Furthermore, the described type of test, which is largely composed of multiple-choice questions, could explain this trend. The use of elaboration strategies is only slightly required for this exam.

Comparing the four study groups, it becomes clear that regular participation in tutor-based learning strategy training in biological courses could contribute to an increased application of learning strategies. In the context of biology, peer tutoring fosters the use of relevant learning strategies in first-semester examinations (e.g., rehearsal, organisational, and time management strategies). These learning strategy trainings could face the various challenges in transition from school to university, in particular the higher periods of self-regulated learning in biology studies. Thus, our results are in line with previous investigations of Donker et al. (2014), Dörrenbach and Perels (2016), and van der Beek et al. (2019).

A limitation of the current study might be that the various learning strategies were assessed using a questionnaire, which measures the self-reported use of learning strategies. In future studies, qualitative methods such as thinking aloud protocols or learning journals could be implemented to measure students' learning strategies closer to the learning situation (Rogiers, Merchie & Van Keer, 2020). In this case, follow-up studies are needed for further clarification.

Overall, peer tutoring settings could foster the biology students' use of cognitive, metacognitive, and resource-based learning strategies. Therefore, tutorials with integrated learning strategy training could provide useful support for biology students facing various challenges in the transition from school to university.

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TEACHING MOLECULAR ORBITAL THEORY USING A CSCL APPROACH IN AN ENTRY-LEVEL UNIVERSITY COURSE

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In recent years, studies have indicated high dropout rates among chemistry students at university level. Since students enter university with very heterogeneous subject knowledge, a central challenge is to understand complex new topics such as the quantum physical description of chemical bonds. Thus, a digital-collaborative intervention was designed to foster chemistry students' learning of molecular orbital theory during the regular basic chemistry lecture in the first semester.

A first iteration of the intervention was implemented and evaluated in January 2021. There, the students first worked individually with a digital learning environment which consisted of interactive learning videos. In the second part, they worked together in small groups to create concept maps.

This paper presents and discusses the study design and results regarding the students' subject knowledge and personal variables. Beside the students' development across the intervention, a focus is laid on the question of how the design of learning materials in the individual work phase affects the students' subject knowledge growth.

Finally, modifications for a second implementation of the study are derived from the results.

Keywords: CSCL, tertiary education, quantum chemistry, Molecular Orbital theory

INTRODUCTION

The development of scientific knowledge can be understood as a process of building on existing ideas (Heeg et al., 2020; Vygotsky, 1978) through conceptual change (Roschelle, 1992) or conceptual growth (Greeno & van de Sande, 2007). The Computer-Supported Collaborative Learning (CSCL) framework utilises this socio-constructivist approach (Zurita & Nussbaum, 2004). At the product level, collaborative co-construction of new problem-solving knowledge has been shown to be a powerful tool when dealing with complex topics, such as highly interconnected content in STEM subjects (Science, Technology, Engineering and Mathematics, Kyndt et al., 2013; Roschelle & Teasley, 1995; Sung et al., 2017). However, there are still research gaps regarding effective collaboration at the process level (Sung et al., 2017). Particularly, questions have been raised about how individual work and collaboration can influence or even benefit each other (Olsen et al., 2019).

In the project presented, we focus on digital collaborative learning in the tertiary education sector. Here, studies show high dropout rates worldwide, especially in STEM subjects and particularly in mathematics, physics and chemistry (Chen, 2015; Heublein, 2014; Larsen, 2013; OECD, 2020). A study by the European Commission (Eurostat, 2018) identifies difficulties with the content of the university curriculum, along with unfulfilled expectations of studies as central reasons for discontinuing.

In chemistry, students enter the first semester with very different levels of prior knowledge, so that many of them have to revise the basics of the subject (Averbeck et al., 2018; Hailikari & Nevgi, 2010; Tai et al., 2005). Nevertheless, every single one of them also has to deal with challenging topics starting in the first semester. Central among these topics are theories of quantum chemical bonding such as valence bond (VB) and molecular orbital (MO) theory. These theories have proven to be particularly difficult for several reasons (Bouayad et al., 2014; Taber, 2002a, 2002b; Tsaparlis, 1997; Tsaparlis & Papaphotis, 2009): First, quantum physics is particularly abstract by nature. In addition, comprehending these theories requires a profound understanding of mathematical concepts in the fields of linear algebra and stochastics as well as basic knowledge of physics, for example regarding wave mechanics.

Nonetheless, a thorough knowledge of these theories is crucial for the understanding of modern advanced chemistry (Mulliken, 1970) and thus for the long-term academic success of any chemistry student. Following the Atoms First approach (Chitiyo et al., 2018; Zumdahl & Zumdahl, 2016), there are several arguments for teaching quantum chemical bonding theories as part of the introductory lecture. If central concepts are introduced early in the curriculum, it is easier for students to build on them in later semesters.

Research interest and research questions

To ensure that their academic career does not fail at the very beginning, many chemistry students need additional support to overcome the high content barriers at the beginning of their studies. Based on the aforementioned considerations, we have developed an intervention to help students acquiring important quantum physical concepts in molecular orbital theory, using the CSCL framework.

To date, few studies have investigated quantum physical or quantum chemical learning processes from a digital collaborative perspective (Bungum et al., 2015; Partanen, 2018). Hence, our aim is to examine the general learning efficacy of the intervention while addressing research gaps in the field of digitally supported collaborative processes, namely the reciprocal influence of individual and collaborative phases in a co-constructive learning process (Olsen et al., 2019; Sung et al., 2017). Overall, these considerations lead to the following research questions underlying the study:

Q1: What is the influence of person-specific characteristics of academic self-concept, self-efficacy, and gender on students' prior knowledge?

Q2: What effect does the digital collaborative learning unit have on the students' (a) subject knowledge and (b) academic self-concept?

Q3: How does the design of the materials in the individual work phase affect the students' (a) subject knowledge, (b) self-assessment, and assessment by others in a subsequent collaborative work phase?

RESEARCH DESIGN

In order to answer the research questions not only at the product but also at the process level, a mixed methods approach (Tashakkori & Teddlie, 2016) was chosen for the development of the research design. A first iteration of the study was conducted in January 2021 during the regular recitation groups (RG) of the basic chemistry lecture at a German university. N = 124 first-semester chemistry students participated in a total of four seminar sessions.

The seminar structure of this first iteration is shown in Figure 1. The intervention took place in two successive phases. In the first phase, students worked individually with a digital learning environment (DLE, Phase 1). In the second phase, students got together to create concept maps in small groups of three to five students each (Concept Mapping Process, CMP, phase 2).

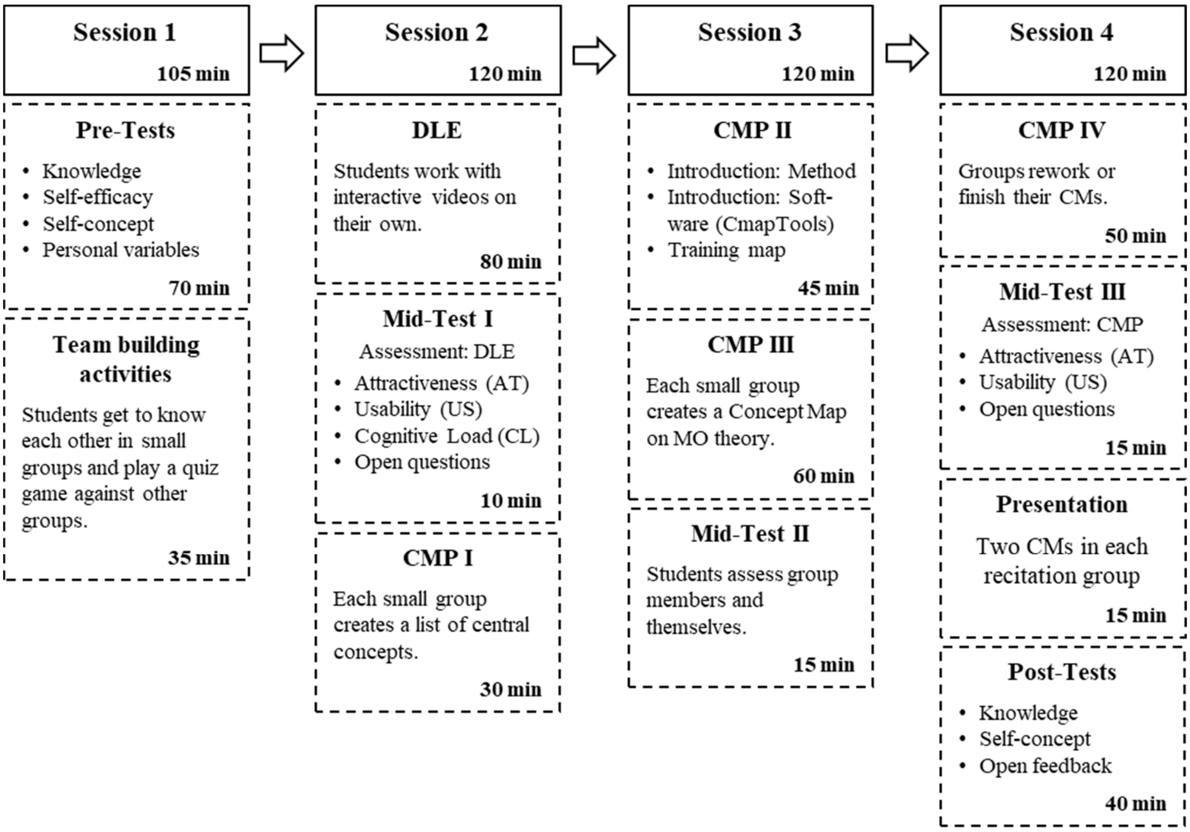

Figure 1. Seminar structure of the January 2021 intervention (CM = Concept Map; CMP = Concept Mapping Process; DLE = Digital Learning Environment).

Phase 1: Digital Learning Environment (DLE)

The DLE consisted of five learning videos. To promote active learning (Brame, 2016), the videos contained interactive elements such as mandatory single-choice questions or supplementary text boxes with additional explanations or information. At the content level, these videos gradually introduced the qualitative Linear Combination of Atomic Orbitals (LCAO) approach of MO theory. These basics were then extended through homo- to heteronuclear compounds. One contentual focus was on the quantum physical foundations of MO theory (Focus 1, F1), another on the application of the theory in the form of the construction and interpretation of MO diagrams (Focus 2, F2).

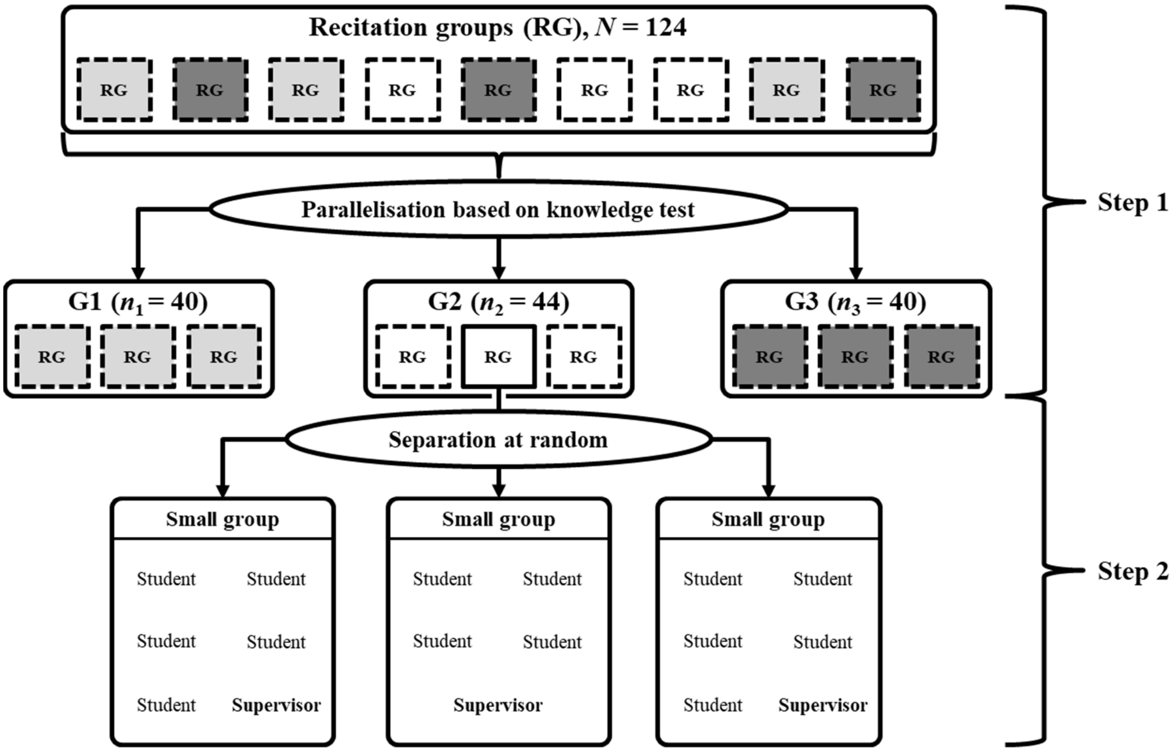

Figure 2. Separation of students from pre-assigned recitation groups (RG) into treatment groups G1-G3 (Step 1) and small groups (Step 2).

As shown in Figure 2, the students were divided into three treatment groups, G1 to G3, to investigate research questions Q2 and Q3. The three groups were parallelised based on the results of the subject knowledge pretest from the first seminar session (cf. Figure 1) in step 1, so that there were no significant differences between any two of the three treatment groups. Throughout the intervention, the students remained in the same recitation groups. In step 2, students within each recitation group were randomly divided into small groups of 3-5 students, each with their individual supervisor.

Table 1 illustrates the three different types of learning videos that students worked with in the three treatment groups: All students in G1 and G2 watched identical videos covering both quantum physical foundations of MO theory (Focus 1, F1) and the construction and interpretation of MO diagrams (Focus 2, F2). Within their respective small groups, the students in G3 were split up: Half of each small group watches videos on F1 only, the other half watches videos on F2 only.

In terms of interactions, the students in group G1 again all work with identical interactive elements. However, the interactive elements differ for students in group G2 and G3. Half of each small group works on interactive tasks for F1, the other half for F2.

Table 1. Explanation of the three different treatment groups G1 to G3 (F1 = Focus 1, quantum physical foundations of MO theory; F2 = Focus 2, application of MO theory).

	G1 ($n_1 = 40$)	G2 ($n_2 = 44$)	G3 ($n_3 = 40$)
Video content	Each group member watches videos containing F1 and F2 ("identical videos").	Each group member watches videos containing F1 and F2 ("identical videos").	Half of the group members watch videos containing F1, the other half watches videos containing F2 ("different videos").
Interactive elements	Each group member works with interactions on F1 and F2 ("identical interactions").	Half of the group members work with interactions on F1, the other half on F2 ("different interactions").	Half of the group members work with interactions on F1, the other half on F2 ("different interactions").

Phase 2: Concept Mapping Process (CMP)

Following the DLE, students worked in small groups to create concept maps together. For this, they compiled, clarified, and discussed a list of about 20 concepts that they considered essential to MO theory. After a short introduction to the method and the software, each small group created a concept map on MO theory using the software '(CmapTools)'. Based on individual formative group feedback, each group was able to revise their maps before some presented their maps to their recitation groups.

Research Instruments

To answer the research questions Q1, Q2a and Q3a related to subject knowledge, we developed a knowledge test which contained 33 closed single choice questions (Knowledge closed, KC, $\alpha_{KC} = .860$) and 7 open-ended questions (Knowledge open, KO, $\alpha_{KO} = .635$). The latter were scored using a low inferential coding manual.

Concerning research questions Q1 and Q2b, students' academic self-concept (Dickhäuser, 2005) and self-perceived self-efficacy (Abele & Spurk, 2009) were assessed by questionnaires.

For each quantitative instrument, Cronbach's α was measured as a means of internal consistency, with overall satisfactory results above the threshold of .700 (Cortina, 1993).

With regard to research question Q3b, we employed additional questionnaires (Brüning & Saum, 2009), in which students assessed both themselves and their group members.

In addition, highly inferential coding manuals are currently being developed for the analysis of the students' concept maps and for screen and audio recordings of the collaborative work phases.

RESULTS

Table 2 shows that the students' prior knowledge correlates significantly with all the personal characteristics surveyed. Weak correlations were measured with self-efficacy and the individual self-concept, medium correlations with the critical, social, and general self-concept. Combining all four subscales of the academic self-concept, a medium correlation with pre-subject knowledge can likewise be observed ($p < .001$, $r_S = .393$). With regard to gender, no significant differences could be measured between the prior knowledge or subject knowledge growth of male and female students.

Table 2. Spearman-correlation r_S of knowledge pre-test results and person-specific variables.

Variable	Example item	*p*	r_S	α
Self-efficacy	„I know exactly that I can fulfil the requirements set for my chemistry studies if I only want to."	.002	.276	.731
Criterial self-concept	"Compared to the requirements of studying chemistry, I find it easy to learn new things."	< .001	.307	.820
Individual self-concept	"When I look at my development over the time I studied chemistry, I find it easier to learn new things now than before."	.011	.229	.822
Social self-concept	"I think I am more talented for my chemistry studies than my fellow students."	< .001	.432	.872
General self-concept	"Learning new things in chemistry studies is easy for me."	< .001	.313	.756

In the evaluation of the knowledge test (Q2a), five closed ice breaker items were removed from the analysis, as they could be answered correctly by more than 80% of the students in the pretest. For the remaining questions, students in all groups were able to significantly improve their content knowledge during the intervention with a medium effect (result relative to total score: $M_{PRE} = .54$, $M_{POS} = .67$, $p < .001$, Cohen's $d = .597$). The high mean value in the pre-tests can be explained by the fact that the students already start the intervention with prior knowledge, as the topic of MO theory is taught beforehand in the corresponding lecture. Neither in the students' academic self-concept (Q2b) nor the open-ended questions (Q2a) could significant differences be measured over the course of the intervention. The latter can be explained by the fact that four of the seven open-ended knowledge questions asked for definitions of fundamental technical terms such as orbitals, the Pauli exclusion principle or Hund's rules, two of which were already answered correctly by over 75% of the students in the pre-test. The remaining three questions alone may not have been sufficient to measure truly significant effects. In any case, an adjustment of the question format seems necessary here.

Furthermore, a comparison of residuals revealed no significant differences between the three treatment groups G1 to G3 in terms of content knowledge (Q3a).

With regard to students' self- and peer-assessments (Q3b), it was found that group members' assessments were often significantly better than self-assessments, even when students complained about passive group members in the open-ended feedback questions on the CMP. This social desirability bias (Bogner & Landrock, 2016) occurred despite the anonymisation of the responses and can be attributed to the low group size of 3-5 students each, since both the self-feedback and the feedback from the group members were sent to the respective students.

