The role of Project-Based Learning in Engineering Curriculum: the case of the Industrial Engineering and Management program at the University of Minho

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Abstract

One of the key questions arising from literature in Higher Education is the mismatch between curriculum and professional practice. This work presents an analysis of an engineering program, based on a model of curriculum development that includes three dimensions: professional profile, curriculum elements and framework of competences. These dimensions were considered in the methodological approach that involves a case study of the Industrial Engineering and Management (IEM) program at the University of Minho, Portugal. Data were collected through a combination of methods, including a survey, narratives, interviews and focus group. The aim was to get to know the perceptions of students and teachers of IEM program and professionals working in this engineering field. The findings highlight the relevance of project-based learning within the engineering curriculum in so far as it provides students with opportunities to develop both technical and transversal competences related to their professional practice. This implies developing learning situations in which it is possible to solve engineering problems, linking theory and practice based upon an interdisciplinary approach. Furthermore, the implementation of project-based learning have implications for curriculum development, namely in regard to the definition of the assessment (e.g. milestones, feedback, etc.), coordination and communication between the faculty, content selection according to the problem to be solved, amongst other issues with impact in teaching practice.

Keywords: Engineering Education; Curriculum Development; Project-Based Learning

1 Introduction

Curriculum design in higher education deals with important challenges, some of which result from complex demands of the labour market and society. Issues such as globalization, fast information spreading, advances in technology and sustainability have to be taken into account. Higher Education institutions are often criticized for the lack of preparation of graduates to solve real problems (Knight & Yorke, 2004). In this sense, one of the main challenges in higher education is to prepare students for the demands of companies and societies. The Engineering programs need to meet this challenge, in order to reduce the gap between university curricula and professional practice, which is recognised in several studies (Jackson, 2012; Markes, 2006; Nair, Patil, & Mertova, 2009; Stiwne & Jungert, 2010; Tymon, 2013).

Engineering programs have been innovating the teaching and learning approaches, as recommended by UNESCO report for Engineering Education "University courses can be made more interesting through the transformation of curricula and pedagogy (…) less formulaic approaches that turn students off" (UNESCO, 2010, p. 32). For instance, active learning methodologies (Prince & Felder, 2006) have been implemented by many engineering programs all over the world, in order to provide students with different contexts and situations where they can develop competences and engage more deeply in the learning process. For example, project-based learning is an active learning approach that "provides students with the opportunity to bring together knowledge-based skills from a number of subject areas and apply them to real-life problems" (Dickens & Arlett, 2009, p. 268). Project-Based Learning (PBL) is another alternative model that can be used to create an environment propitious for the development of both, technical and transversal competences. Implementations of this type of approaches all over the world have some common characteristics, namely: teams of students solve an open problem linked to the professional practice for a predefined period of time, delivering a result / product (Graaff & Kolmos, 2003; Kolmos & Holgaard, 2010; P. C. Powell & W. Weenk, 2003). These link with the professional practice, the hands-on, and the teamwork characteristics allow students to achieve extra motivation that will create an adequate ground for a deep learning (Fernandes, Mesquita, Flores, & Lima, 2014). The CDIO is also an approach that contributes for curriculum innovation in engineering. CDIO is based on four principles inspired in the engineering practice (Conceive - Design - Implement – Operate) and began at MIT (Massachusetts Institute of Technology) taking into account the negative feedback given by the companies regarding to graduates' profile (Crawley, Malmqvist, Östlund, & Brodeur, 2007). However, changing the practices in engineering education contexts implies a complex process regarding, for instance, to faculty motivation, students' dropout or lack of institutional support (Besterfield-Sacre, Cox, Borrego, Beddoes, & Zhu, 2014; Matusovich, Marie C. Paretti, McNair, & Hixson, 2014; Meyer & Marx, 2014).

