Interdisciplinary programs evaluation methods: a review of literature and a model proposal for intensive projects involving academia and industry

Sara Dias[*], Luís Silva Dias[*], Rui M. Lima[*]

[*]Department of Production and Systems, School of Engineering, University of Minho, Campus of Azurém, 4800-058 Guimarães, Portugal

Email: sara.dias.2317@gmail.com, lsd@dps.uminho.pt, rml@dps.uminho.pt

Abstract

The technological evolution occurred in the last twenty years led organizations to a different global business environment requiring them to be increasingly effective and competitive, implying changes in the way they work. The new paradigm focuses on interdisciplinary team work and so it is required from engineering graduates to have higher levels of transversal competences, like interpersonal communication and team work skills as well as to be able to solve complex engineering problems, in some situations involving areas outside engineers' common initial training. These changes have clear implications in engineering education and in order to improve engineering education curricula, initiatives like multi and interdisciplinary programs have been implemented in Engineering Schools, with aim to improve the interaction between academia and business companies with win-win relations. Some of these projects are intensively developed during a short period of time, at the company's facilities. Along with these initiatives emerges the need to evaluate them. According to the literature, there is a lack of systematic evaluation systems of these projects, so the aim of the paper is to suggest an approach to evaluate interdisciplinary intensive projects, focusing on the competences required by the organizations and considering projects' stakeholders – participants, tutors, company representatives and educational institutions. The methodology used is based on a literature review of topics related to Project-Based Learning, aiming to develop a systematic evaluation method that will involve the following dimensions: required outcomes for the participants, competences assessment methods and benefits for stakeholders who participate.

Keywords: Engineering education; multidisciplinary intensive courses; assessment methods; stakeholders' benefits.

1 Introduction

Modern organizations are required to be competitive, flexible, efficient and successful in answering their customer needs. In its turn, customer needs are now changing faster than they used to and products' life cycle is reduced, turning the markets highly competitive for companies and either they can keep up or stay behind. In order to be successful organizations need on a daily basis to be innovative and try to stay ahead of their competitors. According to authors Elmuti et al. (2005) strategical alliances between universities and corporations have increased significantly due to changes in the nature of global business. The author also states that these alliances have the purpose to ensure a stronger presence of corporations in the market as well as to address effectively customer needs (Elmuti et al., 2005). Although in the referred article there is a focus on alliances made for R&D projects and innovation, currently these alliances are extending to other areas and the relations between the two entities are becoming more natural, stronger and integrated.

Another issue about changes in modern organizations is the existence of a shift from disciplinary-focused individual work to team-based work, according to Lewis et al. (1998). This shift gave origin to changes in engineering education and companies now expect from engineering graduates to have higher levels of transversal competences, like interpersonal communication and teamwork skills as well as to be able to solve complex engineering problems, in some situations involving areas outside engineers' common initial training (Skates, 2003).

These new needs have clear implications in engineering education and in order to adapt to those changes, new teaching methods emerged, new ways for assessing engineering programs have been implemented and several other initiatives were created (Felder & Brent, 2003; Olds, Moskal, & Miller, 2005; M. J. Prince & Felder, 2006). An example is the multi and interdisciplinary programs which have been implemented in some Engineering Schools, aiming to improve the interaction between academia and business companies with win-win relations. Along with their implementation, these engineering programs need to be evaluated in order to understand if they are providing results. The results can be split in two paths: understand if students who participate are improving their competences;

and understand if those engineering programs are positive in stakeholders' perspective. The literature suggests the need for a systematic approach to evaluate these programs.

It is relevant to distinguish between multidisciplinary and interdisciplinary approaches. According to Jessup (2007) multidisciplinary approaches uses skills and experiences from different disciplines and works with each different perspective, excluding the integration of those disciplines whereas interdisciplinary approaches work with different disciplines integrating them into a single project. So the distinct factor between both approaches lies on the integration of the different areas. These definitions are assumed in this article and the term "interdisciplinary" is the one used to represent the type of engineering program addressed, once it is intended that team members with different backgrounds should work in an integrated manner.

