Ana Isabel da Costa Vieira **Promoting self-regulation and mathematics achievement: The role of a hypermedia application**

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Universidade do Minho
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Trabalho realizado sob a orientação do
Professor Doutor Pedro José Sales Luís Fonseca Rosário
e coorientação da
Professora Doutora Paula Cristina Soares Magalhães Silva Correia

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“Quem não desistir, há-de conseguir”
in Sarilhos do amarelo, Pedro Rosário.

Promoção da Autorregulação e rendimento em matemática: O papel de uma aplicação hipermédia

Resumo

O presente estudo teve como objetivo avaliar a eficácia de uma aplicação hipermédia na promoção do uso de estratégias de autorregulação, na autoeficácia a matemática e no rendimento em matemática dos alunos. Um total de 2862 alunos e seus 62 professores participaram no estudo. O estudo seguiu um *design* pré e pós teste, com turmas divididas aleatoriamente por três condições de tratamento. No primeiro grupo, os alunos aprenderam o conteúdo da unidade curricular (i.e. Teorema de Pitágoras) utilizando a aplicação hipermédia projetada para o propósito do estudo; no segundo grupo, os alunos foram informados sobre a aplicação hipermédia, mas não a utilizaram para a aprendizagem do conteúdo; no terceiro grupo, os alunos não foram informados da existência da aplicação e as aulas eram lecionadas sem o uso de tecnologia. Os resultados do pré-teste não revelaram diferenças entre os grupos participantes no conhecimento prévio, aprendizagem autorregulada e autoeficácia. Após a intervenção, os resultados mostraram a eficácia da aplicação hipermédia na melhoria do desempenho académico e dos processos de autorregulação aprendizagem. O primeiro grupo apresentou uma subida significativa nas variáveis dependentes quando comparado com os outros grupos, e o segundo grupo obteu melhores resultados nas variáveis dependentes em relação ao terceiro.

Palavras-chave: aplicação hipermédia; matemática; autorregulação da aprendizagem; rendimento em matemática; autoeficácia.

Promoting self-regulation and mathematics achievement: The role of a hypermedia application

Abstract

The present study aimed to evaluate the efficacy of a hypermedia application in improving students' use of self-regulated learning strategies, self-efficacy in mathematics, and mathematics achievement. A total of 2862 students and their 62 teachers participated in the study. The study followed a pre-post design, with classes randomly assigned to three treatment conditions. In the first group, the students learned the contents of a curricular unit (i.e. Pythagorean Theorem) using a hypermedia application designed for the purposes of this research; in the second group, students were made aware of the hypermedia application, did not use it to learn the content, but were encouraged to use technology in class; and in the third group, the students did not know about the existence of the application and classes were taught without using technology. Pre-test results did not show differences among the participating groups in prior knowledge, self-regulated learning, and self-efficacy. After the intervention, the results showed the effectiveness of the hypermedia application to improve mathematics achievement and self-regulated learning processes. The first group achieved a significant increase in the dependent variables when compared to the other groups, and the second group obtained better scores in the dependent variables relative to the third.

Keywords: hypermedia application; mathematics; self-regulated learning; mathematics achievement; self-efficacy.

Promoting self-regulation and mathematics achievement: The role of a hypermedia application

Data from PISA reports (2009, 2012) pose serious challenges to, and incite reflections in, educators and school administrators regarding the outcomes of the educational systems. As a consequence, several educational systems throughout the world have undergone substantial transformations with the aim of providing a quality education to all students and promoting school success. However, despite that the latest PISA reports (2009, 2012) indicated improvements in Portuguese students, their results in mathematics are still below the average of the Organization for Economic Co-operation and Development (OECD, 2012). There is, therefore, a call to develop effective methodologies (e.g., technology-based applications) to provide students with the skills needed to promote school success.