SUMMARY AND OUTLOOK

Subject of this study is to develop and evaluate an intervention that helps students to acquire central quantum chemical concepts of MO theory. As the students participating in the first iteration of the study were able to significantly improve their subject knowledge regarding the closed-ended questions and gave very positive feedback throughout the study, we can conclude that the chosen digital-collaborative approach has proven itself to be viable. Nevertheless, questions remain regarding the collaborative process analysis which need to be addressed with the help of the coding manuals under development. We hope that an in-depth analysis of the concept maps, video and audio recordings will allow us to better understand the learning process, i. e. to find critical leverage points to further facilitate student learning.

Additionally, changes for future iterations of the study can be derived: First, the intervention needs to be extended to 5 dates instead of 4 in order to alleviate the time constraints reported by the students. To facilitate the creation of the concept maps, students will first have to create a glossary.

Secondly, the subject knowledge test will also be revised, since some students entered the study with comparatively high prior knowledge due to their attendance of the lecture in which MO theory was taught. Considering the observed ceiling effects in the subject knowledge test, the too easy items were replaced by more difficult ones. In addition, the open-ended question formats were adjusted to get a better insight into the students' ideas and concepts. In order to better understand the cognitive prerequisites with which students enter the collaborative process and how much they already learn through the learning videos, we will conduct an additional knowledge test directly after the digital learning environment.

To test whether students learn through concept mapping in general or collaborative concept mapping in particular, we will make changes to the design of the comparison groups: While groups G1 (each member of each small group watches the same interactive videos with the same interactive elements) and G3 (members of each group work with different interactive videos) remain, group G2 is replaced by a group in which students create concept maps individually after watching interactive videos in the digital learning environment.

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FROM SCRATCH TO HATCH: DESIGNING AN EVIDENCE-BASED ENTIRE SEMESTER FOR OPTICAL ENGINEERING STUDENTS

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Evidence-based approaches in teaching and learning provide strategies to empower student learning and long-term retention of knowledge. Such strategies can be implemented at the course level by a single teacher, which then happens at a smaller scale. However, a more powerful approach consists in a coherent integration of neuroeducational principles in the entire structure of a term, involving several courses over several months. This represents an educational change at a higher scale, however facing several risks in its in-practice implementation, such as faculty reluctance and resource insufficiency. We report here on the design of a whole academic term for optical engineering students in dual education at the Bachelor level. It was devised in order to maximize retention effects through a coherent and coordinated use of constructive alignment in course design, active learning activities, metacognition course, and spaced learning. The design process is encompassed within a SoTL (Scholarship of Teaching and Learning) methodology cycle. It involved a total of 12 faculty members, led by a core group of six, trained by educational advisors in neurodidactics, and tasked with the global design, planning and management of the project. At the pre-roll out stage, this work delivered collectively elaborated timetables, syllabus, balanced student workloads, and plans for team teaching and shared educational tasks.

Keywords: Evidence-Based Approaches, Higher Education, STEM Education

INTRODUCTION

Long term retention of knowledge and skills is a good indicator of the efficiency of many teaching activities and pedagogical approaches, common to almost any field at any educational level. It is a solid criterion: indeed, deep learning is often a prerequisite to favor fast and efficient retrieval of previously learned material. Nevertheless, teachers reporting students having trouble with retrieval and retention of learning outcomes is a widespread experience – a serious challenge for students expected to review and master an ever-growing amount of material.

Recent references in the field of evidence-based approaches to teaching and learning, as well as neuroeducation and cognitive psychology, provide recommendations for the design of courses and curricula (Masson, 2020; Latimier, 2019). Course design guides have also been made available, but their in-practice implementation is usually rather poorly documented (Roediger & Pyc, 2012), and noteworthily, is mostly exemplified by smaller scales approaches, at course levels. Besides, neuro educational principles are sparsely used across disciplines and institutions. The pursued research objective was to *develop a research-based academic term at the Institut d'Optique Graduate School (IOGS), a French engineering school specialized in optics & photonics*.

150 new students are enlisted at the IOGS each year. They follow a 3-year track (6 terms), starting at the senior year of undergraduate studies and graduating with a French "Diplôme d'Ingénieur", comparable to a Master of Science in optical engineering (see Figure 1.). The scientific training at IOGS is highly specialized in optics & photonics. It involves a significant fraction of fundamental physics courses, complemented with pratical training during labwork sessions. Around 35% of all students at IOGS decide to complete their MSc in optical engineering with a PhD track.

The current teaching approach at IOGS follows the path most frequently encountered in the French higher-education system: the different courses combine a significant amount of formal lectures delivered to the whole cohort of 150 students, followed by several tutorial sessions in smaller groups, typically between 25 and 30 students. Evaluations consist generally in one final written exam. In their curriculum at IOGS, the students have a heavy experimental labwork sessions program, with weekly reports to handle back.

This study focuses more closely on a cohort of 25 students registered in dual-education. Over the course of these 3 years, students in dual-education spend 50% of their time working in a company, and 50% of their time studying at IOGS following the same courses as other students. Students in dual-ed display no specific differences in their professional future compared to other students of the school, as assessed by post-graduation surveys.

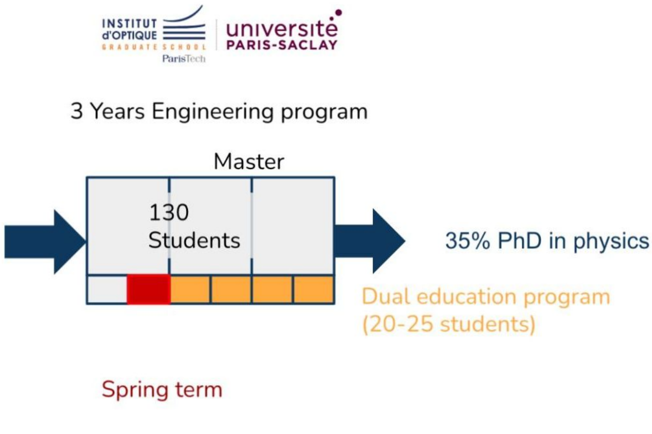

Figure 1. Structure of the Engineering program at IOGS.

This paper reports about the redesign of the second term of a 6 terms academic program for a subset of 25 students among a total of 150 students, it is expected to provide an enhancement of the retention of knowledge acquired during this term over the second and third term of the programme) for these 25 students compared to the remaining 125 students still working with "traditional" lecturing system.

In this paper, we report about the carried design process of the second term of the first year of the engineering track at IOGS, for these dual-ed students. This term is based on seven scientific courses (Polarization, Semiconductor Physics, Electromagnetism, Scientific Computing, Signal processing, Labwork in Optics, Laser Physics). We report about the pedagogically renovated term that resulted from it. The term was conceived in order to maximize long-term retention of knowledge and skills acquired by undergraduate students and expected to provide, in comparison to the traditional "lecturing" system, a solid ground for students to master new material along their entire curricula. This process was based on the implementation of four different strategies, thought as *design rules* for this term: *constructive alignment of courses*, *active learning activities*, *timetable management respectful of spaced learning*, and *metacognition* related activities.

THEORETICAL CONCEPTS

Constructive alignment is a method that aims at building coherence between intended learning outcomes, assessments and learning activities (Biggs & Tang, 2011). It favors deep learning in contrast to surface learning (Ramsden, 2005). It also enables us to quantify and evaluate teaching strategies efficiency.

Active learning practices refer to a variety of activities, such as problem-based approaches, favoring students' cognitive involvement in their own learning process, and enhancing their global performance.

Spaced practice and interleaving are key enablers to long term retention of knowledge and skills, in contrast to massed uninterrupted practice (Latimier, 2019).

Metacognition is about making students aware of their own thought and memorization processes, and to provide strategies to regulate and improve their cognition. Such awareness can improve students' engagement and performances (Sarrasin et al., 2018).

METHODS

The redesign of the whole term involves 13 faculty members of the IOGS, in charge of the 7 scientific courses. We describe here the workforce organization. The *design-based research process* was carried out by a "core" leading team of six teachers (professors), among the whole group of 13 involved in the redesign of the term. For each of the seven scientific courses, a team of two faculty members, including one member of the core team, was formed, and designated in charge of the specific redesign tasks for the course.

Over the course of the project, the core team members interacted with experts in higher-education pedagogy from the Université du Québec à Montréal (UQAM) as participants to an action-research process supervised by the university's department for innovative pedagogy (Research Action Chair on Educational Innovation at Université Paris-Saclay) (See Fig. 2). The design-based process was inspired by the six-step SoTL (*Scholarship of Learning and Teaching*) methodology cycle proposed by Bélisle et al. (2008).

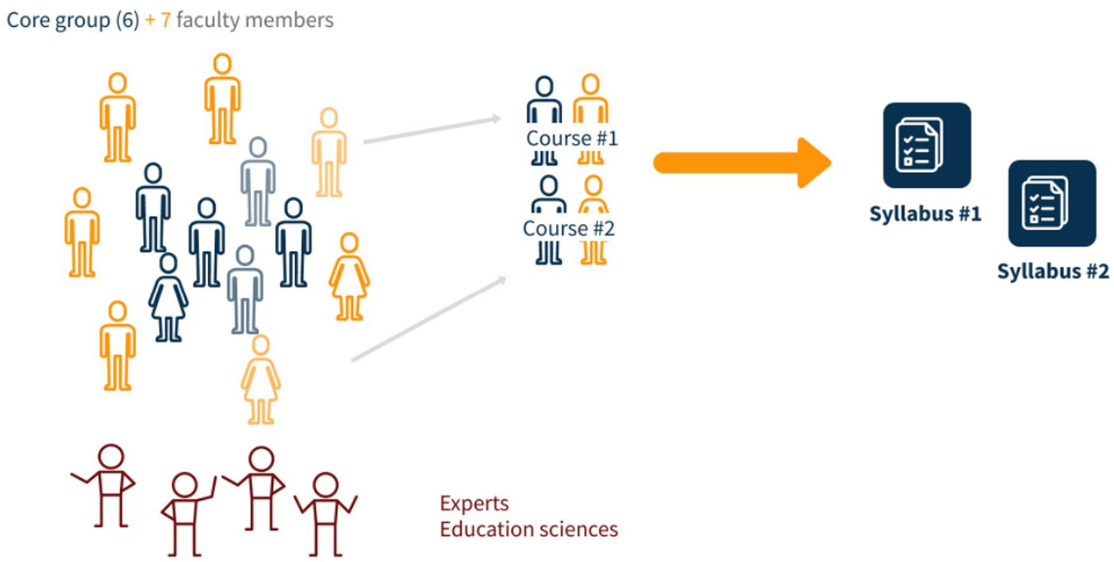

Figure 2. Workforce organization.

The design process involves a group of higher-ed experts training a subset of 6 teachers (the "core" team) among the 13 faculty in charge of the scientific courses taught during the term. Each of course is re-designed by a team of 2 faculty, one of them from the core team.

The project was initiated during a one-week kickoff workshop of the action-research programme in December 2019. The core team got trained on neuro didactic principles and active learning activities by the experts. During this first week, the core team wrote a first draft of the project, clarifying the different design rules to be followed in the redesign process (constructive alignment, spaced learning, metacognition, active learning). Supervised bibliographic works were collectively carried out to further dig the concepts and the methodology to be implemented in the design process.

After this initial training stage, the core team regularly regrouped with the rest of the educational team in order to propose a unified perspective on the project that would allow the coherent implementation of the four pillars of the project, as well as to set a recurring framework for all faculty to continuously progress in the re-design process of their own course (see Transfer/Harmonization step in Table 1) The core team organized a series of meeting for this step, based on feedback discussion of the initial workshop session, discussion of scientific articles and peer instruction during activities, such as the redaction of learning outcomes.

In parallel, the members of the core team took in charge project management tasks. A shared online space was created to store all documents related to the project, such as minutes of meetings, reports, bibliography, timetables, and all digital resources. All resources were accessible to all faculty and experts involved in the project. A shared logbook was also created, keeping track of the different milestones of the project, date after date.

Other resources listed as "tools" were created by the core team, in order to ensure as much as possible the harmonization of practices and the compliance to design rules during the design process. First, a syllabus template was redacted. This template was written to be in adequation with constructive alignment principle. It was provided to all faculty, in order to gather for each of the 7 scientific courses the learning outcomes, the evaluation principles and the planned teaching activities. A catalog of learning activities in an active teaching perspective was also provided. The redacted syllabus were later collected and made available to all teachers. Secondly, a provisional timetable was shared in order to provide an overview of student assessment activities and of the global student workload. Faculty were asked to list their planned activities including the assessment activities and to estimate the time that students will spend of each task. This shared document was used to iteratively design a timetables and tasks to avoid brief work overloads, but also to synchronize the progress of several courses. For example, some notions related to light propagation in matter are present in both the Electromagnetism course and Polarization course learning outcomes. Connections between courses could be established more easily after discussions and interactions based on the respective syllabus and retroplanning of both courses.

Finally, the adequation of the proposed design with all four pillars was discussed during regular consensus meetings or with experts. These meetings serve as validation steps of the design process. The different steps of this elaboration process (adapted from Bélisle et al. (2018) are presented in Table 1 along the four axes of the project.

In practice, this workforce organization was based on regular interactions between higher-education experts and the core team for training and feedback purposes on one hand, and interactions between the core team and other faculty for peer instruction, harmonization of practices and actual implementation of the design rules on the other hand. During the design process, around 30 meetings were set over the course of a year, between December 2019 and the official start of the term in February 2021.Strategies of pre- and post-testing of students along the implementation of the project were designed to monitor the performances of the reference student cohort experiencing the "traditional" lecturing approach of teaching.

Table 1. A summary of methodological steps taken in the design process.

<table>
<tr><th></th><th>Initial training</th><th colspan="2">Transfer/ harmonization</th><th>Tools & methods</th><th>Validation</th></tr>
<tr><td>Constructive alignment</td><td rowspan="3">Training by experts (seminars, coaching during the action research process)
Supervised bibliographic search</td><td rowspan="4">Consensus meetings

Journal clubs

Peer instruction

Feedback about the experience</td><td>N/A</td><td>Work by pairs – syllabus redaction</td><td>Consensus meeting</td></tr>
<tr><td>Active learning</td><td>2-days training</td><td>Activity catalog</td><td>Consensus meeting</td></tr>
<tr><td>Spaced learning / interleaving</td><td>N/A</td><td>Timetables</td><td>Consensus meeting</td></tr>
<tr><td>Metacognition</td><td>Bibliographic search</td><td>N/A</td><td>Feedback from experts and peers</td><td>Feedback from experts and peers</td></tr>
</table>

Several points are to be noted with our methodology. While the scientific perspective of building a system dedicated to the improvement of long-term retention of knowledge is at the heart of the design process, the implementation of a change in pedagogical practices was also strongly motivated by the need to comply to new requirements established by the institution certifying the French Diplôme d'Ingénieur. THis created a concrete sense of urgency, and a need and energy for a curricular change shared among faculty, therefore significantly different from change implementation based on more individual initiatives at the individual course level.

In many aspects, our methodology follows the first steps of the Kotter's change model in the context of engineering education reform by Froyd et al.

RESULTS

The academic term involved seven physics related courses (*Electromagnetism*, *Polarization*, *Semiconductor Physics*, *Laser*, *Scientific computing*, *Signal processing*, *Labwork sessions*) along with metacognition workshops and foreign languages, for a total of 210 hours of in-class presence.

The following paragraphs briefly describe the training formats that were developed at the end of the development cycle:

Spacing/interleaving. Students worked in a dual-education program and shared their presence time between campus and companies. The semester was globally restructured, so that students alternated between three week periods of on-campus work and three week periods of internship time. During campus time, weeks were divided into time slots so that each course was delivered during two 90 minutes time slots on different weekdays (See Fig. 3). This organization results from logistical constraints discussed during consensus meetings, such as teaching or research duties of faculty members.

Figure 3. Timetable and semester schedule.

The spring term of the dual education program lasts 19 weeks, including 9 weeks of full-time internship. Considering the sleep agenda of the students, courses start late in the morning during the weeks of attendance at school.

Constructive alignment. Teachers worked similarly to a think-pair-share scheme, working in pairs of disciplines to share experience and personal research on the topic. All teachers were asked to fill in a descriptive form of their strategy, detailing their intended learning outcomes, assessments tasks and learning activities. Validation of the forms were carried out during consensus meetings and formed a basis for syllabus. This work enabled also to evaluate the students' workload during the semester, to envision synchronization of courses between disciplines and a better repartition of intended learning outcomes (avoiding unnecessary repetition across different courses, sharing same vocabulary, notations, identifying student misconceptions).

Active learning. All courses have introduced active learning activities as part of their teaching strategy. For example, the Electromagnetism course was delivered in a flipped-classroom format. The Laser physics and Semiconductor physics courses introduced case studies and problem based learning activities, etc. Some of the activities also included formal or informal assessments, providing opportunities to give students feedback more regularly along the term.

Metacognition. Weekly metacognition workshops were part of the students' schedule. Sessions focused on a description of cognitive and brain processes and their connection to learning practices, as well as their perceived effectiveness. (See Fig 4.)

Figure 4. Themes addressed during the metacognition workshops.

While not explicitly put in the initial objectives of the projects, additional dimensions arose during the design process: implementation of regular assessment and self-assessment tasks to the students (and related discussion on the repartition of in-class and at-home workload of the students); the time of the first lesson in the morning was set at 9:30 am, 30 minutes later than usual, as an effort to take into account the students sleep time.

This new design was implemented for the first time in February 2021 for a first cohort of students. Evaluation of the courses by the students was carried out to get feedback from the student's perspective through an online survey at the end of the term. A vast majority of students showed highly enthusiastic and positive about the general perspective of being part of an educational change strategy, and expressed a significant interest and satisfaction with the new teaching strategies, in contrast with their previous experience with traditional lecturing. Interestingly, as this cohort was affected by the pandemic, remote teaching was also introduced, but incorporating remote active learning strategies. While students of the reference cohort in contact with "remote traditional lecturing" reported a very low satisfaction rate, we observed a marked contrast with the studied cohort, displaying a satisfaction rate for the "remote active learning" activities in par with physical class.

In parallel assessment of student performances revealed no specific difference, neither positive or negative between students from the reference cohort and students under the revised term. A series of tests are introduced for the rest of their curriculum in order to evaluate the possible effect of this new term on long-term retention.

CONCLUSION

In this paper, we reported about the design of a whole academic term trying to maximize the outputs of a coherent use of spaced practice and interleaving, course design based on constructive alignment, use of active learning practices and awareness of students to metacognition aspects. This project was led at an intermediate scale, involving 13 teachers leading 7 courses, overcoming limitations of a single course implementation of similar strategies. The design was carried out using a team organization based on a core group of six teachers in charge of the global project management, interacting with experts and getting trained on the key aspects of the envisioned pedagogical practices, and then working with the rest of the group to share experience, provide resources and tools and validate elaboration steps during consensus meetings. The impact of the semester on the long term retention of knowledge and skills by students will be monitored during the rest of their time on campus, thanks to a pre-test post-test strategy for which the results will be used to adjust the educational change strategy.