About students' competences assessment there are several issues to be considered: what are we trying to assess, how can we ensure the reliability of the assessment, do the results show what the student is really capable of. The first relevant question related to this matter arises: after all, what is a competence? Searching the literature, many different definitions can be found depending on searched area: psychology, management theories, human resources, education or politics have different definitions for competence. Hoffman (1999) conducted a study about this subject and presented two models concerning for competence meaning:

1) Competence is considered an observable set of performances previously defined and described in written standards;
2) Competence is considered the underlying attributes in a person, in which "attributes of a person" according to Hoffman, is the standard or quality of the outcome of a person's performance;

Other studies, particularly, Definition and Selection of Key Competencies (DeSeCo) published by PISA, Programme for International Student Assessment (2005) and Deist & Winterton's article "What is competence? (2005), support the first model presented by Hoffman where competence is an observable set of performances and so that is the definition assumed in the present article.

About the assessment itself, is intended to assess whether students' attained or not the determined competences. For this matter there are two main aspects to be considered: skills/standards definition (what competences are intended for students to acquire) and clear criteria definition (what are the elements which determine if the student has the skill or ability on that competence). A subsequent issue should be the method used to apply the criteria and to assess the competences (Rowe, 1995).

The interdisciplinary programs which involve academia and industry have repercussions that go beyond the students' competences. Within this relation there is knowledge transfer from both parts, companies acquire industrial expertise through the novelties brought by the students and academia (including students) has contact with real complex problems as well as employment opportunities for participants (Elmuti et al., 2005). Given the importance of the relation between both stakeholders, including their perspective about these programs seems to be also relevant to improve the program. About the stakeholders' perspective, is intended to approach a way to assess it, namely, what are their considerations about programs' deliverables, proposed solutions and program's organization and structure.

So, the purpose of this article is to review the existent literature concerning engineering education, competences, competences' assessment methods and engineering programs' assessment, aiming to propose an evaluation model for intensive projects involving academia and industry.

The article begins with a description of the applied methodology in Chapter 2, which includes research questions, sources of information, research process and data collection. Subsequently, in Chapter 3, search results are presented, in particular regarding selected articles for the literature review. Chapter 4 corresponds to "Discussion" where the content of selected articles is discussed along with the answers to the research questions. In Chapter 5 the evaluation model for the interdisciplinary project is proposed and at last, in Chapter 6 the conclusions of the article are presented.

2 Methodology

The present article was developed according to a literature review structure, using the guidelines proposed by Kitchenham et al. (2009) complementing with integrative literature reviews' structure by Levy & Ellis (2006) and with an example of a systematic literature review (Kitchenham et al., 2009).

2.1 Research questions

The present study aims to answer the following research questions:

Research Question 1 (RQ1): How to assess efficiently and systematically the competences of students whom participate in interdisciplinary projects?

Research Question 2 (RQ2): How to know if the interdisciplinary program was successful?

About RQ1, it has a wider range of issues to consider concerning the definition of the term "competence", which competences should be assessed, definition of assessment criteria and assessment methods.

In RQ2 is intended to consider stakeholders (hosting organization, teachers, coordinators and staff) point of view about the program, understand which factors contribute for the success of the program and which success measures should be applied to evaluate the projects.

2.2 Sources of information

The research process was developed according to the principles of the book Research Methods for Business Students (Saunders, Lewis, & Thornhill, 2007). In the present article secondary sources of information were used, particularly, journals' articles.

In order to search for publications, the following databases were used:

- Scopus
- Google Scholar
- Science Direct

The sources of information used for reviewing literature are listed in the Table 1.

Table 1: Journals, conference proceedings and books used

Research source
The Journal of Workplace Learning
European Journal of Engineering Education
International Journal of Engineering Education
Journal of Engineering Education
International Journal of Project Management

2.3 Search process

The search process is based on Saunders et al. (2007) guidelines which recommend that literature review should occur in the form of an iterative spiral process. The search process adopted for the present literature review was conducted in a similar way, that is, including the spiral form but was complemented with the "funnel" metaphor for literature search process, pointed by Levy & Ellis (2006). This search process begins with a wider search, using more general search terms and as the search process evolves it becomes more and more specific until it reached the desired results.