To accomplish these goals, the introduction of technological tools in class has been considered an essential strategy to assist learning and promote achievement, primarily in mathematics (Garcia & Pacheco, 2013). In fact, nowadays, classrooms are likely to be equipped with technological devices such as computers, whiteboards, and projectors (Cheung & Slavin, 2013; OECD, 2015). These technologies provide new learning opportunities for students, giving them a more diversified access to large repositories of knowledge (OECD, 2010). A recent meta-analysis (Li & Ma, 2010) has shown that students in technology-driven mathematics classes achieve higher grades compared to those in non-technology driven mathematics classes. Still, the sole act of introducing technology in class is not enough to produce important changes in learning (Li & Ma, 2010); thus, new ways to promote an effective incorporation of these tools in the classroom need to be explored (e.g., helping teachers to work towards embedding technology in their teaching lessons) (Cheung & Slavin, 2013).

Self-regulated learning (SRL) and Learning with hypermedia application

Self-regulated learning (SRL) has become a key theoretical framework in psychological and educational research (Rosário et al., 2012; Zimmerman, 2008). SRL can be defined as an active process in which students establish goals to guide their learning and to control their cognition, motivation, and behavior to reach those self-set goals (Fernández et al., 2013; Rosário et al., 2012). Literature offers different models of SRL explaining how the self-regulation of learning occurs. For the purposes of the current study, a model based on the work by Zimmerman was selected (1998, 2000). Zimmerman, (1998, 2000) described the

SRL as a process with three interdependent phases. This cyclical model for SRL set the ground for the model PLEE (Planning, Execution and Evaluation) (see Rosário, Núñez et al., 2010 and Rosário et al., 2015a for a more detailed explanation). The recursive structure of PLEE presents three phases: Planning, Execution, and Evaluation of the tasks, through two paths of logic. The process not only proceeds from Planning through Execution to Evaluation, but the same cyclical loop is also reset in each phase, thus reinforcing the self-regulation logic of the process. Regarding the three phases of the PLEE model, the student begins the *planning phase* by establishing a plan for the task at hand. At this stage, students should analyze their prior knowledge about the task and the contextual resources available, which will help choosing a set of learning strategies to achieve their self-set goals. Afterwards, in the *execution phase*, the student puts the outlined plan into practice by implementing the learning strategies and monitoring the results towards the goals. Finally, in the *evaluation phase*, students check whether they have achieved their goals. The results of this phase inform the planning of new tasks, starting a new cycle (Rosário, Mourão, Núñez, González-Pienda, & Solano, 2007). Lastly, each phase of the SRL processes includes within itself the three phases of the cyclical process. Hence, the two structuring loops of this model reinforce the SRL synergy, allowing the self-regulating process to be experienced as a whole (Núñez, Rosário, Vallejo, & González-Pienda, 2013; Rosário, González-Pienda et al. 2010; Rosário et al., 2015a).

Hypermedia applications, or hypermedia documents, arise and stand out as possible tools to improve the educational achievement of students. These tools are defined as adaptive learning systems that may provide a personalized learning environment (Cueli, González-Castro, Krawec, Núñez, & González-Pienda, 2016; Özyurt, Özyurt, Baki, Güven, & Karal, 2012). In fact, hypermedia applications provide students with non-linear, or non-sequential, dynamics and random access to an extensive amount of information presented in several formats, such as text, graphic, animations, audio, and video (Azevedo, Cromley, & Seibert, 2004; Jonassen, 2007; Scheiter & Gerjets, 2007). To cope with the features of the hypermedia applications, students should be involved in, and regulate, their own learning (Azevedo, 2014; Cueli et al., 2016; Greene, Moos, & Azevedo, 2011). For example, while working with the non-linearity of these environments, students are expected to play an active role (e.g., exercising control over their own learning processes by selecting, organizing, and analyzing the information needed to reach their self-set goals) (Devolder, van Braak, & Tondeur, 2012; Gerjets, Scheiter, & Schuh, 2008). This sense of personal agency is critical to cope with the multiple representations of information available in the applications (Winters, Greene, & Costich, 2008) and learn more effectively.

