

PBL in the first year of an Industrial Engineering and Management program: a journey of continuous improvement

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Abstract

The Integrated Master Degree in Industrial Engineering and Management (IEM) at the School of Engineering of the University of Minho has been introducing Project-Based Learning (PBL) since the year 2004 and it is now in its 14th edition. This is a long time-frame that allowed to consolidate the model. Nevertheless, there is always space for improvement, considering that this learning process is evaluated every year by both teachers and students, in an open and critical free thinking environment. Based on this, it is time to understand the main changes that have happened over the years, since the first implementation. Studying the entire time-frame is a titanic task, so the authors decided to present, for the purpose of this paper, only the changes for the period of 2010-11 to 2016-17 (i.e. seven editions) applied in the PBL model of the first year of the IEM program. The main aspects that will be compared along the different editions will be the courses involved, the coordination team, the inclusion of the project in each course's curriculum, the number and type of tutors involved, the assessment model and the milestones considered. A document analysis, the authors' own experiences and the previous results from PBL evaluation surveys carried out to students are the main methods for data collection. The results show that the PBL model in the IEM program is being refined and adapted in order to promote, not only the best learning experiences for students, but also their continuous motivation to learn. Despite the good results achieved, a greater effort is needed.

Keywords: Engineering Education; Active Learning; Project-Based Learning; Industrial Engineering and Management program, continuous improvement.

1 Introduction

Active learning is considered central for the transformational teaching happening in many courses of universities that are changing curricula to better prepare engineers for current issues (Zhang, Zimmerman, Mihelcic, & Vanasupa, 2008). This transformational teaching is supported by a different paradigm, the one from the teacher centred to student-centred learning environment that benefits from peer-to-peer networks and emphasizes collaboration, team balance and individual performance. Teacher's role is more of a mentor and coach, devising and promoting the conditions for significant learning. This also implies being concerned all the time with continuous improvement of these conditions because there is no perfect recipe to achieve this type of learning. Continuous improvement is a keyword in the Lean context and it means being unsatisfied, all the time, with the status quo, in order to identify and solve problems (Alves, Dinis-Carvalho, & Sousa, 2012). Nevertheless, a lot of education organizations have been applying this same term in order to work more efficiently and effectively (Park, Hironaka, Carver, & Nordstrum, 2013).

One important active learning methodology is the designated Project-Based Learning (PBL), that has been implemented in many universities across the world (Guerra, Ulseth, & Kolmos, 2017). Nevertheless, each PBL model is a different model because it must fit particular contexts and cultures. Even in the same context, the PBL model should be rethought all the time as a continuous learning, every day in every action performed in the project development, involving and engaging all the stakeholders of the learning process.

This learning phenomenon happened since 2004-05 in the Integrated Master Degree of Industrial Engineering and Management (IEM) at the School of Engineering of the University of Minho, which has implemented PBL since then in different curricular years (Lima et al., 2017). The continuous concern of the coordination team (teachers, researchers, tutors) for the significant learning by the students and the solutions adopted along the years in a continuous action-research-practice cycle, have been published in many papers (Alves et al., 2016a;

Alves et al., 2016b; Alves & Leão, 2015; Alves, Moreira, Mesquita, & Fernandes, 2012; Fernandes, Mesquita, Flores, & Lima, 2014; Lima, Carvalho, Flores, & Van Hattum-Janssen, 2007). Following that trend, this paper intends to present a synthesis of the main changes that occurred in the PBL model of the first year, first semester of IEM, over seven consecutive editions (2010-11 to 2016-17). This is important to track the changes being made and, based on their positive or less positive impact, improve the learning process. For this, the authors used their experience and the documents that supported the PBL editions along the years.

This paper is organized in five sections. After this introduction, the second section presents the research methodology. The third section briefly presents the adopted/developed PBL model (first year, first semester). Section four compares the different editions in terms of what has changed and what has not changed. Section five presents some final remarks and future work.

2 Research methodology

Attending to the objectives of this paper, the main research questions defined by the authors are the following:

- What are the main changes in IPIEM1 PBL model, from 2010 to 2017?
- What is the impact resulting from each main change?