Thus the main terms searched were:

- Competences
- Assessment methods
- Interdisciplinary programs in engineering
- Teaching in engineering

It was also used the combination "Competences" AND "Assessment methods", when searching Scopus and Science Direct databases. During the search process it was found that using the term "competence" and "competency" provided different results. In some cases the meaning of both terms coincided while in other cases, there was distinction. The present article considers the distinction of two terms, as presented in Introduction chapter.

The use of upper-mentioned search terms resulted in a large quantity of articles and conference proceedings so selection criteria was applied, according to the following aspects:

- Date
- Place published
- Title
- Adequacy to the study

The including criteria for date was documents' dates between January of 1995 and January of 2010. Documents with dates outside this interval were not considered in this review.

About the place published for each article, the journal ranking was performed in the portal SJR (SCI Journal and Country Rank). In this portal each journal has a ranking category based on the SJR indicator which is calculated according to a systematic method including citations made to that journal. There are 4 categories from Q1 to Q4, where Q1 corresponds to the highest values for SJR and Q4 corresponds to the lowest values. The inclusion criteria was journal where the article was published should be within Q1 or Q2 category, according to SJR.

The selection based on title excluded articles which were too specific (in case of the content was about some specific situation example).

The adequacy to the study was ensured by the revision of the articles and their content considering mostly the aim of the article, the article's proximity to the subject and the methodology developed. Within articles' revision it was also checked if there were relevant keywords to use in the following search process. When other keywords were found, search terms were refined, leading to new search iteration. The refined keywords after first search process were:

- Project-based learning
- Problem-based learning
- Inductive teaching methods
- Skills assessment
- ABET criteria
- Teaming skills
- Team building
- Competency models
- Project-led education

After these iterations the search process continued around the terms above mentioned complemented with new keywords found and combination of above-mentioned terms, leading to the results presented in chapter 3 Results.

3 Results

The search process resulted in a set of selected documents and from each document the following data were collected:

- Year
- Keywords
- Title
- Place published

The documents and correspondent information are presented in Table 2:

Table 2: Studies reviewed

No.	Year published	Keywords	Title	Place published
1	2005	University-industry	An overview of strategic alliances between universities and corporations	The Journal of Workplace Learning
2	2006	Inductive teaching	Inductive teaching and learning methods: definitions, comparisons and research bases	Journal of Engineering Education
4	2002	ABET engineering criteria	Turning students into professionals: types of knowledge and ABET engineering criteria	Journal of Engineering Education
5	2003	ABET Criteria	Designing and teaching courses to satisfy ABET engineering criteria	Journal of Engineering Education
6	2005	Engineering graduates, work	Engineering graduates perceptions of how well they were prepared for work in industry	European Journal of Engineering Education
7	2009	Engineering summer school	A multidisciplinary engineering summer school in an industrial setting	European Journal of Engineering Education

8	2005	Assessment, engineering	Assessment in engineering education: evolution, approaches and future collaborations	Journal of Engineering Education
9	2003	Knowledge, multidisciplinary teams	Knowledge creation in multidisciplinary project teams: an empirical study of the processes and their dynamic interrelationships	International Journal of Project Management
10	1998	Teaming skills, assessment	Assessing teaming skills acquisition on undergraduate project teams	Journal of Engineering Education
11	2004	Assessment, Project-Led Education	Assessment of team-based projects on project led education	European Journal of Engineering Education
13	1999	Project success	Criteria of project success: an exploratory re-examination	International Journal of Project Management
14	1999	Key success factors	A practical use of key success factors to improve the effectiveness of project management	International Journal of Project Management
16	1998	Assessment matrix	An assessment matrix for evaluating engineering programs	Journal of Engineering Education
17	2008	Dynamic environments	Project management approaches for dynamic environments	International Journal of Project Management

4 Discussion

A scheme is presented in Figure 1 as an attempt to illustrate the issues associated to the interdisciplinary programs and the established connections between those issues. The purpose of including this scheme is to help guiding the discussion chapter and to identify relevant subjects to be discussed.