Even though there are several studies on the evaluation of PBL models (Fernandes, Flores, & Lima, 2012; Hall, Palmer, & Bennett, 2012; Spronken-Smith, Walker, Batchelor, O'Steen, & Angelo, 2012; Struyven, Dochy, & Janssens, 2005), this work intends to give a different perspective, based on an integrated curriculum development model. Additionally it presents a PBL evaluation result that emerged from the data collected in a wider research project aimed at investigating the relation between the professional profile and the curriculum dimensions. Thus, this study characterizes the role of PBL in the curriculum and the relation to the professional profile. The study was conducted within the context of an engineering program - Industrial Engineering and Management program at University of Minho, Portugal. This analysis was based on a Model of Curriculum Development, which integrates three dimensions: curriculum processes, professional practice and competences.

2 Model of Curriculum Development

Specific technical knowledge is not enough for engineering practice. Other requirements are needed, such as working in teams, making decisions, solving problems, communicating, creating innovative solutions. Different terms are used to refer to these competences: "generic", "transferable", "core", "professional", "employability", "soft". In this study the term used is "transversal competences" which refers to those competences which can be transferable between different functions, but must be integrated into technical competences for a successful practice of a profession. These competences are being identified by accreditation boards, namely by ABET (Accreditation Board for Engineering and Technology), EUR-ACE (European Accreditation Board for Engineering Education) and Engineers Australia, so they must be also considered in engineering curriculum because "engineering curricula play an important, if not crucial, role in the education process of professional engineers" (Boud et al., 2009, p. 491). Curriculum development enables the conditions, situations, experiences and opportunities for students to develop competences related to their professional practice. According to this idea, Hoffman (1999, p. 283) states: "the design of learning programs may be based on the inputs needed or the outputs demanded". The professional practice requires the combination of both technical and transversal competences and for that reason they must be included in the curriculum. However, the curriculum and the pedagogical practice are not always aligned with this purpose. Analysing the connection between curriculum and professional practice, taking into account a framework of competences, is essential to improve engineering programs and pedagogical practices. Thus, a Model of Curriculum Development was developed within a wider research project and three dimensions were considered - curriculum processes, professional practice and competences (

Figure 1). The curriculum processes were inspired in the ten criteria to assess the quality of teaching in Higher Education identified by Zabalza (2009).

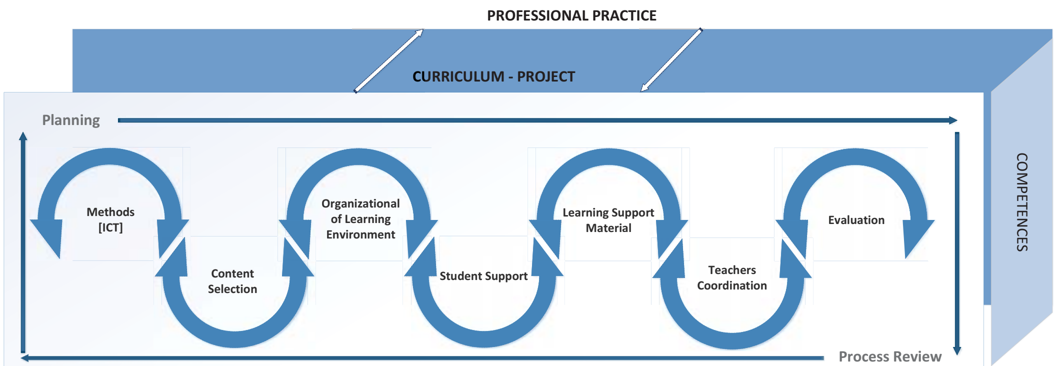

Figure 1: Model of Curriculum Development

This model shows the interaction between all the key components and highlights the importance to relate curriculum with professional practice. Thus, planning the curriculum as a project involves thinking about the activities that will be developed, the strategies to present the contents to students, the learning outcomes that should be defined, amongst others questions. Issues such as methods; contents and strategies to communicate the content to the students; the organization of learning environment to interact to students; student support (e.g. tutorials); learning support material (e.g. guides); teachers' coordination; and the evaluation are also considered in this model. These elements cannot be defined separated from each other. All of them should be aligned (Biggs, 1996) in order to make links between curriculum and professional practice, providing opportunities for students to develop competences. According to Zabalza (2009), the principles of professional practice should provide the orientations for curriculum design. This implies a rigorous and consistent analysis about the perceptions and contexts (social, environmental, cultural) related to professional practice, in order to incorporate them in teaching and learning situations, which aligns the curriculum processes: learning outcomes, methods and strategies, contents, resources and evaluation. Within this context, students have the opportunity to be in contact to their professional context that enable them to enhance even more the making-sense of their learning process (Fernandes et al., 2014).