To achieve these, the research methodology chosen had a qualitative basis as it was grounded on the analysis of data collected from different sources like: (i) documents used in the Integrated Project of Industrial and Engineering Management (IPIEM1) in the context of the PBL project, (ii) authors' own experiences and (iii) previous results from PBL evaluation surveys conducted to students and teachers. Three different surveys are usually conducted, one for students, another for teachers and a last one for the tutors, as an important tool to provide immediate feedback about the PBL semester. The surveys are applied at the end of the corresponding semester.

The students' survey is composed by a set of dimensions, including student's satisfaction with the assessment model and its components (milestones, peer assessment, assessment criteria, project examination, individual vs group assessment), as well as other dimensions (PBL as a methodology, the project theme, the teacher's and tutor's role, teamwork, skills developed, etc.). The students' survey along with the workshop at the end of the PBL edition represent an important continuous improvement strategy used by the PBL coordination team. In the workshop, students have the opportunity to actively participate in the reflection and suggestion of new solutions and/or alternative options to the problems identified by themselves. This is also a key issue for student centred learning environments, where students play an important role in decision making processes and are provided with opportunities that promote their autonomy, critical thinking and responsibility. These are essential skills for the 21st century as well as for what the American Management Association (AMA), (2012) designates as the "four Cs" (4C): Critical thinking, Communication, Collaboration and Creativity, that are indispensable to enable workers to think critically, solve problems, innovate, collaborate and communicate more effectively.

The surveys conducted to teachers and tutors allow a general view of all the stakeholders in the PBL project. This last survey allows the evaluation of the tutoring experience, difficulties and expectations. Also, an action research approach was used every year in order to actively intervene in the planning of the next year PBL edition. That is, at the end of each PBL edition, the analysis of the data collected enable the identification of improving points to be implemented, possibly in the following year. To develop the analysis, a set of categories were selected to describe the main changes that happened throughout the years. These categories were: 1) PBL coordinator; 2) number of students and teams in each edition; 3) participant courses; 4) staff coordination team; 5) number and type of tutors; 6) number of milestones; 7) assessment model; 8) PBL evaluation. In regard to each of these categories detailed information was collected from different sources mentioned previously. Based on a deep analysis of each of these categories it was possible to draw several conclusions concerning the main changes that happened throughout the period studied.

3 Study Context

The Integrated Master Degree on Industrial Engineering and Management program (IEM) embraced the use of a multidisciplinary semester-wide Project Based Learning Methodology back in the 2004-2005 academic year. At that time, the decision to begin with PBL received some stimuli from the rectory, providing diversity on the use of distinct Teaching/Learning Methodologies within the campuses. That experience was put in place in the first semester of the first year of the program, which meant that the first learning experience at the University, for these particular students, would be in a PBL setting. This contrasted with their full prior learning experiences in previous education levels (from primary to secondary) and represented a shift to that of their elder colleagues, who undergone a fully traditional teaching experience, i.e. centred on teacher lecturing's and prone to passive learning.

The first editions of the PBL on the IEM were designed in the top, and within the constraints, of a fixed curricula, using the motivation and good will of a set of lecturers from most of the courses of the first year, that volunteer to build the required structure and provide the operational support for the implementation of the project. The following editions relied on a wide team of lecturers, mostly related to the selected Project Supporting Courses (PSCs) and other staff performing the role of tutor for a given team of students, and additionally some researchers from the field of Education – all these members constitute the so-called coordination team.

In the academic year of 2012-2013, a reformulation of the IEM curricula provided the opportunity to adequate the structure of the program to the existing PBL practice, by creating the Integrated Project in Industrial Engineering and Management I (IPIEM1) course unit. Table 1 lists all the PSCs collaborating in the IPIEM1 in the last editions. These PSCs pertain to two distinct schools (Sciences and Engineering) and four departments (Maths, Chemistry, Production and Systems, IT), all of the same University.