When studying within hypermedia environments, students make decisions about what to learn (e.g., select the content), how to learn (e.g., how much time is spent on each topic), and how to access the content (e.g., which path to follow) (Azevedo et al., 2013; Duffy & Azevedo, 2015). Hence, students are expected to display SRL strategies to, for example, analyze the context of learning, set achievable goals, select and use learning strategies, evaluate their content knowledge, and monitor whether the learning strategy is effective for a particular learning objective (Azevedo, Cromley et al., 2004; Weerasinghe, du Boulay, & Biswas, 2013). However, hypermedia applications should be designed to provide interactive learning environments to facilitate the use of SRL strategies. For example, hypermedia applications should instigate students' planning (e.g., activation of prior knowledge) and control of the execution phase of self-regulation process (e.g., monitoring the various steps necessary for the outcome) (Aleven, McLaren, & Koedinger, 2006; Azevedo & Crowley, 2004; Graesser, D'Mello, & Person, 2009).

Prior studies have already shown the efficacy of these tools in promoting SRL. For example, Azevedo, Guthrie, and Seibert (2004) reported that students who effectively used the strategies while learning in hypermedia environments (e.g., activated prior knowledge, planned their learning, used sub-goals, and monitored their learning) learned more about the contents than students who did not use the strategies effectively. Additionally, Artino and Stephens (2009) found that, as hypothesized, graduate students enrolled in online courses reported greater use of self-regulated strategies (e.g., critical thinking) and lower levels of procrastination than undergraduate students in the same hypermedia environments.

Despite the aforementioned positive findings, research also indicates that some students struggle to regulate their learning when using hypermedia applications (Azevedo & Cromley, 2004; Azevedo, Feyzi-Behnagh, Duffy, Harley, & Trevors, 2012; Azevedo, Cromley et al., 2004; Greene & Land, 2000; Hadwin & Winne, 2001; Moos & Azevedo, 2006). Specifically, struggling students are likely to show difficulties in activating cognitive functions (e.g., inability to activate prior knowledge), in controlling the characteristics of the hypermedia applications (e.g., coordination and access to multiple representations of information), and in regulating their learning process (e.g., lack of planning of objectives, inability to use metacognitive strategies to understand the content, ineffective use of strategies, and lack of reflection on their progress) (Azevedo, Cromley, Seibert & Tron, 2003; Azevedo, Cromley, Thomas, Seibert & Tron, 2003; Azevedo, Guthrie et al., 2004). However, research has shown that when struggling students are provided with explicit support and structure (e.g., offered detailed instructions, reflective prompting, and strategies to help them self-regulate their learning) they are likely to be successful in their learning efforts (Azevedo, Johnson, Chauncey & Graesser, 2011).

The designs of these types of applications should allow students to interact with the applications in a dynamic, participatory, and reflexive way, with the goal of improving their cognitive strategies (Azevedo et al., 2011). To maximize the promotion of the SRL processes and learning, hypermedia applications, among others, are expected to incorporate the following features: (i) the use of scaffolding (Aleven, Roll, McLaren, & Koedinger, 2010; Azevedo, 2009; Koedinger & Corbett, 2006; Lajoie & Azevedo, 2006) - which can be provided through a digital or human tutor, for example -, is expected to enhance the use of deep processing strategies, improve students' self-regulation, and improve the quality of their learning (Azevedo, Cromley et al., 2004; Azevedo, Crowley, Winters, Moos, & Greene, 2006; Greene et al., 2011); (ii) the use of a device to monitor students' progress while using the applications. For example, providing explicit instructions and assessment instructions (Azevedo et al. , 2011; Winters et al., 2008); (iii) and, finally, the incorporation of a hierarchical structure providing organizational links and cues to help the students move effortlessly within the application (Azevedo et al., 2011).