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TEACHING PHOTOELECTRIC EFFECT WITH PHOTOVOLTAIC CELLS USE IN THE PHYSICS LABORATORY

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The photoelectric effect is an important phenomenon in the teaching of Modern and Contemporary Physics in Engineering, as it allows contextualizing science teaching in technological applications associated with the emission and transformation of light. Our research question is: "Can photovoltaic cells be used in the physics lab to teach engineering students the photoelectric effect?" The literature suggests photovoltaic technology, driven by the STEM movement (Science, Technology, Engineering, Mathematics) to teach the photoelectric effect in Engineering. An experiment was structured using a photovoltaic panel for didactic use at night, with artificial lighting, using different types of lamps. We applied the experiment in the classroom using pre and post-tests and an interview. The results of this experiment showed that after using photovoltaic cells it was possible to verify that students correctly correlate the photoelectric effect with the frequency of incident radiation and no longer with the intensity of light. The application of didactic methodology within the scope of Engineering courses also contributed to the integration of teaching, research, and extension in the community, in addition to allowing the student to reflect on the social changes resulting from scientific and technological evolution can contribute to sustainability and changes social and environmental.

Keywords: Photoelectric effect, photovoltaic technology, STEM

INTRODUCTION

By using the photoelectric effect when teaching science in Engineering courses, it is possible to contextualize the teaching of Physics in technological applications. The teacher can associate the concept of emission and transformation of light with different technological applications such as sensors, diodes, lasers, semiconductors, especially when it comes to artificial lighting and sustainability electrical. Bibliographic research has shown that the use of a didactic experiment in photoelectric effects is limited and the experiments are complex for use in education (Reis & Serrano, 2017). Klassen, Niaz, Metz, McMillan, & Dietrich (2012) point out that the experimental work on the photoelectric effect started to be used after the development of solid-state electronic technology, around 1960, with the overcoming of technical difficulties.

Among the applications, photovoltaic technology was boosted due to the negotiations agreed in the Kyoto protocol (2008 to 2012), for reducing greenhouse gases emission (Sark, 2007). With the use of photovoltaic cells in physics classes, it is possible to explore, in a contextualized way, the principle of the photoelectric effect in the transformation of light into electric current. It also makes it possible to explore with students the use of current, voltage (IV), generation power (Boitier & Cressault, 2011; Morgan et al., 1994), and quantum efficiency in the transformation of light (Kraftmakher, 2008).

Especially with engineering students, the technology was applied to evaluate the efficiency of the silicon cell in converting light into energy when exposed to dust in the desert (Molki, 2010). Subsequently, Dark (2011) presents the photovoltaic modules in STEM (Science, Technology, Engineering, Mathematics) courses, to develop quantitative analysis and scientific communication skills, in addition to increasing students' interest in Physics. By observing that the current and voltage decrease as the temperature in the silicon photovoltaic cells increases, using mathematical abilities when performing data collection and analysis, considering uncertainties or in the conversion of units when presenting in scientific articles, it is possible to awaken interest in a career in science and engineering. This application can also contribute to the teaching of silicon-based electronics (Gfroerer, 2013), semiconductor operation (Jenkins, 2005). In these materials, the photoelectric effect on silicon cells behaves as an insulator until there is an external energy source, such as sunlight, capable of 'boosting' its electrons from the valence band to the conduction band, making current-carriers (Richards & Etkina, 2013).

Therefore, this work sought to answer the research question: "How can photovoltaic cells be used in a physics laboratory to teach engineering students the photoelectric effect?"

ASSEMBLY, VALIDATION AND EXECUTION OF THE EXPERIMENT

Assembly of the experiment

The university's Physics laboratory has an experimental kit with a 5Watt photovoltaic panel, with 72 photovoltaic cells, which allows it to be used during the day, with solar lighting, or at night, with two points of artificial light (Figure 1). The teaching set has a current converter with charge accumulator, coupled to measuring equipment (Voltmeter and Ammeter) and on the panel, allowing the verification of voltage, current, and resistance.

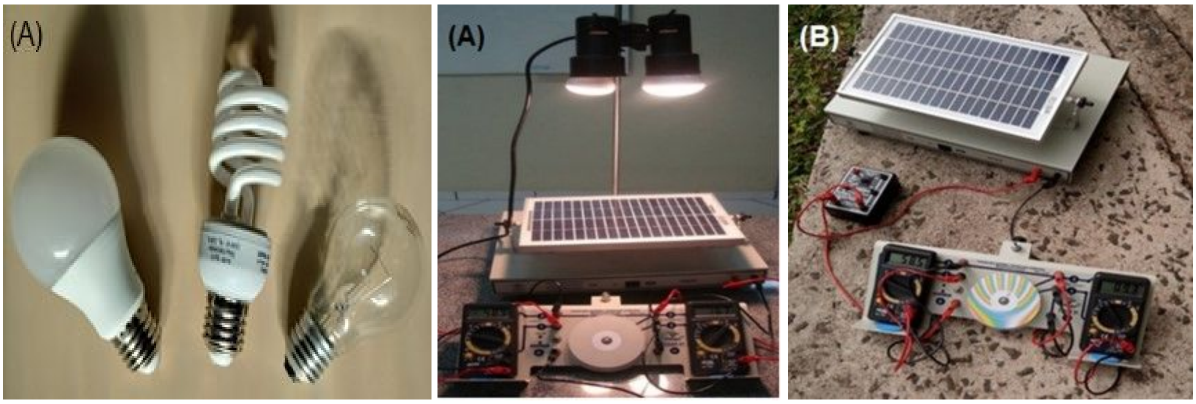

Figure 35. Assembly of the experiment: photovoltaic with artificial lighting (A) and solar (B).

To carry out this experiment, a pilot experiment was created and applied in 2016, with 31 students of two classes ($T_A = 16$ and $T_B = 15$) and in 2017 the definitive experiment, with 24 students. Both experiments were carried out in Physics class 3 for students of Civil Engineering and Environmental and Sanitary Engineering.

The validation of the pilot experiment was carried out at night, with four activities: (i) transforming the light from incandescent lamps (60W) into current; (ii) transforming light from fluorescent lamps (15W) into current; (iii) transforming the light of LED lamps (8.5W) into current and, in the latter, (iv) the activity of evaluating the efficiency in converting light into electricity. All lamps emitted white light, with a luminous intensity of approximately 800 $lm.m^{-2}$ (Figure 2A). In the activities, the students evaluated the current, the voltage, and for these values, the power and resistance calculations. Subsequently, they calculated the efficiency (η) in transforming light into electrical energy. In carrying out the activities, in the validation, the students used a laboratory script, pre-test, and post-test (as used in the definitive experiment), to guide them in the learning process.

The results of the pilot experiment in the students' learning were not satisfactory, since when answering a post-test, the students provided incorrect answers when they demonstrated the alternative conception that infrared radiation (heat) was responsible for the production of energy, justifying that incandescent light generated more current. This conception is mistaken since this lamp presents a peak of initial production and as the silicon cells are heated, the current decreases significantly, increasing the electrical resistance, as shown in the literature (Dark, 2011). This result does not occur with the others light sources (fluorescent and LED), presenting a stable current.

Methodology in the definitive experiment in the Physics laboratory

To solve this problem presented earlier in the pilot experiment, the experiment was changed, adding lamps with the longest wavelength (red) and the shortest wavelength (blue) light. Thus, after carrying out experiments using white light from LEDs, fluorescent and incandescent (Figure 2, A), the students proved that they had replaced the white light bulbs with colored light bulbs (Figure 2, B). In this way, they could assess the influence of light frequency on current and voltage, observing the measurement instruments (ammeter and voltmeter).

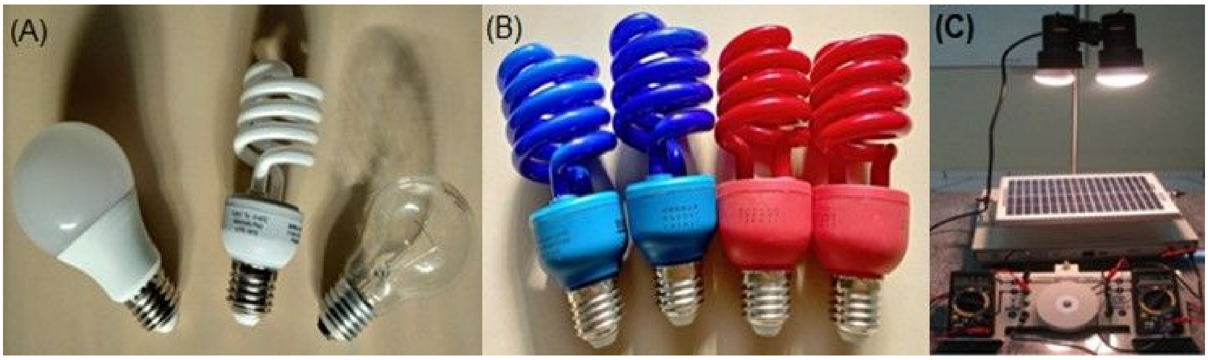

Figure 36. Technologies: The lamps used in the pilot and final experiment (A); Lamps added in the final experiment (B); Setting up the experiment (C).

Interventions with students took place after approval by the Human Research Ethics Committee (Number 2,253,630). Data were collected in the definitive experiment using interventions (Reis, 2019): pre-test, post-test, script for activities in a real laboratory and recorded interviews. The methodological foundations that guide the research is predominantly qualitative, of the case study type (Erickson, 1986).

The script used by the students during the laboratory activity (Reis & Serrano, 2019), was built using the P.O.E. (Predict-Observe-Explain) methodology, similar to that used in a computational experiment (Reis et al., 2021; Tao & Gunstone, 1999), and actually inspired in the Demonstrate-Observe-Explain used by teachers when demonstrating experiments during the classroom. In the visualization phase, after a brief introduction, students should describe their previous concepts of how photovoltaic technology works. In the experimentation phase, they observed the transformation of artificial light into electricity, utilizing LED, fluorescent and incandescent lamps, and recorded current, voltage, power calculation, and resistance to current flow. Then the teacher replaces the white light bulbs with colored light bulbs (red and then blue) and the students repeat the records and calculations (Figure 3).

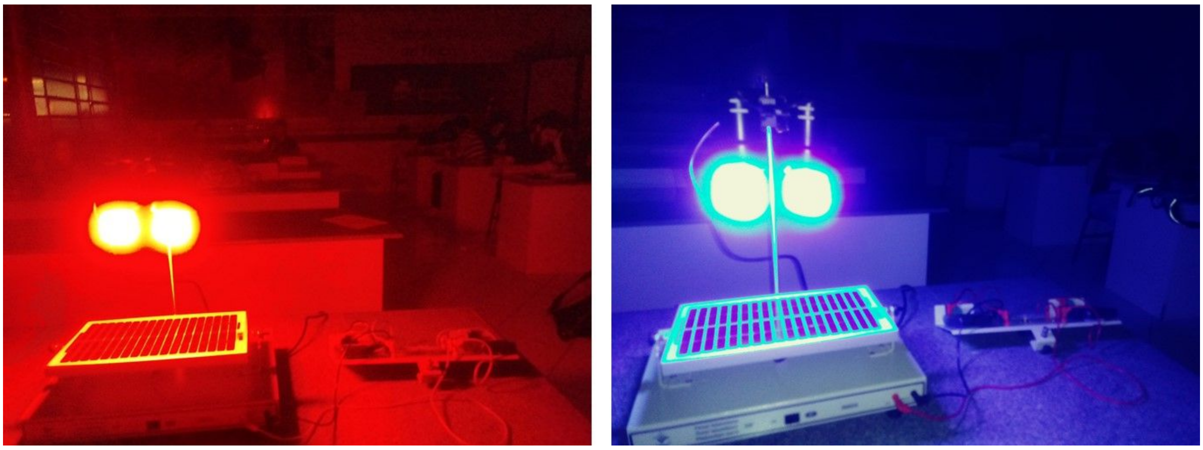

Figure 37. Activities Using Red Light, Low Frequency and Blue Light, High Frequency.

And, in the explanation stage, students can reflect on the results, noting that the current is influenced by the transformation of light into energy. In lamps with resistance, electrical power decreases with increasing temperature, as demonstrated by previous studies (Boitier & Cressault, 2011; Dark, 2011; Morgan et al., 1994). In these steps, they are motivated to reflect on the role of the frequency of emitted light in the transformation of light into energy.

EXPERIMENTAL RESULTS AND DISCUSSIONS

The comparative analysis between the instruments applied at the beginning of the activities (Pre-test) and after the activities (Post-test) showed a significant evolution in the students' answers, for all the investigated concepts. In the interview, it was asked in the interview, it was asked “if the frequency of light changes, what happens to the current and the emission of photons?”. Student E4, for example, who answers in the pre-test that he does not know, says in the post-test "change the current". When justifying, he mentions the "calculations" of the current and voltage on the power generated by the photovoltaic plates when the lamps are white or colored (blue and red), referring to the mathematical modeling of the data provided in the guide (Reis & Serrano, 2019) activities used in the experiment laboratory. In the first columns, the data observed in the lamps, the light intensity (lm) and the measurements (voltage and current) were registered. Then the students performed the resistance and power (W) calculations (Figure 4).

CARACTERÍSTICAS DA LÂMPADA	MEDIR			CALCULAR	
	Intensidade luminosa (lm)	v (V)	i (A)	R (Ω)	P (W)
Vermelha - 14W	180	2,8	0,01	270	2,7x 10⁻³
Branca 14 W	854	31,5	2,22	14,29	8,29x10⁻⁹
Vermelha 26 W	1846	8,05	0,6	14,16	5,1 x10⁻⁶
Azul 26 W	1846	18	1,3	13,84	2,34x10⁵

Figure 38. Calculation mentioned by E4 when relating the frequency of light and electrical current. Note: Measurements: light intensity (lm), voltage (V) and current (A). Calculations: resistance (Ω) and power (W).

To the same question, another student answers: "Because, if I'm not mistaken, the frequency of [...], the frequency of each color is different from one another and therefore, it doesn't increase from nothing and as we observe [...] on multimeters [...] it increased little by little" (E2). In non-verbal language (Figure 5), the student makes an indicative gesture with his hand towards the experimental physics laboratory (Figure 5A) and when he relates the current and voltage variables in the photoelectric effect, he represents the device (multimeter) used in the measurements (Figure 5B).

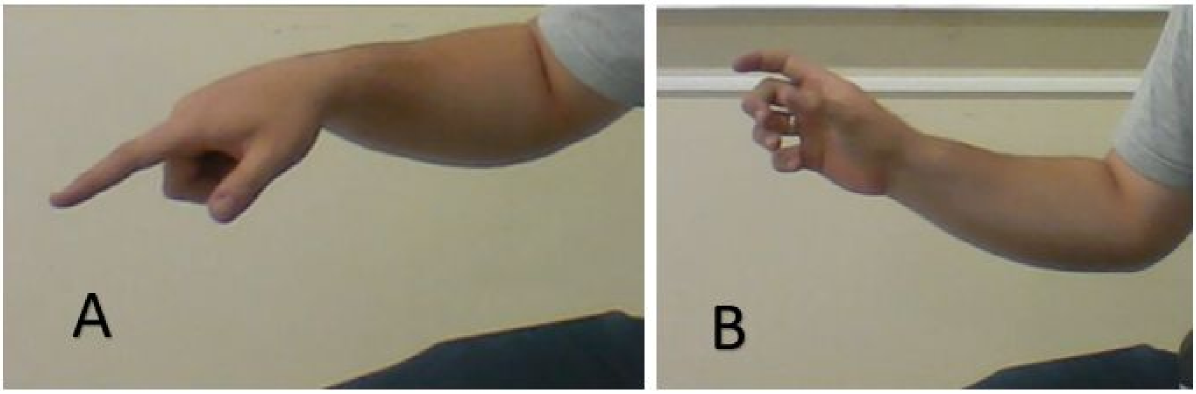

Figure 39. Gestures demonstrated by student E2 during the interview, which show the influence of the experiment on learning concepts: (A) points to the laboratory, (B) makes gestures for measuring current talk.

In the interview, students were asked: If you had to explain to one person what the photoelectric effect is, what would you say?" Student E5 researched the use of thin silicon films and flexible photovoltaics in that period (Schönell et al., 2020), responds:

> Laughter [...] I had to explain to my 5-year-old girl: A beam of light, depending on its color, has a certain length and therefore a certain frequency, because it is faster [...] and oscillates several times in a smaller space it [...] ends up hitting the electron [...] that is on the plate or film, depending on what you are using, hits the electron thus giving energy to the electron and moving to another band of the plate, generating current. (E5)

Other students answered the same question in the same line of thinking, explaining the transformation of light microscopically:

> I would say it is the transformation of light into energy. (E6; E9)

> When there is an incidence of light in a certain material, these electrons that are in the material are energized [...] and there is an exchange of electrons, and this movement is what we call electrical energy. (E14).

The results of this analysis showed that after use red and blue light it was possible to verify that students correctly correlate the photoelectric effect to the frequency of incident radiation and not to the intensity of light. And the testimonies of the students at the end of the interview, when asked "What is your opinion in relation to studying with a teaching unit where we work with different methodologies, containing different practical and theoretical activities?". The students answered:

> (...) sunlight, which is luminosity, what generates energy is the ultraviolet, which is what you do not see. What you do not see generates energy. (...) how the different types of materials react, the stimuli, which was computational and the most interesting was when I understood how photovoltaic cells worked. (E5).
>
> (...) Because the incandescent lamp I thought it produced more energy and, in the calculations, we saw that it was the opposite. That is not quite the case (E13).
>
> Because when you change the lamp, the blue lamp, I think, increases the production of photons, right? That's right. (E17)

Therefore, photovoltaic technology, used with artificial lighting, proved to be effective as a context application in the production and transformation of light, for teaching in engineering, motivating students to learn. It enabled students to associate the different concepts in teaching the proposed theme with the functioning of technology. It also provided opportunities for articulation between research and teaching and university extension on the subject, with applications in photovoltaic production and sustainability in artificial lighting, involving students from the Civil and Environmental Sanitary Engineering course at the Universidade do Contestado (Reis, Reis Júnior, et al., 2020).