Table 1. Courses of the 1st year, 1st semester, of the IEM program

Acronym	Curricular Unit (Course)	Scientific area/School	Nr. of ECTS
LA	Linear Algebra	Basic Sciences/Science	5
CC	Calculus C	Basic Sciences/Science	5
GC	General Chemistry	Basic Sciences/Science	5
AP	Algorithms and Programming	Basic Sciences/Engineering	5
IEM	Introduction to Industrial Engineering and Management	Specialty Sciences/Engineering	5
IPIEM1	Integrated Project in Industrial Engineering and Management I	Engineering Sciences/Engineering	5

All the PSCs, including the IPIEM1 represent 5 ECTS (European Credit Transfer System) each, amounting to 30 ECTS in total for the first semester. The full year has 60 ECTS. The project is interdisciplinary, meaning that all PSCs collaborate in the development of the PBL experience, and, naturally, they also contribute to the assessment process. The PSC contents are, at least partly, influenced by the IPIEM1 itself, which means that the learning on some of the PSC contents can be made more realistic given that the developments of the project relate to a real product and production systems.

Thereby, the students experience a more meaningful learning, where the particular technical contents can be instantiated to real world requirements and developments, and at least some competences are acquired using Learning by Doing, which is known to aid the retention of knowledge and development of skills on the long run. Furthermore, additionally to the PSC related competences, a number of transversal competences are developed and trained within this thrilling experience, that provides a number of challenges for the students, and, with them, a good number of opportunities for the development of such skills, e.g. management of interpersonal conflicts, effective team working, making oral presentations to an audience, conduct meetings, evaluate peers, exercise creativity, being proactive, etc. Figure 1 shows the current model of PBL developed in the IPIEM1 project and the project supporting courses. All the PSCs collaborate in the definition of the project so as to be meaningful for each one of them.

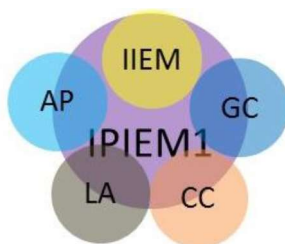


Figure 1. IPIEM1 Schematic representation, Project Supporting Courses (2016_2017) (Alves et al., n.d.)

The IPIEM1 project is developed by teams of students each one with its own tutor (typically six teams, due to resources constraints, namely the availability of team workspaces and tutors). Each team is composed of seven to nine students. Students are responsible for choosing the team members for their group, taking into consideration two criteria: (i) each team should hold at least one student with previous knowledge in Chemistry (from the secondary school); and (ii) each team should be gender balanced, if possible. The last criterion, has not always been achieved (Alves, Moreira, & Leão, 2017), occasionally requiring the intervention of the coordination team. Prior knowledge on Chemistry was considered to be a relevant issue within each team for equitable reasons and, additionally, so that the teams could take maximum advantage and make the best use of that knowledge during the development of the project.

The evaluation of the learning process has always been a concern. The feedback provided by the students, teachers, tutors and the educational researchers contribute to this evaluation. To collect all those perceptions a final workshop has been put in place at the end of the semester. In the workshop, the results of the survey answered by students, the grades obtained, some open questions related with the project theme, the assessment model of the project and the PBL as a learning methodology, are discussed. To make it more effective, the discussion is firstly done in small focus groups and then presented to all.

The definition of the project theme is always crucial, because that theme should involve and motivate the students and, at the same time, be challenging and contemporaneous (Moreira, Mesquita, & van Hattum-Janssen, 2011). The chosen themes were always under the umbrella of Sustainability so as to promote a conscience on this pressing issue (Alves, Moreira, Leão, & Carvalho, 2017; Colombo, Alves, Hattum-Janssen, & Moreira, 2014; Colombo, Moreira, & Alves, 2015).

During the semester the teams have access to a guide of the PBL learning process. This is a document provided by the coordination team that explains the rationale for PBL, including: (i) all the "rules of the game" (i.e., the IPIEM1 PBL model and previous references about it), (ii) the coordination team constitution (with teachers and tutors contacts), (iii) the project theme and its specification, (iv) the tutors role and functions, (v) the learning outcomes for each PSC, (vi) the assessment model of the IPIEM1 and each PSC, (vii) the available resources to develop the project (e.g. project rooms) and (viii) the e-learning supporting tool.