Purpose of the study

In the last decade, schools and families around the world invested in technology hoping to improve the educational outcomes of their children (Bulman & Fairlie, 2015). For example, the OECD report (2015) indicates that, on average across OECD countries, 72% of 15-year-old students reported using computers at school, and the majority (around 96 to 98%) have computers at home. Moreover, 93% of these students reported having an Internet connection at home. Still, the evidence on the benefits of computer use for learning purposes are limited: "*Despite considerable investments in computers, Internet connections and software for educational use, there is little solid evidence that greater computer use among students leads to better scores in mathematics and reading*" (OECD, 2015, p.145). The use of technology in class can help improve the quality of learning, but technology cannot replace poor teaching, as the high rate of low achievers in mathematics shows (OECD, 2012). Thus, there is a need to create tools designed to engage students and teachers in learning. To address this challenge, the present study uses a hypermedia application specifically designed for this study. The development of the application was grounded on the best practices referred to in the literature as promoters of a good quality of learning and SRL processes (e.g., scaffolding, monitoring of students, and hierarchical structure). In addition, this application follows the objectives of the Portuguese mathematics curriculum regarding the Pythagorean Theorem. Mathematics was selected for this study because it is a subject that is globally known for high levels of failure (Levin, 2006; Preckel, Holling, & Vock, 2006). Moreover, Portuguese students have been showing proficiency levels in mathematics below the OECD average (PISA, 2009, 2012). Plus, according to the European Commission (2010), by 2020, the rate of low achievers in mathematics and science should be lower than 15%, and the Portuguese educational system, among others, is far from attaining this educational goal (OECD, 2010). Finally, academic underachievement is one of the educational phenomena that has generated the most concern both in research and in intervention in the school context (Levin, 2006; Preckel et al., 2006).

When planning the design of the present study, Li and Ma's (2010) meta-analysis results and shortcomings were taken into consideration. Specifically, these authors identified the low number of participants as a limitation of prior studies. Hence, the present study attempted to address this shortcoming by including 120 classes from 30 schools. Additionally, studies identified in the meta-analysis (Li & Ma, 2010) tended to include only two groups (experimental and control) in their design. Therefore, to address this problem, a comparison group, other than the control group, was included to examine the effect of using technology in the class. In addition, the results of the meta-analysis (Li & Ma, 2010) showed that shorter technology interventions (less than 6 months) had more impact in promoting mathematics achievement than longer technology interventions (between 6 and 12 months). Taken into account these results, the present study was conducted over three months. Furthermore, the present study required computer use for 30 minutes or more, as recommended by another meta-analysis that showed that studies using a computer for less than 30 minutes were not as effective (Cheung & Slavin, 2013). Another advantage of the present study is that it was conducted in natural environments during regular mathematics classes instead of being conducted in a special session or in an online setting. We believe that conducting a study with such a large number of students and in a natural environment is expected to add to literature. Lastly, an innovative aspect of the present study was the inclusion of a teachers' training prior to the intervention. The aim was to guarantee that each teacher participating in the study followed a controlled script and to provide training opportunities on how to use the platform aiming to promote desired levels of proficiency.

In sum, the present study aims to evaluate the efficacy of a hypermedia application in improving students' use of SRL strategies, self-efficacy in mathematics, and mathematics achievement.

Method

Participants

Junior high schools from the pool of schools that had already enrolled in University research projects were contacted by the authors, and 30 responded positively. Participants were 8th grade students, 1506 girls (52.6%) and 1356 boys (47.4%), aged between 12 and 15 years (*M* = 13.2, *SD* = 1.21). This particular school grade was chosen because the Pythagorean Theorem is taught at this grade. Globally, the families of these students can be considered lower-middle class, evidenced by the high percentage of students receiving free or reduced lunch (38.7%, data collected from the students' offices of the participating schools). Mathematics teachers from the 30 schools that responded positively were invited to participate in this investigation, and 62 accepted (response rate of 64%). All teachers who agreed to participate were invited to attend a teaching program held at the University.

Measures and Instruments

To evaluate the effectiveness of the hypermedia application in promoting SRL and improving students' performance, we took the following as dependent variables: declarative knowledge on the topic "Pythagorean Theorem", mathematics achievement, self-regulated learning strategies, and self-efficacy in mathematics.

Declarative knowledge in the topic "Pythagorean Theorem".

The students' declarative knowledge in the topic "Pythagorean Theorem" was evaluated with two tests of knowledge developed by a team of junior high school mathematics teachers in collaboration with lecturers from the Mathematics Department. These tests focused on content taught in the eighth grade for the Pythagorean Theorem, and were evaluated on a scale of 0 to 100%. The Cronbach's alphas were 0.89 and 0.87.

Students did the pre-test before the Pythagorean Theorem topic was taught to assess their prior knowledge. The post-test was administered at the end of the learning unit to assess the level of knowledge acquired. Both tests followed the same format (i.e. type of questions, number of questions, duration, and correction criteria).