The use of photovoltaic technology in the teaching of Science and Mathematics in Engineering, as in previous research linked to the STEM movement (Dark, 2011; Kartal et al., 2015; Pecen & Nayir, 2010), can engage students to relate knowledge from classes to professional applications. The research demonstrated in arousing the interest of students in researching this application presented years later in Course Conclusion monographs, where often, projects involving photovoltaic technology (Biffi & Reis, 2020; Reis, Reis Júnior, et al., 2020; Schönell et al., 2020) or sustainability in artificial lighting (Both et al., 2021; Santos et al., 2019; Seffrin Júnior et al., 2021). Therefore, the study shows evidence of lasting learning and impact on sustainability promoted by teaching concepts in the photoelectric effect in engineering science classes using photovoltaic experiments. In an extension project, it was possible to take technology to Basic Education schools, explore with high school students, and motivate them to study engineering, as research shows the application of technology in other parts of the world (Dark, 2011; New York Academy of Sciences, 2017; Rose et al., 2010).

CONCLUSIONS

The use of photovoltaic cells as a context of application in the production and transformation of light into a photoelectric effect, from research linked to the STEM movement (Science, Technology, Engineering and Mathematics), was of singular importance for the teaching of the photoelectric effect theme in Physics in Engineering, all contexts considered, not only the learning of the concept itself.

The use of photovoltaic technology as an application context in the production and transformation of light in the teaching of Physical Sciences can motivate students to learn and help in the integration between academic knowledge and professional skills. The expansion of the diffusion of photovoltaic technology in education can, consequently, motivate society to use the Sun's energy in different technological applications in Engineering, as proposed by the STEM movement.

In addition, the system enabled the use of different artificial lighting technologies, contextualizing the students and allowing them to reflect on social changes resulting from scientific and technological evolution, as well as the social needs that this technological ascent provides. Furthermore, the inclusion of the experiment in photoelectric effect had repercussions on teaching, research, and extension, as an opportunity to engage academics of Civil Engineering and Environmental Sanitary Engineering at the Universidade do Contestado, where the research was carried out.

ACKNOWLEGMENTS

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ADDING FICTION INTO PHYSICS' LABS TO ENGAGE UNDERGRAD STUDENTS

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Learning experimental physics is often perceived as being poorly engaging by students, especially at the university level. We wanted to test whether an immersive format could increase student engagement in experimental physics. Twenty-eight ($M \pm SD = 20.4 \pm 1.0$ year-old; 19 males) third year university science students were immersed into a fictional scenario. The learning goals were centered on experimental methodology and transverse skills, such as teamwork. They were all given a role in a story that unfold during the class (i.e. not unlike a live-action role play). All of them had to perform physical measurements, not because their teacher asked for it but because the scenario they were going through required it. We measured the impact of the fictional scenario on the students' behavioral, emotional and cognitive engagement by comparing with teaching as usual. The results show that students' emotional engagement was higher in the context of immersion ($p<0.001$). No behavioral or cognitive effects were found. Student transcripts confirm that students enjoyed the use of fiction, and that the learning goals were achieved. We were concerned that fictional scenarios could result in differentiated effects among gamers; we found no correlation between the students' game culture and any engagement scores. The use of fiction in teaching experimental physics therefore appears to be beneficial for the emotional engagement of students. It would be interesting to test the use of an immersive scenario in other contexts where engagement is known to be poor.

Keywords: Emotion, Physics, Context-based learning

INTRODUCTION

A central objective of physics education is to foster experimental abilities such as modeling, designing experiments, and analyzing data (Kozminski et al., 2014). However, students do not always appreciate physics' labs, particularly in the case of cookbook laboratories where students follow a precise protocol with no margin for autonomy. As physics teachers, we became interested in the question of student engagement, and how to adapt our practices to increase it. We wanted to test whether the use of an immersive approach had an impact on the engagement of our students. To do so we developed a new teaching in which all participants (students and teachers) play a role and must act accordingly. The students perform physics experiments in response to the story they are immerged in.

DESCRIPTION OF THE NEW TEACHING

The pedagogical objectives are to let students work on their experimental skills, in particular letting them build experimental devices that they design themselves. In addition, this teaching includes transversal objectives such as teamwork, resolution of open-ended problems, and finally pleasure of doing physics.

The principle of this new teaching is that students are immersed in a scenario that will encourage them to perform some physics experiments. As in a life-size role-play (LARP), all participants (students and teachers) play a role and must act accordingly. However, in contrast to LARP, students have no specific back story or different set of agendas. They behave as they would naturally and try to solve the different problems that arise. Their roles are generic and similar: they play the role of young scientists, (e.g., an engineering team), who provide technical support for people in difficulty (e.g., spies, astronauts, …). An unforeseen crisis forces them to quickly work on a series of experimental devices needed by non-player characters. The teachers are characters that have no particular physics knowledge but which are responsible for the organization (human relation managers for example): this allows them to keep the responsibility of the schedule while justifying their inability to help the students in the scientific tasks, giving students a large autonomy in their organization and production. Teachers can occasionally switch character if the scenario requires it. A typical example is when a scientific expert is needed: changing a nametag and a piece of clothing is enough to do so. For the immersion to work, teachers must play their roles seriously, as if it was real, but there is no need for good acting skills: they benefit from the students' willing suspension of disbelief (Muckler 2017). This concept, which describes the fact that one is willing to accept a story in order to enjoy it, allows, for example, to seriously consider the different ways to interact with extraterrestrials. Small details (e.g., nametags, graphical charter of all documents, …) help with this. Interactions with the non-player characters and progress in the scenario are conducted through webchats or mails, and also through audio and video messages that have been prepared in advance.

From a practical point of view, this teaching takes up two consecutive full days. It is intended for third-year university students (~30 students / year) in a math / physics curriculum with a very formal approach to physics, and is supervised by two teachers. Prior to these two days, the students are made aware of the objectives and principles of this teaching.

The fiction begins with a convocation letter that is sent to the students, with the date and location (not their usual classrooms, but one from another section of the university). At the beginning of these two days an icebreaking activity is organized, but the given reason for the convocation is an excuse: very rapidly after the icebreaker a crisis is triggered which requires the team to respond to an external demand for technical assistance (for example, a very secret space mission is about to land on an unknown planet and needs help). The story is organized around a series of scientific activities, each activity advancing the scenario, and leading to the next activity. We typically plan for four activities, of about half a day each. These activities are open problems that do not have unique solutions, but require students to build, test, and often document experimental devices. The physics involved is rarely complicated (mainly mechanics and small electronics), and the equipment available is not very advanced: for example, students must design a device to send a camera as far as possible without damaging it. The difficulties for the students are often to organize themselves, and to fully carry out the realization of the requested device, including testing and comparing their results. The scenario sometimes allows for some different outcomes depending on the quality of students' work, but generally the scenario is constructed to avoid complete failure in order to ensure a better experience for the students.

The fiction closes with an end credit, which allows everyone to get back their own identity. A collective debriefing is then organized in order to recontextualize the teaching, to listen to the students' feedback, and to give them feedback on their work.

CONCEPTUAL CONSIDERATIONS

Engagement is a multi-dimensional construct that can describe a student's actions and emotions (Fredericks et al., 2004). In this study, three dimensions were used: the behavioral engagement, which encompass student participation in class activities and outside activities; the emotional engagement which encompass emotions and feelings related to the educational environment; the cognitive engagement, which encompass the learning practices and strategies. It is worth noting that student engagement defined as such can evolve in time and differ between different topic.

MATERIAL AND METHODS

A new version of Parent's survey was used to capture student engagement, (Parent, 2017). Originally each dimension of engagement was measured by 10 questions; we kept 5 for behavioral engagement, 10 for emotional engagement, and 8 for cognitive engagement. To establish an engagement score we took the average of the responses, using the values 1 to 4 of the Likert scale, 4 being the maximum engagement.

Thirty-on students followed the immersive teaching. The same students followed a second teaching with very similar pedagogical objectives, also using active pedagogy but without any immersion. During two non-consecutive days, supervised by other teachers, students had to build up from scratch an experimental setup to study a physics phenomenon. The same engagement survey was given to the students after this class. In the rest of this article, "Immersion" will point to the first teaching, "teaching as usual" to the second. Both surveys also contained open questions at the end to collect students' verbatims and impressions. Of the 31 students, 28 students ($M \pm SD = 20.4 \pm 1.0$ year-old; 19 males) answered both surveys. The statistical analyzes were carried out by performing parametric tests after having verified that the normal distribution correctly describes the results.

We were concerned that, due to the game-like aspect of this teaching, their gaming habit could have an influence on their engagement, and we tested this parameter. To establish the game culture of the students, we adapted a survey made by Berry et al. (in press) used to measure the game culture of the French population. These answers were transformed into a 0-100 scale gaming score, 0 denoting a student that has never played any games, 100 a student who plays often many games. The value of this score has no absolute meaning but it allows to class students and look for correlation between gaming habits and engagement scores. In addition, we also specifically asked the students if they had ever participated in a LARP. The immersion teaching has many common features with LARP, and we tested if there were significant differences in the engagement between the students who had already participated in a LARP and those who didn't.

RESULTS

Cronbach's alpha test gives 0.81, 0.40, and 0.62 for the survey questions related to affective, behavioural, and cognitive engagement respectively. The engagement scores after both teachings are presented in Table 1. For each engagement type, a paired t-test was used to look for significant differences. No significant differences were observed for the behavioral and cognitive engagement scores, but the students were significantly more engaged during the immersion class than during the teaching as usual, see Figure 1 (β=0.36, $F(1,27)$=15.81, p<.001, PRE=.37, IC 95%[0.17,0.55]).

Table 1. Engagement scores for our 28-student population (mean ± standard deviation). Null engagement is 1, maximum is 4.

Teaching	Behavioral engagement	Emotional engagement	Cognitive engagement
Immersion	3.05 ± 0.33	3.41 ± 0.34	3.22 ± 0.39
As usual	3.02 ± 0.44	3.04 ± 0.49	3.10 ± 0.37

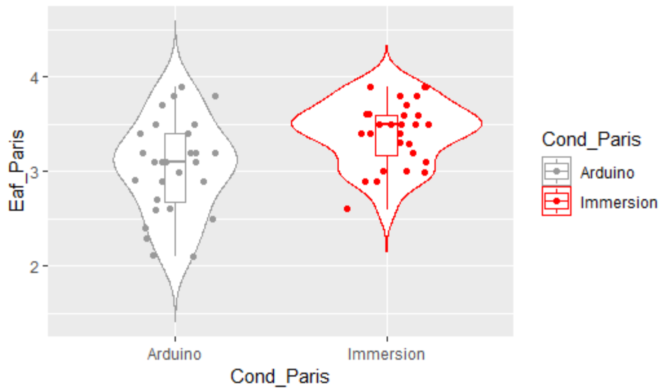

Figure 1. Students' emotional engagement during the immersion and the reference teaching, on a scale from 1 to 4, 4 being the most engaged.

The average gaming score for students is 41.1 ± 10.1, with 0 indicating a student who has never played any games, and 100 a student who plays various games a lot. The correlation coefficients between this gaming score and the engagement scores are not significant for behavioral, emotional, and cognitive engagement. Among the 28 students, 15 answered that they had already participated in a life-size role-play. However, we found no significant effect of this experience neither on emotional nor behavioral or cognitive engagement. There was no gender effect but the small sample size makes this result questionable.

The students' transcripts contain many answers where the fiction was mentioned in relation to their emotional engagement. The role of teamworking was also often mentioned (translated):

- *"[fiction] It motivated us more to do the different tasks";*

- *"I loved that the teachers were fully in their roles until the end, it pushed us to play the role, and it made the experience unique and very interesting, it's a great way to introduce people to science";*
- *"An amazing experience";*
- *"[fiction], it allowed us to get out of school and work in a good atmosphere. [I learned] Mainly to work in a group, to integrate myself, to impose my point of view while knowing how to listen to that of others, to make compromises ..."*

DISCUSSION

The Cronbach's alpha test performed on our survey shows that it correctly measures affective and cognitive engagement; the measurement of behavioral engagement is not as good (Nunnally, 1978). The original survey has been validated but the part measuring the behavioral dimension of the engagement is the part that we reduced the most (only five of the ten questions were kept), which could explain this difference.

The main result is that the students' emotional engagement was significantly higher during the immersive teaching than during the teaching as usual ($p < .001$), without the other forms of engagement being significantly modified in one way or another. Both teachings had the same duration, the same pedagogical objectives (experimental methodology in physics in the broad sense), both used an active pedagogy, with open problems of physics and with large student autonomy: the most likely cause for this increase of positive emotions in the students is the use of fiction during the immersion teaching. Another important result is that this increase did not happened at the expense of the other dimensions of engagement, cognitively or behaviorally. It is however impossible to refute the existence of other biases between the two teachings. We tried to minimize these biases as much as possible. The students' transcripts provide support for the idea that using fiction was a crucial point as it was often mentioned in a positive manner.

These results can be linked to reports that gamification in education generally increases engagement (Hamari et al., 2014). No correlation was observed between the engagement scores and the gaming scores of our students, nor with whether they had already participated to a LARP or not. The use of fiction did not create a noticeable bias between our students. The fact that the game culture does not correlate with the engagement score is surprising. However, our population (young science students) possesses a higher game culture than the rest of the general population (Berry et al., in press) and is likely to be homogeneous with regard to gaming habits.

CONCLUSION

The use of fiction in our teaching increased the emotional engagement of students. This occurred independently of our students' game culture, measured in two different ways. In addition, the transcripts show that our educational objectives were achieved according to the students. However, the statistical power could be increased with larger-population studies. The principle of using a scenario is not restricted a priori to experimental physics and could be applied to other teachings. Proposing different and original teaching formats seems an effective way to break the monotony of yearlong training and to offer students a teaching experience that affects them emotionally; this is undoubtedly all the more important this year when many teachings are done remotely with very little direct human contact.

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RELATING TEACHING ASSISTANTS' BELIEFS ABOUT TEACHING AND LEARNING TO THEIR INSTRUCTIONAL PRACTICES IN AN INTRODUCTORY PHYSICS TUTORIAL

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Teaching assistants (TAs) influence the quality of undergraduate education, but little research has been published about their instructional practices. In this study, I investigated three TAs' enacted instructional practices during tutorials for an introductory physics course at a Dutch university and related those enactments to their expressed beliefs about teaching and learning. Video-recordings of the TA's tutorials and transcripts of their interviews were analyzed using two previously developed protocols. The TAs enacted some of the same instructional practices (e.g., asking students if they had questions about the previous tutorial), but expressed different beliefs for enacting those practices (i.e., help students understand concepts, ensure students enjoy being in the tutorial, help students solve assigned exercises). These findings suggest that TAs' beliefs about teaching and learning should be an important consideration when addressing possible change(s) to their instructional practices during tutorials (e.g., weekly TA meeting, TA professional development).

Keywords: higher education, teaching beliefs and practices, introductory physics tutorials

INTRODUCTION

Undergraduate students primarily cite poor teaching in their courses as one of the main reasons for switching out of science fields (Seymour & Hunter, 2019). Because these students often spend more individualized time with their teaching assistants (TAs) during tutorials than with their course instructors during lectures (Blatchford et al., 2012), improving our understanding of TAs's enacted instructional practices can help inform our structuring of tutorials that encourage and support students' learning of science and persistence in science fields. One theoretical framework that can be used to explain relations between the TAs, students, science content, and tutorial learning environment is Schwab's (1983) four commonplaces (teacher, student, curriculum, milieu). This framework indicates that the enactment of instructional practices that support students' learning of content requires coordinating the commonplaces.

Beliefs about teaching and learning greatly influence the instructional practices that are enacted during class. For instance, Wallace and Kang (2004) found that science instructors who associated successful science learning with deep conceptual understanding primarily used verification labs to illustrate those concepts. They also found that science instructors who associated successful learning with enculturation into science practices used inquiry-based labs to provide opportunities for students to engage with scientific practices. Their finding illustrate how beliefs about teaching and learning may influence the enacted instructional practices.

In contrast to Wallace and Kang (2004), others researchers found similarly enacted instructional practices were associated with varied beliefs about teaching and learning (Goertzen et al., 2010; Speer, 2008). In Speer's (2008) study, the TAs indicated the importance of asking students questions (instructional practice). However, one TA asked questions in order to diagnose the strength of students' conceptual understanding and help them overcome any difficulties in doing so; the other TA asked questions to model behaviors that he wanted students to emulate when problem-solving and to monitor their learning so that students would complete the same problems in a timely manner. Similarly in Goertzen et al.'s (2010) study, each TA checked for students' understanding of target ideas (instructional practice); however, the TAs' beliefs for enacting that practice varied, especially with respect to their self-perceived roles (e.g., help students grapple with traditional problems, ensure students have the right answer, get students going in the right direction).

These findings suggest further investigation is needed about the relationships between TAs' enacted instructional practices and beliefs about teaching and learning, which I address in this study. My research questions were: *What instructional practices did TAs enact during their tutorials? What beliefs about teaching and learning did TAs express about their instructional practices? How did the TAs' enacted practices compare to their expressed beliefs?*

METHODS

To conduct an in-depth investigation of multiple participants' perspectives of an activity situated within a natural context, I used a multiple case study (Yin, 2008); this design helps identify and analyze similarities and differences between individual cases. The two-hour tutorials, which met at the same times twice per week and at possibly different locations, were part of a 20-week introductory physics course at a large university in The Netherlands; student attendance during tutorials was recommended but not mandatory. Of the nine TAs who support this course, three consented to participating in this study—one male undergraduate student ("Coen") and two male master's students ("Daan" and "Lars"). Each TA had prior experiences with this course, in addition to being a TA for other courses.

Data Collection

Data sources included field notes or video-recordings of each TA's tutorials and an audio-recorded interview with each TA. Figure 1 shows the data colletion sources and schedule.

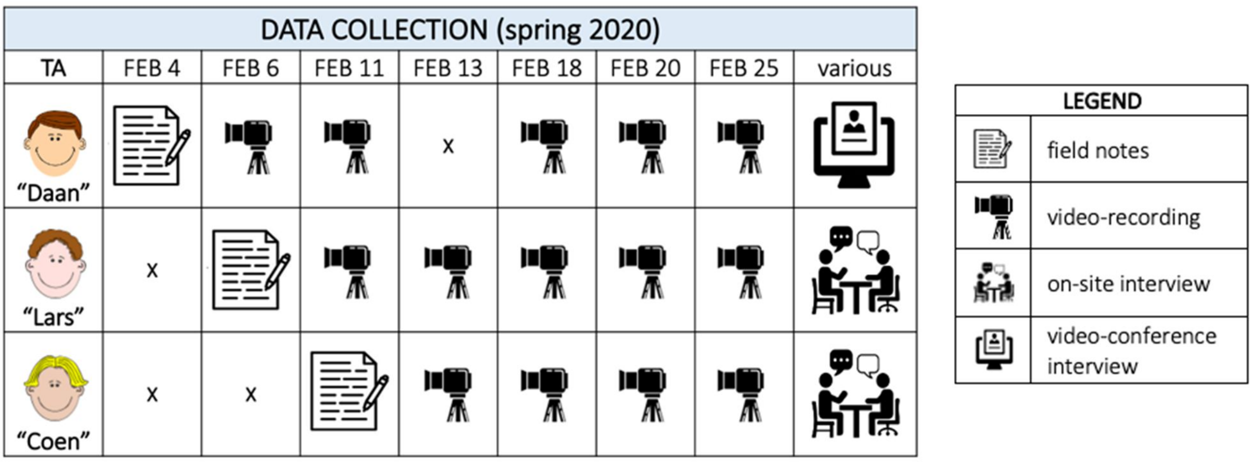


Figure 1. Data collection schedule.