Besides the PSC classes, during the semester the coordinator promotes or facilitates a number of different training sessions to support the development of the project. Such training includes: (i) sessions about bibliographic research, (ii) teamwork sessions (lectured by educational researchers and/or IIEM teachers), encompassing, among others, clarification of the differences between a group and a team, teams formation phases, communication and communicational profile of each individual, (iii) motivation, (iv) tools to support the meetings and ideas generation and (v) tools to support the teamwork. Additional training includes: multimedia presentations, reports writing, cross-referencing and references management, among others.

Additionally, one visit to a company is usually scheduled during the semester. This is not always the case in all editions, due to time constraints, but it is considered to be worthwhile by both students and coordination team. The company is frequently chosen according to the project theme. Also, in 2012-13 a task in the context of the IIEM course was requested. The students valued the opportunity to develop the task in spite of the extra time needed to develop it. The task was called "Project networking" and the idea was to establish a network with first year students and companies. The main results of this are presented in Alves, Carvalho, Mesquita, Fernandes, & Lima, (2012).

4 Main changes from 2010 to 2017

This section presents the main changes that occurred along seven consecutive PBL editions, from 2010-11 to 2016-17. The main aspects that were subject to change were the following: (i) the project as an independent course, (ii) the project supporting courses (PSC), (iii) the number of members of the coordination team, (iv) the number of members by students team, (v) the tutors number and type, (vi) the assessment model and (vii) the number and type of milestones. Table 2 presents such analysis. Conversely, some aspects have been unchanged such as the number of students' teams: six, due to the number of project rooms available in the department facilities.

Table 2. Main aspects changed along the seven editions

Aspect	2010-11	2011-12	2012-13	2013-14	2014-15	2015-16	2016-17
Coordinator	Coord 1	Coord 2	Coord 2	Coord 2	Coord1	Coord1	Coord 2
Nr. of students	42	38	48	50	51	53	48
Project as a course	No	No	Yes	Yes	Yes	Yes	Yes
PSC	4	4	4*+ IPIEM1	4*+ IPIEM1	5+IPIEM1	5+IPIEM1	5+IPIEM1
Others courses	1	1	0	0	0	0	0
Size of the coordination team	16	12	11	14	13	10	9
Roles in the coordination team	Teachers: 8 Tutors: 6 Researchers: 4	Teachers: 6 Tutors: 3 Researchers: 4	Teachers: 7 Tutors: 3 Researchers: 3	Teachers: 8 Tutors: 5 Researchers: 2	Teachers: 7 Tutors: 5 Researchers: 2	Teachers: 7 Tutors: 3 Researchers: 1	Teachers: 6 Tutors: 4 Researchers: 0
Size of the students teams	7	6-7	8	7-9	8-9	8-9	7-9
Nr. of tutors	6 (each with 1 team)	6 (each with 2 teams)	6 (each with 2 teams)	6 (1 tutor with 2 teams)	6 (1 tutor with 2 teams)	6 (3 tutors with 2 teams)	13 (2 tutors with 2 teams)
Type of tutors	3 teachers 3 tutors	2 teachers 1 tutor	2 teachers 1 tutor	2 teachers 3 tutors	2 teachers 3 tutors	2 teachers 1 tutor	2 teachers 2 tutors 9 students
Milestones	7	7	6	6	6	6	6
Assessment model	60% PSC 40% project	60% PSC 40% project	100% IPIEM1	100% IPIEM1	100% IPIEM1	100% IPIEM1	100% IPIEM1
Project grade components & weight of the project in the PSC (before IPIEM1)	Reports: 60% Presentation s: 20% Prototypes: 20% Weight: 40%	Reports: 60% Presentation s: 20% Prototypes: 20% Weight: 40%	Reports: 60% Presentation s: 20% Prototypes: 20%	Reports: 60% Presentations : 20% Prototypes: 20%	Reports: 60% Presentations : 20% Prototypes: 20%	Reports: 60% Presentations : 20% Prototypes: 20%	Reports: 60% Presentations : 20% Prototypes: 20%
Individual grade components	Peer assessment= correction factor Written project test: 20%	Peer assessment= correction factor Written project test: 20%	Peer assessment= correction factor Written project test: 20%	Peer assessment= correction factor Written project test: 20%	Peer assessment plus PSCs lecturers assesment =correction factor	Peer assessment plus PSCs lecturers assesment =correction factor	Peer assessment= correction factor Written project test: 20%
Peer assessment of project reports by students teams	n/a	A team assesses a report from another team. 25% of a team report grade is due to this assessment	A team assesses a report from another team. 25% of a team report grade is due to this assessment	A team assesses a report from another team. 25% of a team report grade is due to this assessment	n/a	n/a	A team assesses a report from another team. 5% of the preliminary report grade of a team that assessed other comes