Mathematics Achievement.

Mathematics achievement was assessed using students' school grades for mathematics. Students' grades from the previous year (7^{th} grade) and their grades at the end of the 8^{th} grade were collected from the schools' secretariats. Portuguese Compulsory Education uses the following grades: 1 and 2 (*negative*), 3 (*fair*), 4 (*good*), and 5 (*excellent*).

Self-Regulated Learning strategies.

The SRL strategies inventory (Rosário et al., 2007; Rosário, Núñez et al., 2010; Rosário et al., 2015c) is a nine-item instrument representing the three phases of the SRL process: Planning (e.g., 'I make a plan before I begin writing. I think about what I want to say and how I need to write it.'); Execution (e.g., 'If I become distracted or lose concentration while I am in class or studying, then I usually try to regain my concentration to achieve my goals.'); and Evaluation (e.g., 'I compare the grades I receive with the goals I set for that subject.'). The items were rated on a 5-point Likert-like scale ranging from 1 (*never*) to 5 (*always*). In this study the Cronbach's alpha was 0.87.

Self-efficacy in Mathematics.

Self-efficacy in mathematics was assessed by a questionnaire comprising 10 items adapted from Rosário et al. (2015b) (e.g., "I can apply the divisibility criteria correctly.") and was purposely developed by the research team for the present investigation. The students evaluated their perceived effectiveness in each item in a 4-point Likert-like scale from 1 (*very easily*) to 4 (*with great difficulty*). In this study the Cronbach's alpha was 0.88.

Hypermedia Application of the Pythagorean Theorem

The Hypermedia Application of the Pythagorean Theorem (HAPT) was designed to help eighth graders learn the content of the Pythagorean Theorem. This application is part of a broader research project called Hypatiamat (available in http://www.hypatiamat.com/). HAPT was built to support the development of students' self-regulatory skills and the acquisition of specific mathematics skills. This tool has, among others, the goal of improving students' motivation towards mathematics (Cueli et al., 2016).

HAPT can be used in a web browser, like Internet Explorer, where access is free. To enter the application, students have to register and then login into their own space ("students' office") where they can monitor and track their performance and do the homework assigned by the teacher. It should be noted that, for the purposes of this research, this application was used in the classroom, and the exercises and homework assignments were adjusted accordingly. Additionally, the teachers have their own space in the application ("teachers' office") where they can track and monitor the work of their students and assign homework.

The HAPT incorporates the aforementioned literature recommendations for hypermedia applications (e.g., scaffolding, digital tutor, and online feedback) to foster student interaction with the application in a dynamic and reflexive way, with the goal of improving their cognitive strategies and SRL. The specific features of the HAPT are the following: i) an avatar (digital tutor) that emulates, as much as possible, the good pedagogical practices of a human tutor. When students face difficulties while solving the exercises (e.g., I don't understand the question asked, I cannot find a strategy to approach the problem) they can ask for the tutor's help. The tutor will display the help needed. When students select the button to disclose the correct answer to the problem without trying to solve it beforehand by themselves, the tutor displays educational messages to encourage students to solve the problem (e.g., Checking without responding is not a good strategy for those who want to learn. Do you want help?; Try to resolve the question before clicking on the "check". Do you want help?); ii) a *skillometer* that displays feedback to inform students about their current level (i.e., 0-100%) on the skills addressed by the HAPT (e.g., determine the unknown sides of a right triangle, apply the Pythagorean Theorem to calculate areas and perimeters). Extant literature highlights the importance of feedback on students' achievement (Azevedo et al., 2011; Koedinger & Corbett, 2006). iii) the *skillometer* also informs students on the amount of work already completed within the application (i.e. number of exercises done, number of exercises corrected) identifying the contents in which the student is facing difficulties; lastly, iv) a battery of exam questions, gathered from national and international exams, is offered to students to help them practice the content learned. These exam questions allow students to check their skills on the topic and regulate their learning. Based on the student knowledge domain, a final feedback is offered indicating whether the student may move forward or is in need of reviewing the previous content.