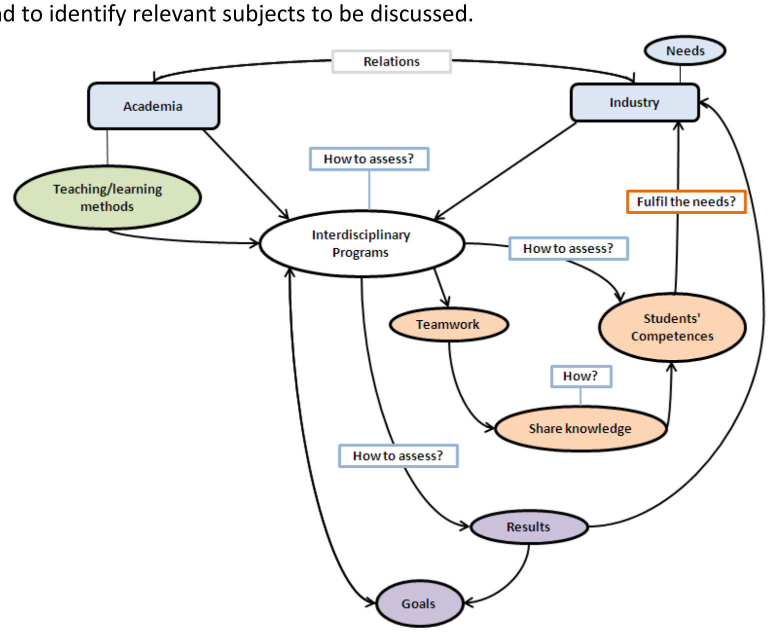

Figure 1: Interdisciplinary programs and related dimensions

In chapter 4.1 a summary of Interdisciplinary programs is presented. This chapter addresses blue and green cluster, respectively, relations between academia and industry and teaching and learning methods, which constitute interdisciplinary programs' context. In chapter 4.2, research questions 1 and 2, represented by orange and purple clusters are addressed.

4.1 Interdisciplinary programs' context

In the reviewed literature it wasn't found a specific definition or characteristics' description for "interdisciplinary programs". Instead the references to these initiatives appear associated with the learning method behind the initiative, particularly, Problem-Based Learning, Project-Based Learning and Project-Led Education (Peter C. Powell, 2004; M. J. Prince & Felder, 2006). These methods constitute new methods of learning which implementation has been increasing (Peter C. Powell, 2004). These methods belong to the concept of "Inductive learning" which is an instructional method focused on the student (*learner-centered*) and based on a constructivist approach, that is, based on the principle that students construct their version of reality instead of absorbing the reality presented by teachers in traditional teaching approaches (M. Prince, 2004; M. J. Prince & Felder, 2006).

The inclusion of interdisciplinary programs within education programs was first recorded at McMaster University - Medical School in Canada, in the early 70's according to authors Felder (2003) and Powell (2004). Since then other initiatives based on new learning methods have already been performed by many engineering schools. These kind of initiatives have been recorded in several universities around the world, for example, in Danish universities as Aalborg and Roskilde; Bremen, TU Berlin, Dortmund and Oldenburg, in Germany; Delft, Wageningen and U.Twente, The Netherlands; Monash University and Central Queensland University, in Australia; and Olin College, in the U.S.A. (P.C. Powell & Weenk, 2004; M. J. Prince & Felder, 2006).

There is also not much literature describing or analyzing these kinds of initiatives. The most complete description was found in the article "A multidisciplinary engineering summer school in an industrial setting", by Larsen et al. (2009) where authors describe in detail the multidisciplinary intensive program, its characteristics, the work developed and an analysis of the programs' evaluation, relevant for the present article. The widespread of these initiatives and also the demand for certain competences in engineering graduates led to research and investigation about engineering programs' assessment which in its turn gained an increasing relevance among researchers (Olds et al., 2005). In spite this concern, currently there's still no consensus about the best way for assessing learning outcomes and students' competences (Olds et al., 2005).

4.2 Research questions

4.2.1 How to assess efficiently and systematically the competences of students whom participate in interdisciplinary projects?