							from how well they assess the other team
Surveys' results (1)	4,16	3,97	4,02	4,04	3,86	3,91	4,05

* Calculus and Linear Algebra were considered as one course in the project.

⁽¹⁾ Average score on a set of questions related to PBL as a Methodology for teaching and learning in the survey conducted to the students, using a Likert scale from 1 (totally disagree) to 5 (totally agree) on the final students' survey on PBL at the IPIEM1.

In general, it is possible to see that very few changes happened throughout the past years, which means that the PBL model is quite stable and adapted to the IEM programme's goals and professional profile.

One of the main changes, in terms of curricular issues, can be found in the year 2012-13, when the project abandoned its "informal" nature (a common agreement established by all teachers responsible for the curricular units of the semester) and became an official course (curricular unit) of the IEM curriculum (Alves et al., 2014). This new curricular unit, which materializes the learning environment for the application of PBL, is the IPIEM1 (Integrated Project of Industrial Engineering and Management I). This change had implications in regard to the students' assessment model, as before 2012-13 the assessment model was made up of 60% of the PSC grade and 40% of the project grade; after the inclusion of IPIEM1, the assessment is 100% of the project grade. With this, students can better see and follow their performance during project development, distinguishing this from the PSC performance.

It is interesting to compare the results of the final survey, regarding the accordance with the "PBL as a Methodology for Teaching and Learning" category (which included 8 questions), applied at the end of each PBL edition. In general, the surveys revealed very similar results along the years with slight differences only. In the cohorts of 2014-15 and 2015-16 was introduced a different correction factor (Moreira et al., 2017) and the final written project test was removed, in an attempt to tackle frequent complains about the test. However, apparently the results indicate that the new mechanism was not fully accepted, resulting in its removal and return to its previous setting in the following edition. Hypothetically, the results seem to support the decision made by the coordination team, which was not consensual among the lecturers of the PSCs.

As previously mentioned, the students' answers to the surveys, along with the outcomes of the reflection from the workshop at the end of each PBL edition identified opportunities for improvement. Having this in mind, the coordination team decided to introduce in the assessment model, one more element beyond the individual peer assessment: each team should assess the report of another team. Thus, the teams of students gain the responsibility of assessing the work of another team and also face the difficulty of conducting that process. Additionally, they have the opportunity to see a report different from their own and learn with that (e.g. what we did wrong/right, what was missing). This was introduced in the 2011-12 edition and the idea is that students evaluated a preliminary report of a different team. Their evaluation is incorporated in the grade of the evaluated team. After three editions this practice was interrupted in 2014-15, due to coordinator change. In the 2016-17 edition this approach was reinstituted but with differences: 5% of the preliminary report grade of each team comes from the rigour/quality of their work when they assess the report of another team. This change was needed to reinforce the responsibility of the team in the assessment process and to avoid incorrect practices (e.g. attributing a grade without thinking first or just because the other team is friendly/unfriendly). Nevertheless, it is worth to reinforce the peer assessment since it is an employability skill needed for the undergraduate and graduate students and valuable by professionals (Paul, Chrispen, & Alexander, 2013).