The field notes were organized by addressing Schwab's (1983) four commonplaces of teaching and focused on (a) descriptions of TAs' activities (e.g., solving exercises on chalkboard, talking with students), (b) descriptions of students' activities (e.g., working with friends), (c) concepts that were addressed during the lectures (e.g., divergence, electrostatics), (d) questions about aspects of the tutorials from student's perspectives (e.g., attending tutorials scheduled over lunch, online vs. onsite tutorials), and (e) questions about aspects of the tutorials from the TA's perspective (e.g., using two different rooms each week).

For the video-recordings, the cameras were set-up in each room by a graduate student and myself. We set-up the video-cameras at the back of the room and aimed them towards the the front of the room, which was where the TA was often located and to avoid recording students' faces. Once the video-cameras started the recording, the graduate student (or I) left the room to minimize outside intrusion; we returned at the end of tutorial to stop the recordings and collect the cameras. These video-recordings continued until the tutorial after the first exam (third week of course). Afterwards, they were content-logged (same format as field notes, with time stamps) and partly transcribed for analysis.

The semi-structured interviews were conducted towards the end of the course. Informed by the field notes and content logs of the video-recordings, I designed interview prompts to address four constructs: (a) beliefs about teaching (e.g., "What is your role as a TA?"), (b) beliefs about learning (e.g., "How do you think students learn electricity/magnetism?"), (c) descriptions of tutorial activities (e.g., "What do you do on a typical day?"), and (d) considerations of alternate curricula (e.g., "What are your thoughts about this [proposed] tutorial activity?"). Some of the interview prompts could address multiple constructs. The audio-recorded interviews for Coen and Lars were conducted in person; Daan's interview was audio-recorded through a video-conference due to COVID-19 constraints. The audio-recordings of the interviews ranged between 1.5 to 2.5 hours and were fully transcribed.

Data Analysis

My analysis involved comparing the TAs' enacted instructional practices across tutorials, characterizing the interview responses with respect to their beliefs about teaching and learning, and identifying (any) relations between the instructional practices and beliefs. I selected two instruments to help me achieve these goals.

- *Real-time Instructor Observing Tool* (RIOT; Paul & West, 2018). This can be used to qualitatively describe the TAs' activities (from field notes and video-recordings) with respect to their interactions with students (i.e., talking at them, dialoguing with them, observing them, not interacting with them). I used the RIOT to code video-recording excerpts of the TAs' instructional activities.
- *Teacher Beliefs Interview* (TBI; Luft & Roehrig, 2007). This can be used to locate the TAs' beliefs about teaching and learning on a teacher- to student-centered continuum: traditional (most teacher-centered), instructive, transitional, responsive, and reform-based (most student-centered). I used the TBI to code interview excerpts of the TAs' responses with respect to their self-described instructional practices during tutorials, perceived affordances/constraints with the physical/social environments, and perspectives on aspects of other instructional strategies (e.g., group work).

Beliefs about teaching and learning are tacit and must be inferred from congruences between instructors' descriptions of/intentions towards/enactments of teaching (Lombaerts et al., 2009).

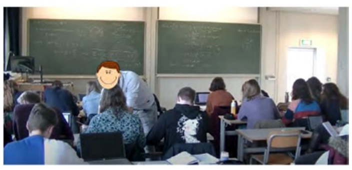
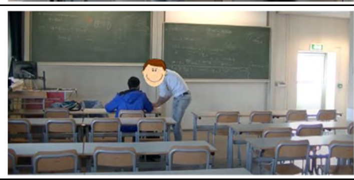
I used grounded theory (Corbin & Strauss, 2007) to develop in-vivo codes describing the TAs' enacted instructional practices and responses to interview questions. This process occurred iteratively and in parallel with both data sources. A researcher external to the project checked a subset of the codes for credibility, neutrality, and consistency. After both data sources were coded, I used thematic analysis (Braun & Clarke, 2006) to identify patterns in the data based on the theoretical concepts addressed in the RIOT and TBI. Video excerpts and interview quotes that did not require extensive references to other parts of the videos/interviews were selected to illustrate examples of each TA's instructional practices and beliefs about teaching and learning.

FINDINGS

Enacted Instructional Practices (video-recordings)

For each TA, snapshots from the beginning, middle, and end of the video-recorded tutorial on February 18 are shown in Table 1. This tutorial was chosen because students had already been attending tutorials for two weeks (enough time for TAs and students to develop a routine) and the exam was scheduled for the following week. For Coen and Daan, the desks in their room were placed in rows, facing the chalkboard at the front of the room; for Lars, the room was arranged such that there was one group of ten desks organized as a big circle and smaller pairings of two or three desks (arranged by the previous class). Although the room arrangement and organization of activities differed for each tutorial, the TAs enacted some of the same instructional practices.

Table 1. Snapshots from beginning, middle, and end of the tutorial on Feb 18 for each TA.

	beginning	middle	end
Coen			
Daan			
Lars			

Coen started tutorial by writing the assigned exercises on the chalkboard and then asking students about the lecture. He then reminded them about the upcoming exam and shared some test-taking strategies. Coen spent the majority of his time sitting at the front of the room. When a student (infrequently) raised his/her hand, Coen walked over to explain the answer(s); afterwards, Coen would glance around the room before returning to his seat. This tutorial ended about ten minutes early, when the last students left the room.

Lars said he typically starts tutorial with a greeting, sometimes asking students about the previous lecture, before writing the assigned exercises on the board. In this tutorial, Lars spent the majority of his time walking around the room to see how the students were progressing on the exercises. Lars rarely stayed in any part of the room for an extended period of time and his interactions with students were usually one-on-one; he rarely addressed the whole group. Lars also rarely went to the chalkboard to write explanations. At the scheduled end of this tutorial, Lars was helping two students; a few students were working independently.

Daan started tutorial by apologizing for his previous absence and then telling students he would present a few exercises that previous students found difficult. After writing the givens for an exercise on the chalkboard, Daan asked students how they would proceed for each step of the solution and gave feedback with respect to its correctness. During the second half of the tutorial, he walked around the room to address individual questions, occasionally addressing the whole tutorial if the same question was raised by multiple students. At the scheduled end of this tutorial, Daan was still helping one student; the rest of students had already left.

Using the RIOT, the enacted instructional practices can be described as primarily observing students for Coen; observing and dialoguing with students for Lars; and talking at, observing, and dialoguing with students for Daan.

Beliefs about Teaching and Learning (interviews)

The TAs expressed different beliefs about teaching and learning, which was reflected in the responses about their self-perceived roles (Table 2) and descriptions of activities during a typical day in their tutorials (Table 3).

With respect to their roles, the TAs responses indicated that they prioritized helping students: solve the assigned textbook exercises (Coen), have fun and make progress on the book exercises (Lars), and understand concepts and learn problem-solving tools (Daan).

Table 2. TAs' descriptions of their self-perceived roles.

	Responses to: "How would you describe your role as a TA for this course?"
Coen	"Well I think that really differs per person, everyone does it in their own way. Um, but my, my goal was kind of to try and help them solve the assignments, not to completely show them, like a mini lecture on how to do it. Uhh, I prefer them to work on it themselves. But I wanted to give them the time as well. So, it's kind of why I usually I ask if there's any questions about the assignments from previous tutorial and then I will do those on the board. Also, I would ask because doing them all is way too much."
Lars	"I see myself as a guide to make sure that people have fun and progress during the making of the [book] exercises. That is my main goal. And of course, that means that sometimes you have to do a bit more than just give answers or give hints towards answers. So, you should-I don't know-tell something about some physical intuition you can have for certain situations or some context-'when is something used.' To be very fair, I'm not very good at context. That's something I think other TAs are really good-and a bit better-at. A bit better, I think, in building physical intuition for things. And then joking around that makes people come to the tutorial even when they don't necessarily feel like it would be the best use of their time- because in the end, I think tutorials are a best use of their time."
Daan	"So, I think as a TA it's, um, your goal or your aim should be to, in the first place, I think clarify stuff that was not really completely clear from the lecture. So, that's what I, what I always start with. And secondly, well basically just help them to kind of get a right set of tools with which they can actually solve the problem. So, it's not really doing all the, all the problems completely on the, on the Blackboard. Well more guiding, I, I think guiding them and providing them with a, with a

	set of tools to um, just solve, solve the problems that they are given. I think that's, that's the role overall. Yeah. And also, maybe to get feedback about, uh, the lectures about whether it was doable or not and then transfer that back or feedback back to the lecture. I think those are, for me, those are, I think the main, summarizing points for what I do as a TA…"

The TAs' descriptions of the activities during a typical tutorial session also differed. Coen indicated his instructional practices were to complement lectures and address lingering questions from previous tutorials. For Lars, his responses highlighted his social interactions with the students. Daan's brief response addressed helping students understand the book exercises, which was described more fully in his responses to other prompts (e.g., response to self-perceived role as TA in Table 2).

Table 3. TAs' descriptions of a typical day in their tutorials.

	Responses to: "How would you describe a typical day in your tutorial?"
Coen	"…I usually start by saying 'Ok, we have these questions', uh, the past few weeks I've also been asking on updates how the lectures are going, because I heard that the lectures are slightly behind. … So, I improvise the lectures kind of during the tutorials. …if the lectures are behind, um, then I would, uh, well actually first I would do the, I would ask if there's any questions about the previous tutorials or I would ask if they finished everything."
Lars	"I walk in, I say 'good afternoon, good morning,' whatever. Good morning, because it's always in the morning. And sometimes I ask 'How was the lecture?' and I write down the tutorial questions that they need to do – from memory, on the board, because that's an inside joke I have with them. I remember the problems that we need to do by heart. And then people start working – usually in the beginning, it's quite, quite quiet – yeah – because everybody's reading the question, trying to solve it for themselves at first. … Yeah, then during the tutorials, more and more conversations start to form and I, I get more busy – yeah – running around. Usually the last hour or hour and a half, I'm usually answering questions. … usually what you see is that if people, if they're done with a question and there is only 5 to 10 minutes left, they leave. And yeah, I think I think that's fair enough. I don't want to force people to stay. But sometimes people are still working on something when it's 49 minutes – usually we end at 45 minutes. Sometimes I've got something else to do directly after the tutorial. … There's not really a designated end. I don't end things centrally, generally speaking."
Daan	"…they [students] just do the exercises [on typical tutoral day]. Uh, and I try to help them or I do stuff on the blackboard…"

Using the TBI, the TAs' beliefs about teaching and learning was characterized as instructive for Coen, transitional for Lars, and a combination of instructive and transitional for Daan.

DISCUSSION

The description of each TA's tutorial classroom, enacted instructional practices (and associated RIOT categories), and expressed beliefs about teaching and learning (and associated TBI categories) are shared below in Table 4.

Table 4. Summary of TAs' beliefs (interviews) and enacted instructional practices (video-recordings).

	Coen	**Lars**	**Daan**
Classroom	▪ 16 students ▪ chairs/tables in rows	▪ 22 students ▪ chairs/tables in rows and circles	▪ 32 students ▪ chairs/tables in rows

Enacted instructional practices	▪ wrote assigned exercises on board ▪ asked about previous exercises ▪ waited at the front of the room for students to ask questions	▪ wrote assigned exercises on board ▪ asked about previous exercises occasionally ▪ walked around and talked with one or few students on previous exercises and/or social well-being	▪ wrote assigned exercises on board ▪ asked about previous exercises ▪ guided students through select exercises and addressed individual questions
RIOT	*observing students*	*observing students, dialoguing with students*	*talking at students, observing students, dialoguing with students*
Beliefs about teaching and learning	▪ *role*: **helps students understand concepts** – expresses desire to have conceptual physics discussions with students ▪ *gauge progress*: difficult to do without students asking questions ▪ *success*: students need to ask questions	▪ *role*: **guides students in having fun** while sharing insights that help develop intuition for exercises ▪ *gauge progress*: looks at facial expressions or at written work on students' papers ▪ *success*: addresses success in course (study previous exams) vs. physics (develop intuition)	▪ *role*: **provide tools** that help students learn concepts; **communicate difficulties to instructor** ▪ *gauge progress*: looks at body language ▪ *success*: students need to be consistent with their notation and develop good study habits (hard work is its own reward); indicates physical intuition develops with repeated practice
TBI	*instructive*	*transitional*	*instructive and transitional*

Each TA enacted a few of the same instructional strategies, but expressed different beliefs about teaching and learning with respect to their self-perceived roles and definitions of student success. Using the RIOT (Paul & West, 2018) to analyze the video-recordings, an enacted instructional practice common across the TAs was *observing students*. Using the TBI (Luft & Roehrig, 2007) to analyze the interview transcripts, the TAs' beliefs about teaching and learning corresponded to different locations on the teacher- to student-centered continuum. These findings are consistent with the findings from Goertzen et al. (2010) and Speer (2008) – that the same enacted instructional practice may be motivated by different beliefs about teaching and learning. However, the characterizations reflect a partial snapshot of the TAs' enacted practices and expressed beliefs for a given context. One limitation is that the video-recordings captured only the first few weeks of tutorials; for instance, Coen said he used different instructional practices at the end of the course, partly because the topic had changed. This study also did not address the nature of the TAs' prior teaching experiences or the undergraduate students' interactions with their peers during tutorials, factors which can influence/contribute to their enacted instructional practices and/or beliefs about teaching and learning. Despite these limitations, these findings highlight key similarities/differences between the TAs' enacted instructional practices and beliefs about teaching and learning that can inform TA professional development designed to encourage and support students' learning of science and persistence in science fields.

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EXPLORING BIOLOGY INSTRUCTORS' AND STUDENTS' CONCEPTIONS AND APPLICATIONS OF SCIENTIFIC HYPOTHESES AND PREDICTIONS

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Guidelines for undergraduate biology education identify evaluation and application of scientific hypotheses as an essential area of competency for biology majors. There is, however, clear evidence that undergraduate students need more support to fully grasp the concept and application of scientific hypotheses. Additionally, while established perspectives regarding the nature of scientific inquiry and experimentation emphasize hypotheses alongside the associated concept of "predictions", guidelines and resources for biology teaching rarely mention predictions. Furthermore, we see a lack of explicit definitions of these fundamental concepts in teaching resources. There is, hence, a clear indication of an implicit assumption of common understanding regarding the concepts, role, and application of hypothesis and prediction in the context of scientific inquiry. We explored this assumption via characterization of the variation in conceptions of hypotheses and predictions among biology faculty, graduate students, and students. We interviewed Biology faculty, graduate teaching assistants (TAs), and undergraduate students at a large, Midwestern, public University with very high research activity in the United States (US). Thematic coding of interviews used deductive codes derived from Karl Popper's 'The Logic of Scientific Discovery' and inductive codes derived from the data. We find that faculty members' conceptions of hypotheses and predictions – regarding concept, application, and role – align closely with Popper's perspective, while graduate TAs and undergraduate students' ideas are more varied. Undergraduate students' definitions suggest that they conflate the two concepts and both graduate TAs and undergraduates are less familiar with the definitions and use of predictions than hypotheses. Undergraduate students are less able to explain the role of hypotheses and predictions as compared to faculty and graduate students. Lastly, we discuss challenges and opportunities in student learning of these concepts identified by our different participant groups.

Keywords: Undergraduate, hypothesis, prediction, scientific inquiry

INTRODUCTION

The process of scientific inquiry is closely linked to the nature of science and is fundamental to our understanding of how scientific knowledge is developed (Lederman, 2006; Popper, 1959). Our explanation of the process of scientific inquiry has undergone some revision over time, especially in the context of teaching – from a linear "scientific method" that was popular in science textbooks for decades to the current description of a more complex process with interlinks between observation, theory, and experimentation (Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002; Lederman, 2006; Mccomas, Clough, & Almazroa, 2005; Windschitl, Thompson, & Braaten, 2008). An idea that has persisted through the changes in established narrative about the process of and teaching practices regarding scientific inquiry is that of scientific hypotheses and predictions being critical to many types of scientific research.

In the context of experimentation, hypotheses can be generated from prior inquiry as well as serve to formally frame new investigations (Kell & Oliver, 2004). Scientific hypotheses (in contrast to statistical hypotheses) frame a novel claim within the established scientific framework and scientific predictions outline multiple lines of evidence necessary for supporting that claim. Karl Popper's seminal work 'The Logic of Scientific Discovery' (Popper, 1959) elucidated this concept and role of hypotheses and predictions in the context of scientific inquiry. Popper's perspective may be summarized as deductive falsificationist – a perspective still used to illustrate the "scientific method" in classrooms (Ruxton & Colegrave, 2011). Popper theorized that a hypothesis and a prediction are two components of a causal explanation for a phenomenon. Based on Popper's characterization, hypotheses and predictions should function to guide data collection and analysis in the process of scientific inquiry (Popper, 1959; Wilson & Rigakos, 2016). In this role, hypotheses and predictions are of particular importance in shaping experimental design, which is an essential part in the work of science researchers and in science education (Vision and Change; AAAS, 2011)

Current recommendations for undergraduate biology education explicitly state that evaluation of scientific hypotheses is an essential competency for biology majors and calling specifically for inquiry-based teaching and hypothesis testing to be included in undergraduate programs (AAAS, 2011). Assessment tools for biology education, a yardstick for teaching and learning expectations, include hypothesis recognition and evaluation as skills integral to scientific inquiry (Khodor, Halme, & Walker, 2004; Sirum & Humburg, 2011; Dasgupta, Anderson, & Pelaez, 2014; Deane, Nomme, Jeffery, Pollock, & Birol, 2014; Pelaez et al., 2017). However, these many guidelines fail to explicitly define what hypotheses, or predictions, are, how they are related to each other, and why they are important. Further, Dasgupta et al. (2014) documented evidence of challenges encountered by undergraduate biology students in grasping the concept and application of a hypothesis. They also found evidence that students may need additional guidance in other key aspects of experimental design and scientific claim validation such as determining the experimental variables, measuring the right relationship to validate a proposed explanation, and overall alignment of the experiment with the claim to be tested - all of which are aspects of experimental design that tie into the function of hypotheses and predictions as described by Karl Popper. The literature, thus, indicates that 1) there is an unverified assumption of common understanding of the concepts of hypotheses and predictions and their role in inquiry among scientists and educators, and 2) students face challenges in grasping these concepts. While it is likely that many of Popper's ideas endure, it is important for biology teaching to keep up with current scientific ideas and practices in scientific inquiry (AAAS, 2011). To ensure this, it is necessary to first evaluate current practices of biology researchers as well as the representation of these practices being conveyed to students. Accordingly, our exploratory study aimed to –

1) Compare faculty members', graduate students', and undergraduate students' conceptions of scientific hypotheses and predictions and their role in inquiry.