The answer to this question will be split in two main parts. Before knowing how can we assess competences and what are the best ways to assess them is relevant to understand which are the competences we want to assess and why. So these two aspects constitute the first main part. The second part focuses on the question "how to assess?" including reviewed documents about assessment methods and the implications of the assessment.

The fundamental purpose of training students in a certain area is to prepare them to perform efficient and successfully a set of activities and functions which in its turn are needed to be performed in order for the organization achieve its goals.

An attempt to accreditation of engineering programs was developed in United States of America by the Accreditation Board of Engineering and Technology (ABET) which created an engineering criteria that was firstly introduced in year of 1996 and reviewed in 2001.These engineering criteria contain requirements that engineering schools should meet in order to accredit their engineering programs (Felder & Brent, 2003; Gorman, 2002). One of the criterion is Criterion 3 and has the outcomes that engineering graduates should have at the end of the course (Felder & Brent, 2003). It is possible to split the referred outcomes in two groups: technical outcomes and non-technical outcomes. The first group includes, for example, the ability to apply knowledge of mathematics, science and engineering, while the second group includes, for example, the ability to function on multidisciplinary teams (Felder & Brent, 2003).

According to authors Larsen et al. (2009) and Lewis et al. (1998) engineering graduates lack the ability and experience of working in multidisciplinary teams, which are required when entering the industrial setting. Larsen et al. (2009) complements that engineering graduates are not aware of the complexity of the "real world" nor how to approach that complexity. Also Martin et al. (2005) identify communication and teamwork in multidisciplinary teams as competency gaps in engineering graduates. In the same article there is a set of issues used to conduct a study about engineering graduates' perceptions and their preparation to work in industry. Those issues are coincident with the outcomes mentioned in ABETS's Criteria 3 as well as the competences mentioned by the authors Larsen et al. (2009) and Lewis et al. (1998) upper-mentioned. Therefore it seems to be a consensus about these competences in the way they reflect organizations' needs of engineering graduates and at the same time constitute a gap in engineering graduates' training.

After knowing what to assess comes the part where it's needed to decide how to assess. Olds et al. (2005) describes a set of assessment methods which are commonly used for assessing in engineering education and includes a review of studies which support the validity and reliability of those methods. Also in article "Designing and teaching courses to satisfy the ABET engineering criteria" authors mention a list of assessment tools to be used in programs' evaluation, some are coincident with the ones referred in Fong (2003). In this article authors highlight triangulation technique and its relevance regarding an effective assessment. Triangulation means using multiple methods for gathering information.

In the article "An assessment matrix for evaluating engineering programs" authors develop an assessment matrix which includes 6 main fields: program objectives, performance criteria, implementation strategy, assessment methods, timeline and feedback. The purpose of this matrix is to be built for each program objective required to assess. Authors recommend the exploration of a range of assessment methods and triangulation of those methods, in order to ensure an effective assessment (Olds & Miller, 1998).

So through reviewed literature analysis is possible to understand that there isn't only one best method ore a set of methods constituting the best way to assess, instead the core of assessment activities' should be in establishing programs' objectives and ensuring the reliability and validity of the applied methods (Felder & Brent, 2003; Olds et al., 2005).

4.2.2 How to know if interdisciplinary program was successful?

A project is considered successful when the expectations of projects' stakeholders are fulfilled, that is, projects' success depends on the perceptions of its different stakeholders (Lim & Mohamed, 1999). Within the scope of interdisciplinary engineering programs, there are several stakeholders involved such as academia, industry and students. Thus, the success of the program and related issues will diverge according to those stakeholders.

There are two issues related with the success of a project which are: success criteria and success factors. According to Lim (1999), criterion can be defined as "a principle or standard by which anything is or can be judged"; factor in its turn is "any circumstance, fact or influence which contributes to a result". For better understanding, it is plausible to say that factors influence criteria which in its turn conducts to the results and allows the judgement of those results (Lim & Mohamed, 1999).

The core of determining the success of programs lies also in the establishment of goals and expectations, which should be done in an advanced phase.