Procedure

The research took place during the first school term (October – December) and followed a quasi-experimental design, with pre-post measures. The intervention was conducted over three months during which all participating students attended eight, ninety-minute mathematics lessons.

Prior to the intervention, all the participating teachers (62) enrolled in a training program, lasting for 50 hours. At this stage, teachers were blind to their treatment condition. This training program, organized by the authors with the help of research assistants, aimed to: 1) promote more thorough knowledge of the SRL processes; 2) introduce, and train how to work with, the hypermedia platform; and 3) train how to apply the hypermedia tools to the classroom context. During the training sessions, teachers were asked to create a script for each of the Pythagorean Theorem classes using the HAPT. Furthermore, during the training, role-play sessions were held and several suggestions for improvement were presented, as well as changes to the methods used in class and to the lesson plans for Pythagorean Theorem classes using the HAPT. At the end of the training, teachers showed enthusiasm for the platform and for implementing the platform in the classroom.

Three groups were enrolled in the current research, each incorporating 40 randomly assigned classes. In the first group, EG1, the students had knowledge about the existence of the HAPT and the teachers used the application in class to teach the Pythagorean Theorem. Additionally, students were encouraged to use the application at home by performing tasks and homework. In the EG2, students were informed about the hypermedia application to learn the Pythagorean Theorem, but teachers did not use the HAPT in class. Students were still encouraged to use other technology in class as a resource for learning. Lastly, in the third group (CG), students did not know about the existence of the application to learn the Pythagorean Theorem and classes were taught without using technology. All the 120 classes followed the Portuguese curriculum for this particular content.

Data analysis

Data from the different dependent variables (i.e. declarative knowledge, mathematics achievement, self-regulated learning strategies, and self-efficacy in mathematics) were gathered in two occasions: before learning the contents of a curricular unit (i.e. Pythagorean Theorem) and at the end of the intervention. Data were collected by questionnaire and by performing two tests of knowledge (pre-test intended to evaluate the initial knowledge of the content and a post-test intended to evaluate the knowledge acquired by students after the intervention). The results of the knowledge tests (pre and post-test) and the information collected by questionnaire were subsequently analyzed in two steps: firstly, a multivariate analysis of variance (MANOVA) was run for to confirm whether there were statistically significant differences among the three groups of students in the pre-test, regarding the variables examined. Secondly, building upon the results obtained in the first step, a second MANOVA was carried considering the dependent variables together with the purpose of knowing the effect of the program. Statistical tests were conducted on SPSS 23.

Results

Table 1 summarizes the averages and standard deviations related to the study variables (declarative knowledge in the Pythagorean Theorem, mathematics achievement, SRL strategies, and self-efficacy) in the two moments (pre-and post-test), and for the three groups of participants (CG and EG1 and EG2). Additionally, the distribution of variables (skewness and kurtosis) was analyzed to verify whether they met the requirements. Adopting the criterion of Finney and DiStefano (2006), who defend maximum values of 2 and 7 for skewness and kurtosis, respectively, the values of the four variables met this criterion.

As expected, there was an increment of students' declarative knowledge on the domain from the pre- to the post-test in the three groups. However, differences in mathematics achievement were only found for the EG1. Finally, for the SRL strategies and self-efficacy variables, the mean increased for the groups EG1 and EG2 from the pre-test for the post-test, but not for the CG.

Table 1.

Mean and standard deviations of the variables included in the research (pre- and post-test)

	Pre-test								Post-test							
	CG		EG1		EG2		Skew	Kurt	CG		EG1		EG2		Skew	Kurt
	M	*SD*	*M*	*SD*	*M*	*SD*			*M*	*SD*	*M*	*SD*	*M*	*SD*		
Declarative Knowledge	45.91	19.42	45.67	19.79	45.61	18.68	0.20	-0.66	47.84	30.15	62.47	21.07	51.47	23.44	5.16	-0.74
Mathematics Achievement	3.06	0.91	3.10	0.90	3.06	0.85	0.52	-0.45	2.79	0.89	3.21	1.02	3.00	0.99	0.50	-0.61
SRL Strategies	3.47	0.70	3.50	0.68	3.47	0.70	-0.38	0.10	3.42	0.69	3.75	0.69	3.49	0.73	-0.35	0.17
Self-efficacy	2.35	0.58	2.32	0.64	2.36	0.59	0.10	-0.17	2.30	0.61	2.81	0.73	2.60	0.71	0.14	-0.53

Legend: Skew- skweness ; Kurt - kurtosis

Analysis of the intra-subject differences at the pre-test

Classes were randomly assigned to a treatment condition, but participating students, individually, were not. So, to confirm whether there were statistically significant differences among the three groups of students in the pre-test, regarding the variables examined, a MANOVA was run.