2) Reveal perspectives on challenges and opportunities in student learning of these same concepts identified by faculty members, graduate students, and undergraduate students.

DATA COLLECTION AND ANALYSIS

This study was conducted at a large Midwestern public doctoral University with very high research activity (IRB#1907022442). We recruited Biology faculty members (n=3), graduate teaching assistants (TAs) (n=7), and undergraduate students (n=7). The criteria for participation were a) for faculty – at least a 25% appointment within the Department of Biological Sciences b) for graduate TAs – must have been a teaching assistant for a minimum of one semester and c) for undergraduate students – must be majoring in biological sciences. We conducted semi-structured interviews with all participants. These interviews were designed to obtain detailed information about our research participants' conceptions of scientific hypotheses and predictions as standalone concepts as well as within the larger context of scientific inquiry. Interviews also included questions about challenges undergraduate students may face while learning the concepts of hypothesis and predictions (for undergraduate student participants these were self-reflection questions). Interviews were audio-recorded and transcribed, and transcripts were analyzed using thematic coding (Saldaña, 2013). Deductive codes were derived from the widely accepted perspective of Karl Popper (1959). Box 1 describes Popper's ideas of scientific hypotheses and predictions, and the deductive codes derived from them. Additional inductive codes were derived from the data. The complete dataset was coded by one researcher and a subset (20%) was independently coded by another researcher. Coding results were discussed to consensus.

Box 1: Deductive codes derived from Popper, 1959 <u>(code terms are underlined)</u>.

HYPOTHESIS is a <u>broad</u> statement that provides a <u>conceptual</u> explanation for an observed phenomenon. Such an <u>explanation</u> must be deduced from <u>prior knowledge</u>, exclude alternative explanations (<u>exclusive</u>) and must be <u>falsifiable</u>.

PREDICTION is a <u>specific</u> statement that follows <u>logically</u> from the hypothesis and describes an effect (<u>expectation</u>) of the causal explanation. A prediction must be <u>exclusive</u> to one hypothesis and <u>testable</u>.

RELATIONSHIP BETWEEN HYPOTHESES AND PREDICTIONS:

Hypothesis is a broad statement, while prediction is specific (<u>specificity</u>). Prediction is derived logically from the hypothesis (<u>order</u>). Hypothesis and prediction have different <u>roles in inquiry</u>.

FINDINGS AND IMPLICATIONS

Analysis shows that faculty definitions of hypotheses (Fig. 1) and predictions (Fig. 2) are largely aligned with the Popperian perspective. Faculty members' conceptions of predictions are more consistent across participants and show more alignment with deductive codes as compared to conceptions of hypotheses. In contrast, responses from both TAs and undergraduate students were more variable and different from the faculty as well as more divergent from Popper's ideas (more inductive codes). Both these participant groups expressed fewer descriptive features while describing predictions, as compared to hypotheses – a trend not seen in faculty members. Undergraduate students' definitions suggest that they conflate the two concepts, with several descriptive features overlapping between the two.

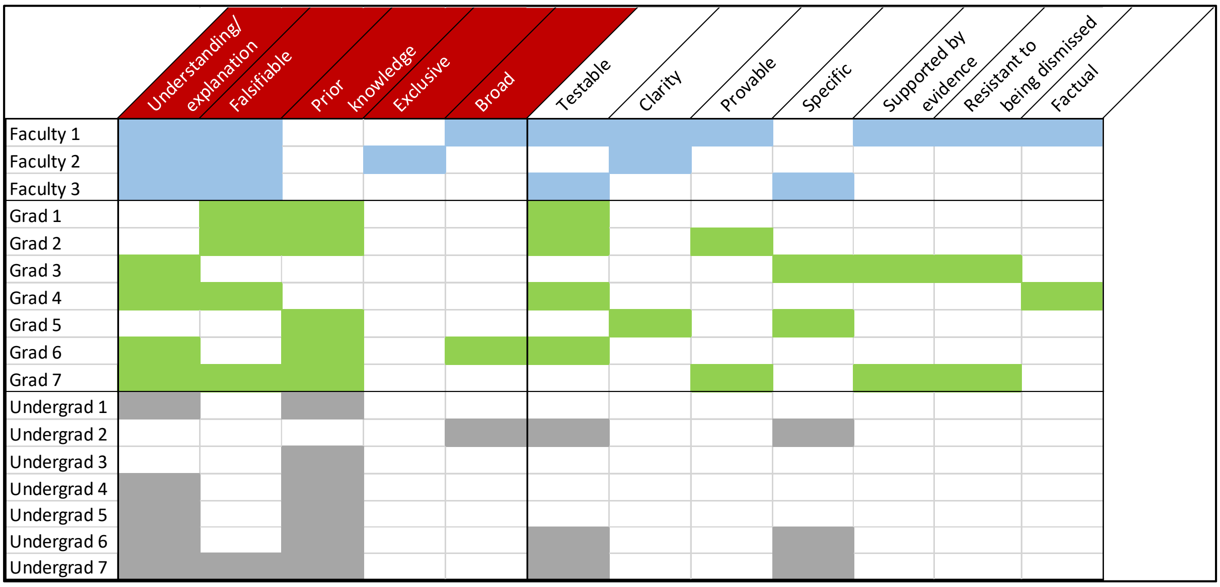

Figure 1. Participants' conceptions of scientific hypotheses. Red column headers indicate deductive codes. Highlighted cells indicate occurrence of a code in participant response.

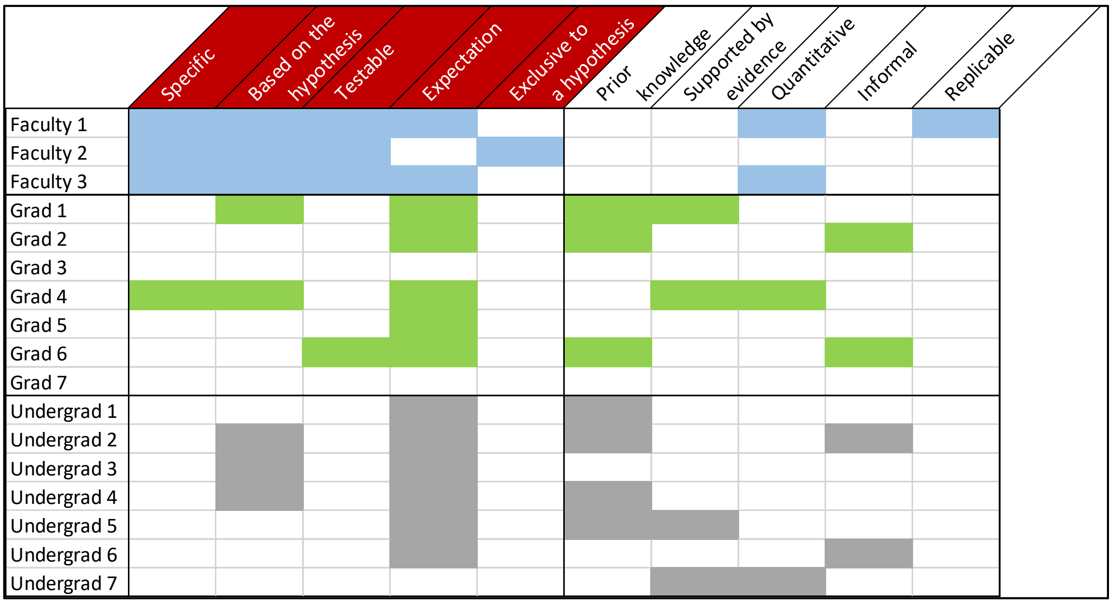

Figure 2. Participants' conceptions of scientific hypotheses. Red column headers indicate deductive codes. Highlighted cells indicate occurrence of a code in participant response.

Both faculty members and graduate students' conceptions regarding the role and importance of hypotheses and predictions in science align largely with Popper's perspective, though the data also revealed several inductive codes (Fig. 3). Undergraduate students had very few descriptive features for importance and role of these concepts, as compared to other participant groups. These findings suggest that both graduate TAs and undergraduate students may be relatively unfamiliar with the concept of a prediction, as compared to a hypothesis. Faculty, on the other hand, seem to have narrowly defined conceptions of the concept and application of predictions which align with the Popperian perspective. Both faculty and graduate students shared detailed and varied perspectives on the role of hypotheses and predictions in scientific inquiry, but undergraduates did not show much knowledge about application and importance of these concepts.

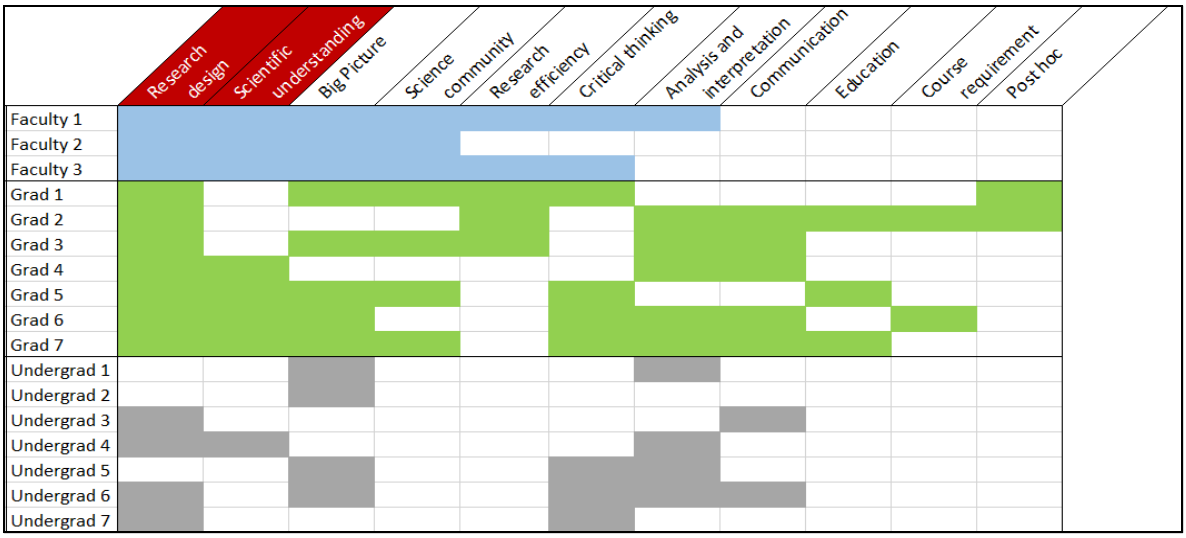

Figure 2. Participants' conceptions of the role of hypotheses and predictions in science. Red column headers indicate deductive codes. Highlighted cells indicate occurrence of a code in participant response.

Lastly, we see that faculty and graduate student groups identified similar challenges to student learning and opportunities to improve based on those, including 1) research experience, 2) explicitly teaching the concepts, 3) emphasizing student diligence towards these concepts, and 4) acknowledging that different schools of thought exist regarding how to define and use hypotheses and predictions (Fig. 4). Undergraduates, however, did not self-identify any challenges, which further strengthens our claim of a strong need to support undergraduate students in better understanding the nature and role of these fundamental concepts.

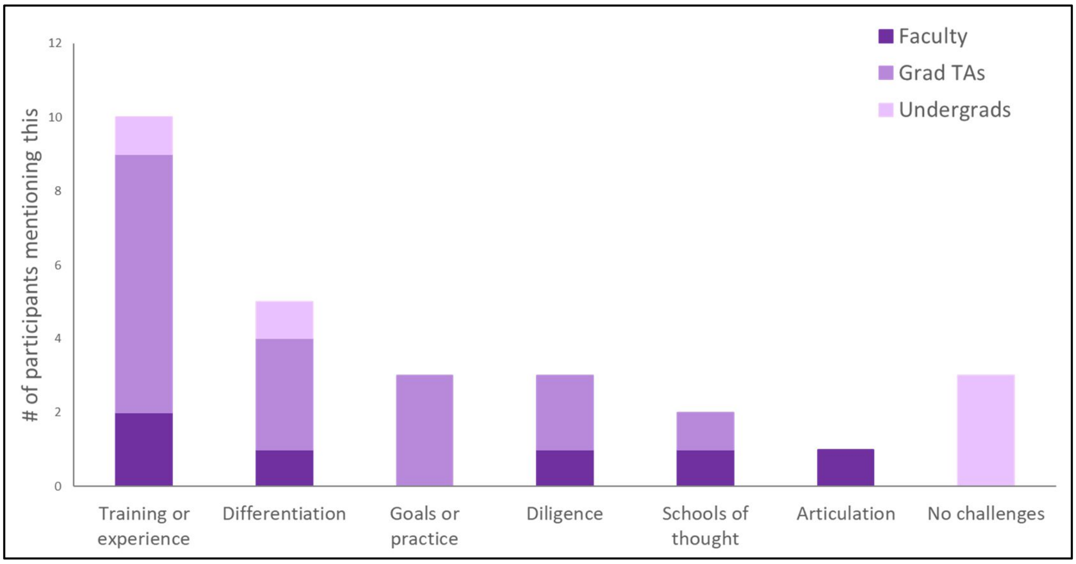

Figure 2. Challenges and opportunities for student learning identified by participants. Faculty n=3, graduate students n=7, undergraduate students n=7.

These findings suggest that both graduate TAs and undergraduate students may be relatively unfamiliar with the concept and application of a prediction, as compared to a hypothesis. This is similarly reflected in these two groups' diversity of conceptions regarding the relationship between hypotheses and predictions. Faculty, on the other hand, seem to have narrowly defined conceptions of the concept and application of predictions which align with the Popperian perspective. This is also mirrored in the consistent descriptions of the relationship between hypotheses and predictions. All participant groups had similarly diverse conceptions of hypotheses, which is notable considering the emphasis generally placed on scientific hypotheses in both research and teaching. Further analysis with more participants will be aimed at revealing patterns in this diversity that may exist between participant groups as well as within faculty members from different research sub-disciplines. Given the recent advances in methodologies and approaches to science (E.g.: data mining, computational and modelling techniques), it is interesting that the conceptions of inquiry expressed by all biology faculty in our limited sample still reflect the ideas originally put forth by Popper.

While there is continued emphasis on scientific hypotheses and, sometimes, predictions in prescribed guidelines for science education, this study is the first to explicitly investigate whether instructors' and students' understanding of these concepts is similar. Our preliminary findings serve to highlight the existence of variation in conceptions of scientific hypotheses among biology instructors and indicate divergence in conceptions of both hypotheses and predictions between instructors and students. These findings open up the discussion about the varied ways in which biologists think about hypotheses and predictions in relation to their own research as well as how they are framed for undergraduate students. A critical piece in our understanding of how best to support students in developing competence with these concepts and experimental design is to identify challenges that students face. Therefore, our study marks an essential first step in designing clearer and more consistent instruction and assessment regarding scientific inquiry for students of biology.

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PROVIDING WAYS TO A HEALTHY DIET: PROFESSIONALIZATION IN THE CONTEXT OF SUSTAINABLE HEALTH EDUCATION IN ZANZIBAR

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The purpose of the interdisciplinary study Proshed (Professionalization in the context of sustainable health education in Zanzibar) is to improve the professional development of students at the School of Health and Medical Sciences (SHMS) from the State University of Zanzibar (SUZA). The aim is to find a suitable design for a lecture[19]*, that is likely to strengthen the students´ pedagogical content knowledge (PCK) with regard to sustainable health education. PCK includes the knowledge about conveying a certain content, that can be applied by patients in their everyday life. Therefore, a comprehensive concept and materials for a university course are developed and implemented in close cooperation of scientists and science educators of the University Bremen (UB), SUZA and Leibniz Institute for Prevention Research and Epidemiology – BIPS (BIPS). Following the paradigm of Design-Based Research (DBR) this explorative study is organized in cycles. This publication focuses on the first cycle, conducted in 2020. The pre-analysis is based on a first literature review and previous research activities within the project "Increased competencies for nutrition in Zanzibari health care" (MENTION). MENTION aimed to incorporate nutrition and health maintenance topics into the curriculum of the training programme for medical professionals in order to train medical experts' content wise and to provide current data on the Zanzibari society. This prior analysis results in a first design framework visualized in a Conjecture Map (CM). Based on the CM the initial cycle is led by the first Research Question (RQ): "What is a suitable design for lecture materials on sustainable health education for SHMS students?" Empirical data is drawn from interviews with 6 SHMS lecturers and a placemat on the method of Material-Based Writing, that was created during a lecturer-meeting. Based on those Design Principles (DP) for improved PCK - promoting materials and teaching concepts are deduced, the initial CM is specified and conclusions are drawn with regard to the practical implementation, design methodologies, design frameworks and further research steps. The findings indicate, that 1) building an own scientific-based and target-group oriented judgement with the method of material-based writing and 2) developing target-group oriented instructional strategies might be suitable mediating processes in order to promote the health and medical students´ PCK (design framework). Furthermore, the CM is seen as a useful tool to frame designs at the beginning of DBR-studies (design methodology). The specified CM is used to develop a first concrete Activity sequence, that allows research* ***on*** *the material and an evaluation of the first design approach.*

Keywords: Pedagogical Content Knowledge, Health Education, Design Based Research

[19] In agreement with the practitioners at the SHMS the term "lecture" is used to describe a university course for students, that enables student-student and student-teacher interaction and discussions.

CONTEXT AND RELEVANCE TO SCIENCE EDUCATION

Based on principles of Design Based Research (DBR), this study provides advantages for research AND practice (McKenney & Reeves, 2019) in the context of health education. Trainings on communication skills and sustainable health education are rare (Warde, Papadakos, Rodin, Salhia & Giuliani, 2018). These challenges are also faced by the SHMS (Nyangasa, Buck, Kelm, Sheikh & Hebestreit, 2019). After nutritional challenges have been identified (ebd.), a workshop was conducted at SHMS together with members from BIPS and UB in 2018 ending with the outlook of finding long-term solutions for better health outcomes by improving the medical students´ academical education. The resulting project MENTION aimed to incorporate nutrition and health maintenance topics into the curriculum of the training programme for medical professionals in order to train medical experts content wise and to provide current data on the Zanzibari society (Hebestreit, 2022). As part of MENTION, Proshed aims to provide innovative educational concepts and materials to promote students´ professional development. Beneath the practical output, DBR aims to further develop or use existing theories in new contexts (McKenney & Reeves, 2019). In this study the theoretical framework of PCK by Park and Oliver (2007) is transformed into the context of education for health and medical students and therefore aims to fill a gap between science education and medicine. PCK includes knowledge of how pedagogy can be effectively combined with content knowledge. It is thus knowledge of how a topic can be made understandable for learners (and possibly patients). While theory application and development are still background in the first cycle, first results in the areas of design frameworks and design methodologies (Burda-Zoyke, 2017) are generated. Design frameworks are given through first Design Principles (DP) and aim to provide concrete advice for a lecture design. Such DP stay hypothetical in a qualitative study (Bakker, 2018). Design methodologies can help researchers to design future DBR-studies in similar contexts. This publication provides an example of how Conjecture Maps (CMs, Sandoval, 2014) can be used for the pre-Analysis.