5 Evaluation model proposed

5.1 Interdisciplinary program characterization

The initiative to be implemented within collaboration between academia and industry is an interdisciplinary intensive program to be performed by engineering PhD students during a period of three weeks and it has emerged in University of Minho, Portugal. The purpose of this program is to provide PhD students contact with an industrial setting and prepare them to participate in industry's innovation and product development processes.

During those three weeks, students work in teams in the same physical place and tackle engineering problems proposed by the organization they are cooperating with. At the end of the three weeks is expected that teams deliver a research plan and a position paper about the problem they studied. A relevant aspect of this program is that students are selected from several European universities, promoting and adding the multicultural issue to teamwork.

The expected outcomes for students are:

- Work within multidisciplinary teams, to promote creativity and innovation;
- Adopt techniques like abstraction, modeling and simulation, to manage complexity;
- Prepare applied research plans, to support a policy for patents and industrial property and to sustain industry development.

It is also expected from each team to deliver the following outputs:

- Applied research plans - written by the students for the considered engineering problems;
- Position papers - written by the students to explain their research plans to the scientific community;
- Simulations and presentations – made by students about their research plans.

Concerning the hosting organization, it is expected for them to be more sensitive about PhD graduates' integration within development processes in the industrial setting as well as the usability of their research competences.

As for the academic partners, the implementation of these programs allows the acquirement of experience and also the awareness of the needs and perspective of industrial organizations.

5.2 Evaluation model

Considering the reviewed literature, the first step to build an evaluation model is to establish the objectives for the program, which can be split in two groups: technical competences and transversal competences' objectives. A set of 5 objectives were defined as presented in Table 3.

Table 3: Defined objectives for the interdisciplinary engineering program

Type of competence	Objectives
Transversal	Ability to function on interdisciplinary and multicultural teams
Transversal	Ability to communicate effectively
Technical	Ability to tackle complex engineering problems
Technical	Ability to develop a research plan concerning the given problem
Technical	Ability to develop a position paper concerning given problem

About transversal competences, teamwork and communication were defined according to the reviewed topics about the Research Question 1 (chapter 4.2.1) and also the interdisciplinary and multicultural character of the program, which requires students to develop these particular competences. In order to assess these competences, as recommended by the reviewed literature, triangulation should be applied. In article "Multidisciplinary engineering summer school in an industrial setting" authors refer the use of questionnaires for collecting students' perceptions about the development of their project, the work within a team and about the program in general. Authors' Felder & Brent (2003) and Fong (2003) mention that observation is a descriptive method, not much used in engineering assessment but promising in what concerns results. At last, in the same articles, interviews and focus groups are mentioned as a good method for collecting feasible information, as long as conducted correctly. These should constitute the methods to be included in triangulation of assessment.

About technical competences, the ability of tackling a problem as well as the abilities to develop a research plan and a position paper, are competences achieved through teamwork. Therefore, the assessment should consist in the results of that teamwork, that is, by analyzing objectively the deliverables of each group. To ensure unbiased assessment a team of examiners should be constituted (Peter C. Powell, 2004) and an assessment matrix with weighted criteria should be developed as a tool for the assessment.

In order to understand whether the project was successful considering different stakeholders perspectives, it is plausible to conduct interviews to each stakeholder, particularly, organization representatives, academia coordination team and participant teachers (tutoring the teams). The interviews should be performed before the beginning of the program with the purpose to understand what stakeholders' expectations are and then, at the end of the program, to understand if stakeholders' expectations were fulfilled and if they considered the program as successful.

6 Conclusions

Implementation of engineering programs based on inductive learning methodologies such as Project-Based Learning, Problem-Based Learning and Project-Led Education has been increasing and spreading around the world. There is a consensus about the need for changes in engineering education and engineering community has been searching and developing new ways to evolve. Although the initiatives already presented good results, there's still much work to be done. Along with these emerging initiatives, programs' assessment becomes an issue which requires much more research and analysis once it is a wide subject and involves many dimensions.

This article presents the assessment issue in a summarized way, without approaching some details related to assessment which are important to be considered such as: cognitive process of learning, knowledge creation within teamwork and teamwork dynamics.

About the evaluation model, further studies should follow the application of the assessment methods and analyze results found, in order to understand the model as a whole, find gaps and suggest improvements.

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