This model shows the importance to understanding curriculum as a project, involving a set of processes that must be planned considering not only the alignment between them (Biggs & Tang, 2011; Cowen, 2006), but also the contexts of professional practice. The competences that are expected from professional practice must be considered in the curriculum development in order to reduce the gap between these dimensions. In other words, if students do not develop the competences related to the professional practice, the curriculum is not providing the contexts and situations relevant to engineering practice. Furthermore, this model provides an overview of the curriculum, carried out by an analysis where is possible to identify the curriculum processes that contribute to students' competences and those that need to be improved. It is within this framework that this paper was developed, taking into account the perspectives of students, teachers and professionals about the curriculum of Industrial Engineering and Management program at University of Minho.

3 Methods

This paper is part of a wider research project that is being developed at the University of Minho, Portugal, since 2010. It aims at analysing the curriculum elements and competences related to professional practice, in order to contribute to the improvement of the quality of the training program in engineering programs. The Industrial Engineering and Management Integrated Master program (IEM-IM) at the University of Minho was analysed, as a case study, taking into account the key dimensions of the Model of Curriculum Development presented earlier – professional practice, curriculum processes and competences. The perspectives, experiences and expectations of students, faculty and professionals (including alumni) about these dimensions were taken into account. The research design, illustrated in Figure 2, presents a set of methods for data collection used in the different stages, namely document analysis (to identify the competences and other dimensions related with the professional profile), questionnaire (to get an overview from the participants mainly about the professional profile defined in the previous stage), interviews, narratives and focus groups (to understand the relation between curriculum and professional profile). From data analysis, provided by triangulation (Denzin & Lincoln, 1994), it was possible to get an overview of the curriculum of IEM-IM, considering its the strengths and weaknesses identified. Project-based learning (PBL) experiences within engineering curriculum emerged as an added value for professional practice. PBL has been implemented in IEM-IM since 2004/05. In the first year of the course there was a PBL process implemented in the first semester. Two additional PBL processes were implemented in both semester of the fourth year. This model was inspired in the Project-Led Education (PLE) work of P. Powell and W. Weenk (2003). Several studies have already been developed within this context (Fernandes et al., 2012; Lima, Mesquita, & Flores, 2014; Mesquita, Lima, & Flores, 2013; van Hattum-Janssen & Mesquita, 2011).

This paper seeks to address the following research questions:

- What is the role of PBL in curriculum development within the IEM-MI training program?
- How does it contribute to the development of competences relevant to future professional practice?

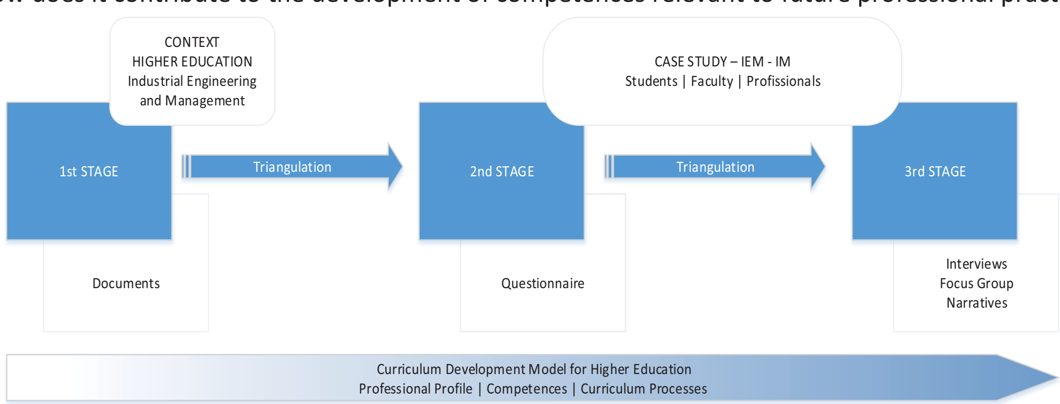

Figure 2: Research Design –data collection, participants and the model developed within this project

4 Findings

The analysis of IEM-IM curriculum was supported by the dimensions defined in the Model of Curriculum Development (

Figure 1) considering the perspectives of students, teachers and professionals. The relevance of PBL experiences within IEM-IM curriculum emerged from the data for their contributions in the preparation of students for professional practice, particularly due to the opportunity to link theory and practice, the interdisciplinary approach and the development of both technical and transversal competences.