THEORETICAL BACKGROUND

Health Literacy (HL) comprises ‘cognitive and social skills which determine the motivation and ability of individuals to gain access to, understand and use information in ways which promote and maintain good health (Nutbeam, 1998, p. 357). The lack of HL is a huge public health challenge (Sørensen, 2019). The way of communicating medical information can influence the patients´ HL (Bittner, 2016). Nevertheless, trainings to foster communication skills and sustainable health education for medical students are rare (Nyangasa et al., 2019; Warde et al., 2018). Approaches to promote the competence of transferring knowledge sustainably are common in science education, but not yet in medical education. Kuhnert (2011) suggests to use school pedagogy to improve communication skills of medical students. Surely, the concepts cannot just be copied into another context, but serve as a starting point in order to design environments, that enable health and medical students to provide sustainable health education. Park and Oliver (2007) provide an integrated concept of how to promote teachers PCK in science. From their perspective PCK is the “teachers’[doctors] understanding and enactment of how to help a group of students [patients] understand specific subject matter using multiple instructional strategies, representations, and assessments while working within the contextual, cultural, and social limitations in the learning environment."[20] (ebd., p. 246) Based on a structured literature review, they provide an inclusive PCK-model, that is used in this study as a basis for an adjusted concept for medical students. As Park and Oliver (2007) point out, the different elements of PCK are not distinct and influence each other. Therefore, aspects like Knowledge of Science Curriculum (knowing what information are important) or Knowledge Assessment (knowing how to asses if the learners / patients understand the given information) are automatically part of the research and the design and cannot be excluded. Nevertheless, initially the focus is put on Instructional Strategies and Student [in this context patient] Cognition, because their importance for PCK-promotion is highlighted in several studies (Herzog, 2019; Park & Chen, 2012). With regard to Instructional Strategies Magnusson, Krajcik and Borko (1999) distinguish between general approaches to instruction, that include inquiry-oriented instruction and specific strategies for teaching a particular topic (as cited in Park & Oliver, 2007, p. 266). Student [Patient] Cognition[21] is referring to typical arrows and misconceptions students [patients] might have on a specific topic (e.g., healthy nutrition, nutritional needs), their motivation, interest, need and diversity in ability (Park & Oliver, 2007).

PRE-ANALYSIS

The above described Workshop, which was held in 2018 with members of UB, SUZA and BIPS and aimed to develop first approaches for better health outcomes in the Zanzibari Community resulted into an internal report, that defined prioritized target groups, topics and suitable channels for Nutrition Education. Based on this report (Hebestreit & Alawy, 2018) a pre-analysis is done and framed in a Conjecture Map (CM). CMs are a "technique for conceptualizing design research […], a means of specifying theoretically salient features of a learning environment design and mapping out how they are predicted to work together to produce desired outcomes" (Sandoval, 2014, p.19). Further Sandoval (2014) describes this method as supportive tool for conceptualizing and carrying out research on learning environments and Reinmann (2014) adds that design assumptions can thus be made explicit and open to criticism (and therefore improvement). This is why the CM is chosen as a tool for framing a first concept, that has to be specified later in the research process. For this, main results of the Workshop report were outlined and allocated to the sub categories given by Sandoval, serving as first possible embodiment of main features of the lecture. The CM for the first design of a Proshed-lecture is given in figure 1.

[20] In brackets the hypothetical transmission into the context of Proshed.
[21] This term is used by Kuhnert (2011) and is considered more suitable for this context. Park and Oliver use the term "Knowledge of Students´ Understanding in Science".

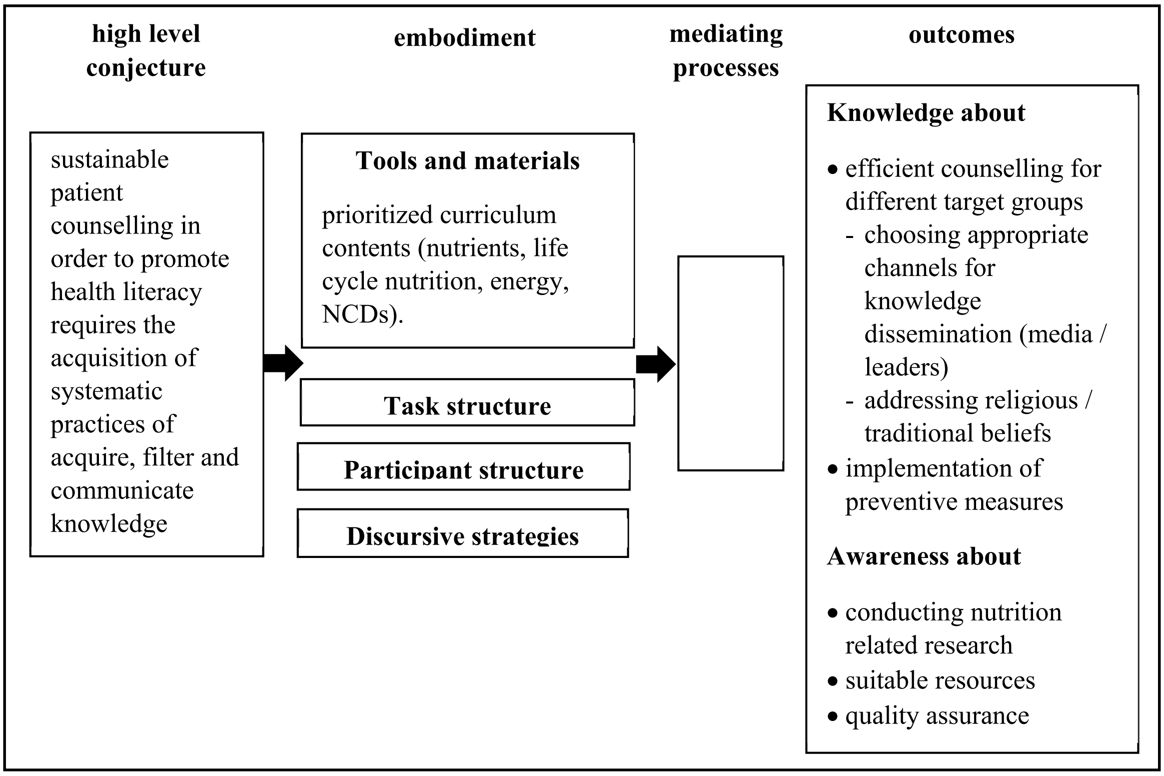

Figure 1. Conjecture Map based on the Pre-Analysis.

The high-level conjecture is a "theoretically principled idea of how to support some desired form of learning, articulated in general terms and at too high a level to determine design" (Sandoval, 2014, p.22). It is objectified in specific design features, that are captured in the embodiment. Tools and material of the embodiment should include contents that have been prioritized through the Workshop in 2018. Sandoval (2014) names three other elements within the embodiment: 1) Task structure (goals, criteria and standards of tasks), 2) Participant structure (way of participation of students and teachers in the tasks, roles and responsibilities) and 3) Discursive practices, that are referring to the "ways of talking" (ebd., p.22) within the lecture. Those still need to be more explored, as well as the Mediating processes - activities, that possibly produce intended outcomes (ebd.). Based on the MENTION Workshop Report (Hebestreit & Alawy, 2018), desired outcomes are an efficient counselling for different target groups, while using appropriate channels for knowledge dissemination and addressing religious and traditional beliefs, and preventive measures. In order to support these goals, it is seen as useful to raise awareness about conducting Nutrition related research, high qualitive resources and quality assurance. The CM, as a result of the Pre-Analysis, serves as a first and rough design framework. This framework is used to structure the first cycle within the DBR approach, that is divided into three sub-cycles: Analysis and Exploration, Design and Construction and Evaluation and Reflection. The research question (RQ) of the first cycle is directly building up on the CM and aims to provide a more detailed specification of the lecture design with the focus on the embodiment and mediating processes.

RESEARCH QUESTIONS (RQ)

The RQ1 "What is a suitable design for lecture materials on sustainable health education for SHMS students?" leads the first cycle. Lecture material includes information resources and material that structures tasks and enhances communication, e.g., working booklets. RQ1 focuses on research for material design, specifically on needs for a hypothetical design. Not only the sub-cycle Analysis / Exploration, but also Design / Construction and Evaluation / Reflection serve a needs and context analysis, that builds up on the MENTION Workshop and deepens its results with regard to embodiment and mediating processes. The sub-questions are shown in table 1. The leading question of the first sub-cycle is focusing on getting more specific perspectives on the needs of the SHMS. The leading questions within Design / Construction are building up on the results of the first sub-cycle and lead to a first design of activities, that can be evaluated in the following sub-cycle Evaluation / Reflection, that is not part of this publication.

Table 1. Core phases and sub-questions of RQ1.

What is a suitable design for lecture materials on sustainable health education for SHMS students?	
Core phase	Leading questions
Analysis / Exploration	What are the needs of SHMS lectures to improve the medical training with regard to sustainable health education?
Design / Construction	How should the lecture material be designed to address the needs of SHMS students and lecturers? What is known about the method of material-based writing and the development of a scientific based judgement?
Evaluation / Reflection	How is the first draft of the material developed received; What should be maintained and improved? (not included in this publication)

RESEARCH METHOD AND DESIGN

To answer RQ1, different qualitative methods are used. In Analysis / Exploration, based on a previous literature review, interviews with 6 lecturers of SHMS from different disciplines of the Medical Doctor and Environmental Health Program (e.g. biochemistry, nutrition) are conducted with the focus on needs identification. In Design / Construction first material is designed on the basis of a literature review on material-based writing (MBW). A document analysis of a placemat on the lecturers' perspective on MBW supplements the data. After the lecturers have been introduced to possible teaching methodologies, that might fit to intended outcomes (MBW, mysteries, video and business games, syndrome approach), the lecturers were asked to fill a placemat with the heading "How can we use the new impulses for the first semester of the new students?". The lecturers decided to focus on MBW, because it seemed most promising. They noted own ideas, which were commented by the other lecturers and lead to a summary of main elements, that need to be considered by implementing MBW. This summary is used as supplement data. In Evaluation / Reflection the implementation will be evaluated. This sub-cycle is not reported in this publication. The interviews are coded deductively based on the focus question of the sub-cycle and then coded inductively to identify emergent aspects. The categories are summarized in several steps, until core elements are determined. The core elements form the empirical part of the DP. Together with findings from literature, first DP for the skeleton design of the material are formed and afterwards summarized in pragmatic and specific principles (Bakker, 2018). For the document analysis (Placemat), the already summarized desired characteristics of MBW are compressed and thus serve as a supplement to the proposed establishment of MBW in the literature. Based on the findings DP are formulated and used for adjusting the CM.

FINDINGS AND DISCUSSION

In the following the pragmatic DP for the first two sub-cycles are given. For each sub-cycle one example of a specific DP is provided.

Table 2. Pragmatic and specific principles of cycle 1.

Core phase	Design principles
analysis and exploration	**Pragmatic Principles:** If you want to design a lecture for health and medical students on sustainable health education, you are advised to… 1) Provide a foundation with a holistic understanding of health and use an inquiry and student-oriented approach, that can be easily implemented by lecturers and students, includes diverse methods and materials and promotes community work. Test- and Evaluation strategies should be provided. (**foundations of the lecture**) 2) Focus on relevant topics, that have a strong influence on health and prioritized target groups for Nutrition Education. Consider different influences on health promoting decisions as well as interdisciplinary perspectives on nutrition. Provide scientific-based information and highlight the importance of efficient and targeted knowledge dissemination strategies. (**lecture contents**)
	Example of a specific principle of the pragmatic principle 1: Provide diverse methods and material, including e-learning material, because chances of e-learning possibilities for medical education in low- and middle-income countries are not yet fully utilized and explored and a high diversity of materials can support the adaptability to the learning environment. (Barteit et al.,2019)
design and construction	**Pragmatic Principles:** If you want to implement the material-based writing as methodology in a lecture for medical students on sustainable health education, you are advised to… 3) Chose a guided inquiry approach with a supporting learning environment with explanatory tools, and diverse materials – including e-learning materials and support students in finding a focus topic as well as evidence in scientific-based material for their own argumentation. For this introduce the correct use of scientific sources and provide tiered assistance before and within the writing process. (**methodology**) 4) Encourage self-regulated learning in groups with possibilities for peer exchange and support lecturers in their role of mentors. (**social form**) 5) Provide interdisciplinary content with a focus on local challenges and environments and strengthen the students in building their judgements based on scientific knowledge. (**content**)
	Example of a specific principle of the pragmatic principle 5: Focus on local challenges and environments by considering challenges and the availability of specific food types in Zanzibar, because health and nutrition behaviour is complex and influenced, among others, by environmental and personal determinants and the students can get the chance to gain specialist knowledge in this area [with support of MBW]. (Feilke, 2017; Schlüter, Vamos, Wacker & Welter., 2020; Sturm, 2017)

The deduced DP provide detailed information for the lecture design. Future results will merge with these and lead to more specific DP and in the end to concrete activity sequences. As a result of this initial study, general important features are outlined in order to provide a more detailed CM as a framework for future design processes. The adjusted CM is given in figure 2. The arrows indicate how design features are expected to work together. Each indicated relation is open to empirical investigation (Sandoval, 2014). Dotted arrows indicate less likely interrelations - because learning environments are complex and cannot be differentiated they all lead more or less to a pattern of change in outcomes (Salomon, 1996 as cited in Sandoval, 2014).

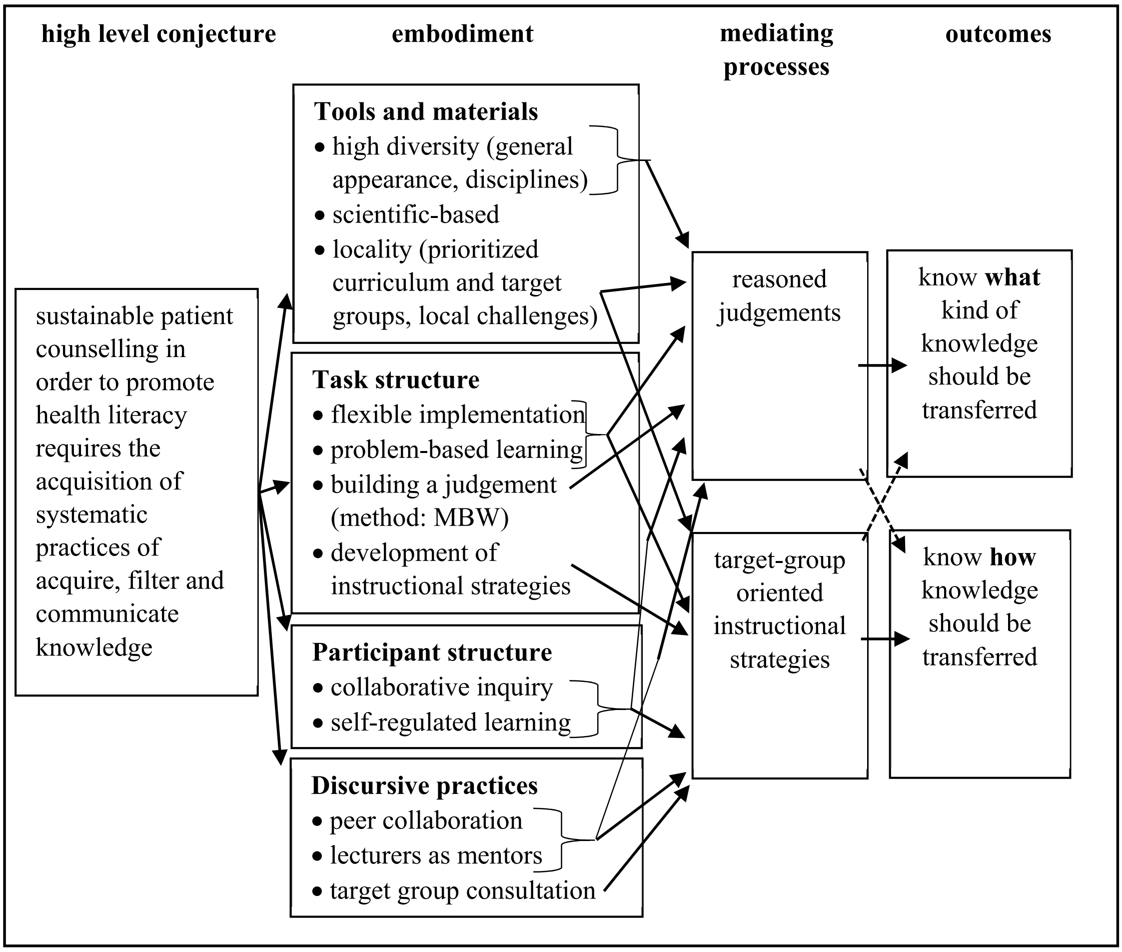

Figure 2. Adjusted Conjecture Map based on the Design Principles

Embodiment

Tools and materials should have a high diversity concerning their general objectives and reference to the nature of topics, that are taught at SHMS in order to strengthen the linkage between those disciplines. Furthermore, they should be scientific-based and referring to prioritized curriculum goals, that have been highlighted in the MENTION Workshop report (e.g., training on traditional believes with regard to nutritional needs). The tasks should be flexibly implementable to assure a sustained usage. Based on local challenges of the target groups, students should learn to build an own scientific judgement. It was discussed with workshop participants, that it might be supportive to develop instructional strategies in the lecture. Collaborative inquiry and self-regulated learning are seen as possible participant structures. This is not only a potential way of learning to transmit knowledge sustainably, but also an opportunity for the university to produce up-to-date and materials, that can support health outreach events. Argument-based inquiry, that includes constructing evidence-based claims and negotiations, seem to promote a sustainable implementation (Suh & Park, 2017). Self-regulated learning can support trainee doctors to develop self-efficacy, that enables them to use own resources and gain experience in complex decision making (Paes, Leat & Stewart, 2019). Three discursive practices are outlined. Students should collaborate with peers, while lecturers should function as mentors. Group work and guided learning might improve skills development in the area of evidence based practise and research knowledge translation (Hickman et al., 2018). This refers to the need of SHMS, that the lecture should be flexible implementable (mentoring is more flexible than settled lecture times). Thirdly target group consultations supplement the design of instructional strategies for patients, that can be used during these consultations. As underlined by Somporn, Ash and Walters (2018), community work has advantages for learners, patients and the health system.