The MANOVA data indicates that the observed differences in pre-test between groups are minimal and not statistically significant [Λ = 0.999; F(8.6150) = 0.575; p = 0.799; η^2= 0.0019]. Analyzing the results for each of the four variables taken, the data from the MANOVA indicate that the differences are not statistically significant: declarative knowledge [Z (2.3078) = 0.056; p = 0,945; η^2 = 0.0009], mathematics achievement [Z (2.3078) = 0.516; p = 0.597; η^2 = 0,000], SRL strategies [Z (2.3078) = 0.847; p = 0.429; η^2 = 0.001], and self-efficacy in mathematics [Z (2.3078) = 1.190; p = 0.304; η^2 = 0.001]. These data indicate that, although the participants had not been randomly distributed across the three conditions, the three groups are equivalent.

Analysis of the inter-subject differences at the post-test

Data of a second MANOVA indicated that, at the end of the intervention, there were significant differences among the group of students [Λ = 0.872; Z (8.6130) = 54.212; p = 0.000; η^2 = 0.066], which indicates that the intervention was effective to promote mathematics with a medium effect size. Analyzing the data for each of the four variables, the results of the MANOVA indicate that the differences are statistically significant for all variables: declarative knowledge [Z (2.3068) = 101.791; p = 0.000; η^2 = 0.062], mathematics achievement [Z (2.3068) = 47.730; p = 0.000; η^2 = 0.30], SRL strategies [Z (2.3068) = 67.897; p = 0.000; η^2 = 0.042], and self-efficacy in mathematics [Z (2.3068) = 144.699; p = 0.000; η^2 = 0,086]. These findings confirm the initial hypothesis. In particular, considering the post hoc analysis of the results, students who used the HAPT in class (EG1) achieved a significant increase in the four dependent variables relative to the other two groups. Specifically, the scores were higher for the declarative knowledge and self-efficacy variables, presumably because these were the variables that the HAPT most actively promoted. Regarding the other dependent variables (mathematics achievement and SRL strategies) the increase was lower than for the other two variables. Lastly, students who had knowledge of hypermedia application, but did not use this tool in class (EG2), obtained higher scores in three of the four variables studied (declarative knowledge, SRL strategies, and self-efficacy in mathematics) relative to the control group.

Discussion

This study examined the efficacy of a hypermedia application to improve students' achievement in mathematics, promote the use of SRL strategies, and develop students' self-efficacy in mathematics. Findings showed that the HAPT helped students achieve higher scores in mathematics than their colleagues who learned the content in class using resources other than HAPT. Moreover, students using HAPT in class (EG1) improved in all dependent variables (i.e. declarative knowledge, mathematics achievement, SRL strategies, and self-efficacy in mathematics) when compared to their counterparts.

Our findings are consistent with previous investigations. In the study by Funkhouser (2002), students of the 10th, or 11th, grade used the computer to learn geometry concepts. Findings showed that these students achieved higher in mathematics when compared to students following a traditional approach to geometry instruction. Additionally, the research by Pilli and Asku (2013), and Cheung and Slavin (2013), reported that using a hypermedia application to work mathematics contents was related to positive results, although weak. Lastly, the meta-analysis by Li and Ma (2010) concluded that the use of technologies in mathematics classes promotes higher achievement compared to that achieved by students in non-technology driven classes.