Teachers and tutors surveys are also important because students are not the only stakeholders in this project. So, their ideas, opinions and feelings about IPIEM1 PBL are also welcome. A good collaboration between the coordination team is crucial for the project success. Teachers and tutors experiences, difficulties and how they manage them have been collected, registered, analysed and a solution was thought by the team. The summarized results in terms of difficulties had been: to deal with workload of this learning methodology (Alves, Moreira, Sousa, & Lima, 2009), student assessment (assessment methods, criteria, weights, etc.), teachers' role and collaboration between teachers (Alves, Sousa, Moreira, Carvalho, et al., 2016; Alves et al., 2016) and integration of courses in the project (Alves et al., n.d.).

Pursuing the continuous improvement, the coordinators are always trying different approaches regarding the way IPIEM1 PBL is organized. One of those approaches was to enable more senior IEM students (3rd year students) to perform the role of tutor of the teams. This contrasted with previous IEM PBL experiences, where the tutor role was reserved to lecturers. In fact, from 2016-2017 onwards, each team was attributed more than one tutor, at least one of them being a lecturer. The students that accepted to perform as a tutor are voluntary and, as previously mentioned, belong to the 3rd year of the IEM degree. This role was given to these students since the students' union at University of Minho delegates the responsibility of reception and integration of the newcomers on the 3rd year students for each degree. The student tutors have performed this role well and some results can be found in Alves, Moreira, Leão, & Teixeira (2017) and synthesized as a good experience, being considered as "godfathers" or "mentors" and someone that had experienced the same IEM PBL experience and difficulties.

5 Conclusion

This paper presents the results of an analysis of seven editions of IPIEM1 PBL showing the main changes that this learning process has been subject to in a continuous improvement effort. These changes were related with the coordinator, the number of students, the curricular plan structure, the project supporting courses and other courses, the coordination team members (number and role), the size of students' teams, tutors (number and type), the milestones of the project and the assessment model and components.

The main change surely was the modification of the formal structure of the project which allowed a better sense of the performance of each student through a grade obtained in the project. Other changes occurred in the assessment model (components' changes), particularly, the change of the correction factor (inclusion of teachers' contribution) – it seems that students didn't like and teachers were not so comfortable with this. Peer assessment of project reports by a different team was a valued change from the point of view of students and teachers because it gives responsibility to the students and, at the same time, it is a good learning mechanism.

The results of the survey from students regarding PBL as a learning methodology, have been always positive which shows their satisfaction with this model. Nevertheless, a continuous improvement journey never stops and there are always improvements to make. Some new endeavours could improve the individual assessment; more stages on the preliminary report and its correction; development of a mechanism to avoid the specialization within each student in the team (in terms of performed tasks); develop a public repository of all outputs of the teams; involve companies in the PBL process. Nevertheless, once more, more institutional support is necessary because the effort involved in the organization and implementation of this kind of projects is quite large, the process is quite time-consuming and it is not adequately recognized at the institutional level (teaching versus research activities).

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Implementation of Industrial Engineering and Management Projects in Interaction with Companies

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Abstract

Active learning strategies have gained relevance in the context of Higher Education Institutions. This growing relevance is due to the fact that there is evidence that these strategies, in addition to being more appealing, are also more effective, resulting in deeper learning. In the context of active learning, one of the most used approaches in Engineering Education is the Problem and Project-Based Learning (PBL). Although there are many publications about PBL in Engineering Education, it is not common to find work that systematically describes the process of implementing these experiences. In addition, there are not many examples of PBL in interaction with companies, neither in Engineering Education in general, nor in Engineering Education in Industrial Engineering and Management (IEM). Thus, this article intends to describe in a systematic way a PBL approach in interaction with companies, which has been applied since 2005, in the Integrated Master in Industrial Engineering and Management (MIEGI) of the University of Minho, Portugal. This description, although it has some chronological references, will be fundamentally focused on the project that runs from September 2017 till the end of January 2018. In this way, it is intended to serve as a reference for other teachers who wish to implement projects inspired in this model.

Keywords: Project-Based Learning; Active Learning; University-Business Cooperation; Engineering Education.