Mediating Processes and Outcome

Recapturing the embodiment and the desired outcomes, possible mediating processes are identified. Health and medical students should arrive on a reasoned judgment with regard to specific target groups. Based on this, they should develop instructional strategies. These mediating processes intend to produce the outcome, that students learn what kind of knowledge is important for the target group and how it should be transferred in order to make it usable for the patient.

CONCLUSION

A conclusion can be drawn for the first implementation of the Proshed lecture as well as theoretical considerations on design frameworks and design methodologies (Burda-Zoyke, 2017).

Implications for practice and research

The CM is used for the first design of activity sequences, that can be conducted with students in order to evaluate the first design. The evaluation will lead to a new focus and RQ for the second cycle, which will emphasis research **on** material in order to improve the lecture concept.

Implications for design frameworks and design methodologies

Design frameworks: The DP presented above provide a more detailed framework for the lecture design, that aims to enhance health and medical students PCK. The DP serve as a basis for further specification of the design and will be combined with results of future cycles and so merge into new and more specific DP. Nevertheless, if you want to access all specific DP that feed the presented general DP, don´t hesitate to contact the first author.

Design methodologies: Using CMs as a tool to visualize and structure first design ideas supports the initial phase, when first ideas from practical experience and hints from literature, need to be structured in order to determine a suitable research question. Although possible influences are still highly hypothetical, the visualized interrelations can be used for planning in-depth analysis. Based on the experience of this study, the CM should be used as a tool for structuring initial ideas, visualizing current status and planning further steps in the research process. They should not be seen as rough settled concepts of the final design.

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AN INNOVATIVE SHORT BLENDED FORMAT FOR TRAINING GRADUATE STUDENTS TO FOOD CHEMICAL SAFETY

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A new innovative short blended teaching format is described here. It combines group activity in class based on a Thiagi frame game with production of graphical representations, and distance self-learning using open-access interactive digital resources organized in several successive modules. The total duration of the lesson is 7 hours, and its scientific content concerns the food chemical safety and related risk assessment. It is proposed in a Food Toxicology course of a second-year master degree academic program related to Toxicology and Environmental Health, with a majority of biological students as audience. Testing this new format with a cohort of students showed benefits: students were more engaged and encouraged to collaborate, learning from their peers through the production of graphical representations in class; in addition, success rates on the final exam increased. Because open-access resources were used to design this innovative teaching format, they could be used by colleagues interested in food chemical safety. Besides, the innovative format tested could be transposed to other teaching issues.

Keywords: Cooperative learning, Graphical Representations, ICT Enhanced Teaching and Learning

INTRODUCTION

Food safety is a major issue in the 21st century, as access to safe and nutritious food is crucial to sustain life, promote good health, and economic growth (Fung, Wang and Menon, 2018). Diet is recognized as a major contributor to exposure to several chemical hazards, with possible long-term deleterious effects on human populations. Several chronic diseases are suspected to be related to chemical contaminants in the food chain, such as obesity possibly related to endocrine disruptors. Future managers in the health or food sector need to be trained in food chemical safety, especially as several global factors (such as climate deregulation) are driving changes in food safety systems (Food and Agriculture Organization, 2006).

The academic context

The graduate program considered here is the second year of a Master's degree in *Toxicology and Environmental Health*, delivering 60 European Credits (EC). Food chemical safety is part of one-week *Food Toxicology* course (30h, 3EC) placed at the end of the first semester and offered as an option to students. Students taking this course come from a variety of backgrounds (biological background with little knowledge of chemistry; biological or chemical engineering students; pharmacy or medical students; professionals wishing to acquire new skills). A 6-hour course dedicated to food chemical safety is taught in this course with a traditional format of two 3-hour periods and primarily transmissive instruction. The learning objectives are fairly high in Bloom's taxonomy, with the final exam requiring critical thinking and risk calculations. A portion of the course time is devoted to an exercise to familiarize students with chemical risk assessment and to somewhat align the learning activity with the final exam, but the teaching method still needs improvement.

Theoretical considerations

The learning modalities were designed to provide "E-focused" blended learning along Jone's continuum (Chew, Jones and Turner, 2008), with interactive digital resources for distance learning and a student-centered pedagogical approach. Instructional techniques designed to have students work together in small, structured groups to achieve common goals (i.e. cooperative learning) were also considered, as group activities provide real opportunities for free discussion among students, with the potential to bring students into their zone of proximal development, thereby promoting learning and development (Eilks, Markic, Bäumer and Schanze, 2009). Tasks that require students to cooperate within the group are recommended (Gillies, 2016); producing a graphical representation seems to be an appealing option, as this task has been reported to improve scientific thinking (Fan, 2015).

A NEW STUDENT-CENTERED BLENDED FORMAT

The innovative blended format is designed to integrate the above theoretical considerations: (i) interactive digital media for distance self-learning; (ii) cooperative learning; and (iii) the production of graphic representations.

Session One: in-class cooperative learning (3h)

This classroom session is based on a cooperative Thiagi frame game focused on the issue of consumer risk assessment due to neoformed toxic compounds, immediately following a short instruction to impart the required knowledge about these types of food contaminants. Named "*Group grope*" (The Thiagi group, 2016), the game is played in several rounds with students divided into defined groups (they were asked to pick up a playing card as they entered the classroom, to be quickly divided into groups). First, each student is given four blank paper cards, and asked to write a kea idea on each card related to the main topics of the course issue (e.g., what data to acquire, collect and combine to assess risk). The teacher then collects and shuffles all the completed cards, before redistributing three cards to each student; the remaining cards are left visible on a table. Students may swap cards with those left on the table or with their peers, while keeping three cards in hand. Later, students work within their group to select only three of their cards to keep, and to draw a graphic representation detailing the content of those three cards to explain how to assess the risk to consumers of a particular example of neoformed toxic compounds in food. A short time is set aside at the end of the session to give oral feedback on the students' production, and to provide them with key knowledge relative to the risk assessment methodology.

Second session: distance self-learning on a case study (3h)

This session focuses on analytical methods for food chemical contaminants. The scientific content is available on the LMS platform, with distinct, short and successive modules (see illustration in **Figure 1**) offering different selected materials: texts and graphical representations, a short video, interactive digital educational resources in free access (specific pages of the CHIMACTIV website) and evaluation tests.

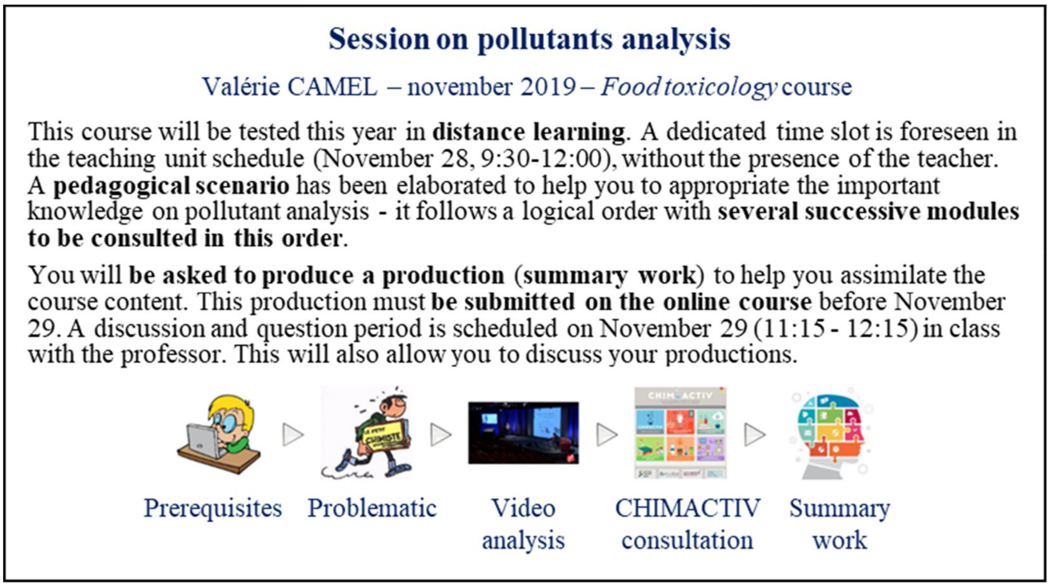

Figure 1. Home page of the asynchronous distance learning course offered on the LMS. (student view, originally in French and translated here into English; the modules images are interactive – by clicking on each module, dedicated pages and content are available).

Students are expected to consult these resources in autonomy and produce an individual assignment summarizing the highlights and ideas related to the course issue, with application to a case study on neoformed toxic compounds in foods. Instructions are given for completing this individual summary assignment, which must be submitted on the LMS platform by the last day of the course.

Third session: classroom exercises (1h)

This session is devoted to giving feedback on the students' individual productions and answering their questions. Key points relative to food regulations are also presented, before practicing on a risk assessment case study.

The learning scenario finally designed and proposed to the students is illustrated in **Figure 2**.

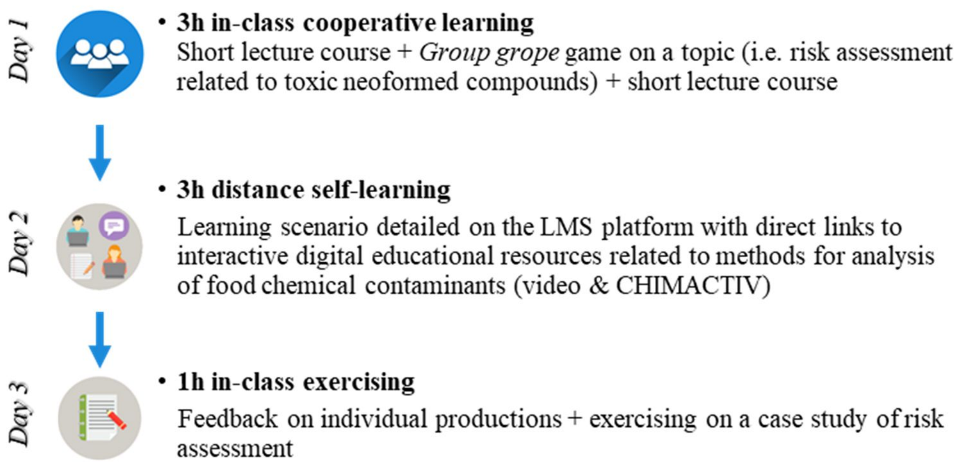

Figure 2. The proposed student learning scenario for the blended format.

RESULTS

Student views and academic performance

The detailed opinions, collected through an anonymous online questionnaire (18 respondents out of 18 students), were clearly favorable: 6 comments attributed the Thiagi frame game and the distance lesson as strenghts of the course, and 2 comments suggested adding more distance lessons. The remote session was cited 8 times as a weakness due to the long learning time (several students spent nearly double the time to view the resources). When considering student academic performance on the food chemical safety portion of the final exam for this *Food Toxicology* course, a comparison of the last three cohorts clearly shows the median pass rate improved from 42 to 52% with the innovative instructional format, as illustrated in **Figure 3**.

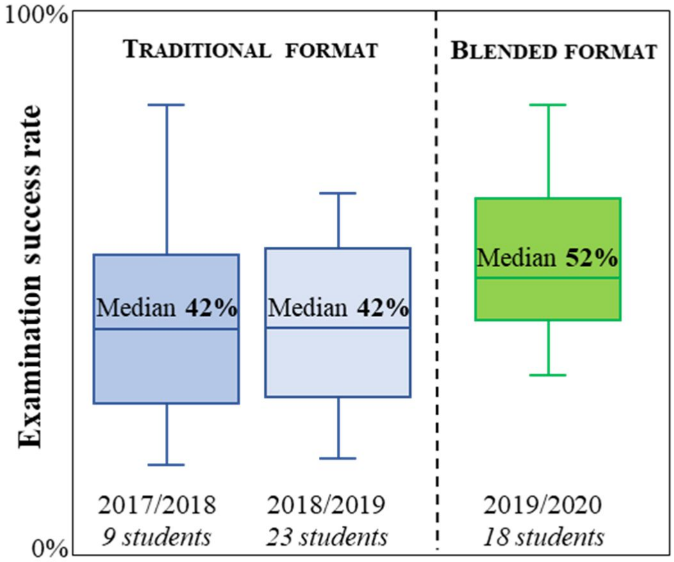

Figure 3. Pass rate on the food chemical safety portion of the final exam for three cohorts of students taught in traditional (2 cohorts) or blended (1 cohort) mode. (median values as well as minimum and maximum values are shown).

The teacher's perception and feeling

The positive attitude and commitment of the students during the Thiagi frame game was very impressive. They all made it through the session without taking a break, which would be unrealistic with transmissive teaching. This activity provided information about their prior knowledge, questions and learning difficulties for themselves and the teacher. Their final graphic representations were of high quality, as shown in **Figure 4**; the students were so proud that they took selfies of their group next to their poster.

For distance learning, even though the individual summary work was not concluded with a final grade, all students sent their production on time. The quality was somewhat uneven but quite satisfactory as shown in **Figure 5**, reflecting the time they spent consulting the digital resources and completing the assignment. With the exception of one student (who misunderstood the content), all students demonstrated their learning of the topic and thinking skills.

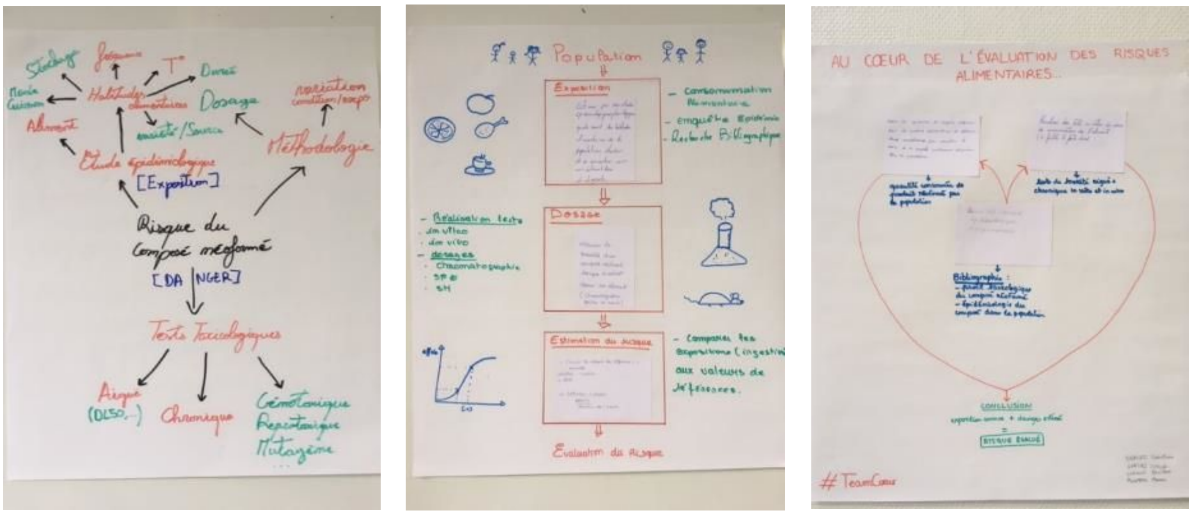

Figure 4. Classroom productions of student groups at the end of the Thiagi frame game.

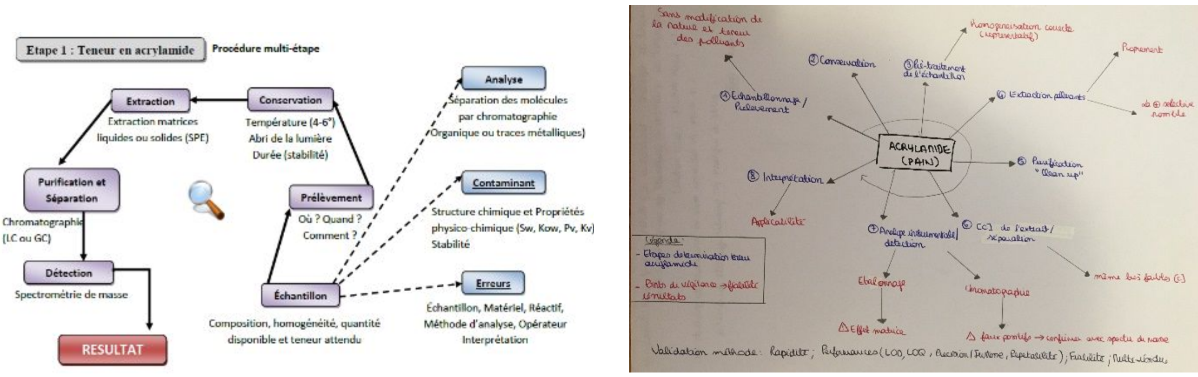

Figure 5. Examples of individual summaries completed in autonomy by students.

DISCUSSION AND CONCLUSIONS

Positive impacts on teaching and learning

The combination of an in-class cooperative work (with a graphic representation as output) and distance learning (with individual synthesis work) appears to be an innovative and effective short format for training master's biology students in food chemical safety. This student-centered format promotes student engagement in their learning, especially the cooperative learning activity as has been previously reported in higher education (Herrmann, 2013); student attitudes and engagement during this group activity are illustrated in **Figure 6**. Distance self-learning allows students to learn at their own pace with flexibility.

Feedback is improved for both the teacher (on the students' questioning and knowledge) and the learners (on their individual or collective productions); this is useful for quick remediation for both parties. This may have contributed to better learning compared to traditional teaching.

Figure 6. Groups of students debating which cards to select during the Thaigi frame game proposed in class.

A format easily transposed to other academic contexts

Due to their simplicity, Thiagi frame games offer interesting alternatives to the Jigsaw class frequently proposed as a cooperative activity (Eilks, Markic, Bäumer and Schanze, 2009; Gillies, 2016; Karacop & Doymus, 2013). Developed and used primarily for corporate training, these simple games are freely available on the web with a wide variety that allows one to choose the appropriate game based on the pedagogical intent. Most of the interactive digital resources used in this study are also freely available (Camel et al., 2020). Thus, this teaching format can be easily used or translated to other scientific issues by colleagues.

Some pitfalls and limitations

The amount of time spent preparing for the remote lesson is significant for the teacher. Another major constraint was to maintain a similar amount of time in the schedule so that the time spent on other lessons remains the same in the program. In the case of distance learning, time must be allowed for face-to-face discussions between the teacher and students, as the students are clearly in demand. It is also very important to take time at the beginning of the course to explain to students the pedagogical intent, and to carefully design the classroom and distance activities.

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