Besides, results of the present study showed that students using the HAPT application increased their reported use of SRL strategies. Particularly, students who used the HAPT in class (EG1) reported using more SRL strategies when compared to their counterparts. In addition, EG2 (students in classes who had knowledge of the hypermedia application but did not use it and were rather, encouraged to use other technologies) did not show higher scores in their reported use of SRL strategies when compared to students in the CG (students who were unaware of the application and learned the Pythagorean Theorem without technological resources). Our findings are consistent with that of Kramarski and Gutman (2006) indicating that when SRL is embedded in the hypermedia application the students' performance is significantly higher compared with that of students working with a hypermedia application without SRL features. Therefore, we believe that the inclusion within HAPT of the aspects detailed in section 2 might have contributed to the promotion of students' SRL in the present study (Aleven et al., 2006; Aleven et al., 2010; Azevedo, 2009; Graesser et al. 2009; Koedinger & Corbett, 2006; Lajoie & Azevedo, 2006).

Finally, regarding self-efficacy in mathematics, students who used the HAPT in class (EG1) achieved higher scores than their colleagues in EG2 and CG groups; besides, students in EG2 achieved higher scores compared to those of students in the CG. These results are consistent with the literature; that is, the improvement in self-efficacy may have promoted students' motivation, encouraged their use of the SRL strategies, and, consequently, increased their academic success (Rosário et al., 2012). In fact, prior research (Schunk, 1995; Schunk & Ertmer, 2000) has indicated the need to include the following features in interventions aiming at fostering self-efficacy: specific, set learning objectives, case-sensitive feedback to help students on their queries, and feedback on the progress. These features were all included in the HAPT, and they may have contributed to the present findings.

Conclusion

The use of technology has become increasingly popular, and pervasive, in elementary and secondary schools over the past decades (Garcia & Pacheco, 2013; Li & Ma, 2010). In fact, it has been considered indispensable in teaching and learning, and an essential element of any good teaching (Cheung & Slavin, 2013; Li & Ma, 2010). Furthermore, technology is incorporated into the daily lives of students, and students show favorable attitudes, being are often inclined to use technology in class (Cueli et al. 2016; Pilli & Aksu, 2013). However, recent educational reports using non-experimental, cross-sectional data (e.g., Bulman & Fairlie, 2015; OECD, 2015) warned that the vast amount of resources invested in technology for education are not associated with clear improvements in student achievement in mathematics. High exposure to technology is not enough to impact students' achievement; the current findings indicate that higher exposure in class to evidence-based tools designed to promote learning might help to improve students' motivation and achievement. In fact, extant research shows that the use of these types of applications promotes the acquisition of academic content (Cheung & Slavin, 2013; Li & Ma, 2010). Most importantly, evidence-based hypermedia applications enhance strategic and self-regulated learning, increase student motivation, and promote positive attitudes towards mathematics, which are all essential aspects in the learning process and, consequently, in the success of students (Cheung &

Slavin, 2013; Cueli et al., 2016; Li & Ma, 2010; Rosário, Núñez et al., 2010; Zimmerman, 2008).

Limitations and future research

The current study has some limitations that should be acknowledged. First, the scaffolding provided is not completely adaptive, as advocated by Azevedo and Jacobson (2008). Future studies may want to address this issue by redefining and restructuring the feedback provided by the tutor. Secondly, the length of time of the intervention with the platform was limited and a single mathematical content was examined. Future research might consider extending the duration of intervention to allow the collection of repeated measures and also examine applications designed with the same framework targeting other mathematical content. This diversity of data would allow for further examination of the potential of these applications to teach mathematical content and promote SRL. Thirdly, due to parsimony, analysis of log files was not included in this paper (e.g., frequency of use of HAPT, average time on HAPT). This analysis would provide an understanding of the behavior of different students while using HAPT and could represent an important, and invaluable, measure to assess students' performance and progress. Fourthly, few variables assessing students' motivation were included and none addressed the teaching process. To build a holistic perspective of the phenomenon, further investigation may want to include other variables, such as academic goals, students' attitudes towards mathematics, and family characteristics (e.g., involvement of parents or caregivers), but also variables related to the educational processes, such as the teacher's approaches to teaching (Rosário et al., 2014) or the type of assessment (Cerezo et al., 2010). Finally, despite the efforts made, it was not possible to ensure the strict compliance by the teachers in each of the experimental conditions. In future research, observers could randomly visit the classes to check the fulfillment of the respective protocol.

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