4.1 Linking theory and practice

PBL provides learning situations in which theory and practice are linked in such a way that create a learning environment for students to solve a problem in teams. According to students, this approach contributes to their motivation and engagement in the learning process. The following quotes illustrate this:

> «With the projects, for instance, we didn't say: "let's go study", we say "let's go work!". I think this says a lot about what happens. We work, indeed, because we need to link what teacher said in class with what we are doing in the project. So, we are not just studying the concepts and repeating them over and over again, or just doing exercises! We are working! » (Focus Group 4th year Students P1)

> «I think that this is the best way [through PBL] to link theory and practice. And it is not the theory that we've already had, but the theory that we are having in that moment. This makes more relevant what we are learning. » (Focus Group 3rd year Students P4)

Teachers also recognize the importance of linking theory and practice to enhance students' motivation in the learning process. PBL was used as an example to illustrate this purpose.

> «I think that 4th year students need to see the application of what they are listen during the lectures, because they were three years waiting for that moment, I mean, to see the relevance of what they are learning. So, if they are in the class and do not realize what is going to contribute for their future as an engineers, they are not motivated to listen, to participate, whatsoever! But then I see them working in the project and everything changes. In fact, the project enables students to apply knowledge in a real situation, and this is what they are looking for and what they need. » (Focus Group Teachers P2)

In the case of 4th year, the projects are developed with industrial companies. These are a powerful experience for students because they have the opportunity to be in contact with their professional context, as some students mentioned:

> «I think the projects that we have developed in the companies were the best thing that happened to me at the university. It is a really advantage because you see how things work and you also understand that they could be different from what you saw during the lectures. For instance, in the real worldit is difficult to get information. At the university the teacher give us the exercise with all data that we need to solve, but in a company data are spread around the departments and incomplete. » (Focus Group 4th year Students P1)

> «When these projects are related to companies, where we had a chance to come in, observe, learn and even participate with our perspectives and opinions, this is really good, because learning in practice is much more relevant. » (Narrative Final Student 31)

4.2 Fostering an interdisciplinary approach

An interdisciplinary approach is one of the main characteristics of project-based learning, which is related to the nature of a real problem. This is not undermined by knowledge boundaries and enables linking theory and practice described in the previous section. Interdisciplinary projects challenge teaching practice. Teachers involved in this study identified some of them, such as the difficulties of communication and cooperation between teachers, the complexity of planning and management of the project (e.g. organizing milestones, defining the problem, etc.), heavy workload when comparing with traditional approaches, amongst others. This can be noted in following quote:

> «The project also brings additional difficulties in order to foster the link between the courses and the integration that is needed. In fact, with the project we are in a different level, it is more complex and demanding for teachers, because everything needs to be coordinated and everybody needs to be engaged and committed. » (Focus Group Teachers P3)

However, teachers involved in this study also recognized the advantages of the interdisciplinary projects, in which students are able to solve engineering problems.

> «The courses are organized in "lockers" and we know that this is not what the students find out when they go outside. But we can link some courses with each other and the IEM-IM shows that this can happen with the projects. » (Focus Group Teachers P1)

4.3 Developing competences

University teachers' perspectives about PBL point out some dimensions that are discussed in the literature, namely the importance of teachers' role in order to create learning situations for students to develop competences related to their professional practice. One of the concerns of the faculty relates to technical competences, as mentioned by the following quote:

> «With the project I think that we cannot cover a lot of technical issues. That is possible in a lecture, where the teacher talks for two hours. In the project we didn't talk for two hours! For instance, to explain a technique, like Kanbans, I can even explain to students using examples and giving some exercises until they get the idea, but if they have contact with reality and feel real environment, the learning process is totally different (…) The student already had the experience and it would be easier, when he/she goes to a similar situation, and has to apply the technique. The learning process is much more effective in this way than in a lecture where I am taking about kanbans. So, the quality of the technical knowledge in a project is wider; you cannot cover everything, it is true, but the knowledge that student achieve is higher. » (Focus Group Teachers P4)

This perspective is also reinforced by the professionals (alumni students), which highlighted PBL as an added value for their professional practices, particularly those projects that were developed within industry context. When graduates go to their professional contexts, they face and deal with similar situations as those experiences provided with the project.

> «For example, I have never had that feeling "oh, what I learned in the university is so different from what I am living now!" Not at all! In this company, I show that what I learnt is useful. There were situations where an issue is under discussion and I had never been afraid to give my opinion and explain my perspective, supporting with what I learnt at the university. I was sure about what I was saying… but the projects that I was involved in allowed me to get this confidence, because if it was the first time that I was in a company. » (Interview Professional – Alumni P7)

For students PBL create opportunities for them to develop competences related to professional practice, not only those that requires technical knowledge, but also transversal ones, such as teamwork, time management, communication skills, amongst others.

> «A project was presented to us right at the beginning of the 1st year and we have to learn how to deal with it. When we go to a company it will be almost the same, we have to work with people whom we do not even know… but it will be the similar experience that we've had with the project during which we've learned how to deal with the difficulties. » (Focus Group 2nd year Students P1)

> « (…) but then it is exactly what is going to be asked to us in a company. You have to work in teams, even bigger than the teams that we had in the project, and maybe we have to work with other engineers from different areas. I think that we are well prepared, because we are having similar experiences here. For instance, I had a lot of problems within my project team, especially at the beginning and I had to learn how to deal with it. I have learned to pay attention to people and somehow I have learned how to deal with situations that I am not used to, because everything has to be all right at the end. » (Focus Group Students 3rd year P2)

5 Final Remarks

Drawing on the findings from this study, it is possible to recognize the importance of PBL within IEM-IM curriculum in order to improve student learning and prepare them for professional practice. The main contributions that emerged from the findings are the link between theory and practice, the possibility to foster an interdisciplinary context and the development of students' competences.

Thus, the PBL experiences play a significant role within the IEM-IM program, for instance, professional situations become more familiar and students are able to understand the relevance of the content addressed within a course, for instance. PBL is also considered by graduates as an added-value for professional practice (Mesquita et al., 2013). Other studies reveal similar results, such as Kolmos and Holgaard (2010). Evidence highlights that PBL provides opportunities for students to be in contact with real problems within interdisciplinary contexts where it is possible to solve engineering problems (Heywood, 2005) or, in other words, to *practice the professional practice* (Lima et al., 2014). This provides an important contribution for students' motivation and engagement in learning process (Fernandes et al., 2014). Furthermore, students are aware that engineering problems require a combination of technical and transversal competences, and for that reason working in teams, for instance, is an industry requirement for engineering practice (Lima, Mesquita, & Rocha, 2013). PBL provides learning opportunities where students need to combine technical and transversal competences, in order to solve the engineering problem they are facing.

The contribution of PBL for professional practice has implications for curriculum development, particularly for teaching practice. The Model of Curriculum Development presented in this paper support the analysis of IEM-IM curriculum and it is possible to relate the challenges that PBL provides for teaching practice with the curriculum key elements, particularly in the context of PBL. PBL has implications for teachers' coordination because of interdisciplinary contexts and also the organization of teaching processes, such as assessment. If the students are provided with learning situations based on pedagogies of engagement (Smith, Sheppard, Johnson, & Johnson, 2005) the methods of assessment need to be different from the traditional approach (Fernandes et al., 2012). Feedback practices, for instance, are quite relevant in a curriculum oriented to competences development (Flores, Veiga-Simão, Barros, & Pereira, 2014). PBL have also implications for other curriculum issues, such as learning environments, student support, in the use of Information and Communication Technology, amongst others that may be discussed in a future work.

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