Students' first-hand experience on the development of competences: solving interdisciplinary industry problems

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Abstract

The Integrated Master in Industrial Engineering and Management is a very challenging degree, mainly because it encompasses so many different scientific areas. It is very common for students to feel a little bit overwhelmed with the amount of competences that need to be developed and put in practice. The University of Minho takes a lead role in terms of creating projects which allow the interaction with companies as well as promote the development of transversal competences. The Integrated Project of the 4th year of Industrial Engineering and Management of the University of Minho is a Project-Based Learning (PBL) strategy sustained by the interaction with industrial companies in an active engineering learning process. Students should be able to accomplish the project's milestones and assimilate the company's culture in their weekly visits, during the 5 months of the project. The main objective of the present article is to analyse the student's visions of the work experience provided by the realization of this project. The methodology is based on the qualitative analysis of a group of students' narratives related to their visions on the experience. The results show that they perceived the advantages of interdisciplinary learning, development of transversal competences, learning methodologies of team management, and strategies applied in order to deal with the different project's stakeholders. The main result of this project is the recognition of PBL methodology as an efficient and ingenious form or learning that encourages the students to cope with the requirements and challenges of the actual labour market, while developing technical and transversal engineering competences.

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

1 Introduction

Active Learning strategies and principles have been promoting Engineering Education through innovative learning environments, which challenges students to reflect and experience learning in engaging and meaningful activities (Bonwell & Eison, 1991; Christie & de Graaff, 2017; Felder & Brent, 2003; Prince, 2004; Prince & Felder, 2006). Active learning can be implemented in several different approaches, e.g. Problem and Project-Based Learning (PBL), Team Based Learning or Flipped class room (Lima, Andersson & Saalman, 2017).

The Industrial Engineering and Management (IEM) area need from its professionals, both technical and transversal competences that should be seriously taken in consideration, not only during their degree, but notably in terms of a long term projection related with the moment in which they will join the labour market (Lima, Mesquita, Rocha, & Rabelo, 2017). Industrial Engineering and Management (IEM) professionals should be prepared to solve interdisciplinary problems, in other words, they must be qualified to manage and frame knowledge from different areas of expertise, such as Costs Managements, Production Systems Organization, Production Planning and Control, among others. These competences applied and related to the technical areas of IEM, are assigned as technical competences. Withal, there still are a very notable type of competences that are transferable and transversal between different professions and functions (CEDEFOP, 2012), who might be known as soft skills, for instance, teamwork, leadership, critical thinking, negotiation and conflict resolution, work ethic, communication skills, self-motivation, responsibility, flexibility, decisiveness, problem-solving, creativity, among others.

A question that should be bring to the table is: Why is Active Learning in Engineering Education so needed and why it might be considered a successful teaching and learning practice? Several authors have been studying this question and found that these learning approaches are particularly effective for students' success (Freeman et al., 2014; Prince, 2004). Moreover, particularly with regard to the Industrial Engineering and Management area of knowledge (Aquere, Dinis-Carvalho, & Lima, 2013; Fernandes, Flores, & Lima, 2010; Fernandes, Mesquita, Flores, & Lima, 2014; Lima, Dinis-Carvalho, Flores, & Hattum-Janssen, 2007; Lima, Dinis-Carvalho, Sousa, Arezes, & Mesquita, 2017) a great emphasis has been put on Project-Based Learning (PBL) as one of the most complete approaches for implement active learning. Considering these approaches this work intends to add a new perspective on the impact on the learning process, from the point of view of students. Thus, the question that the paper tries to answer is: Why students consider that PBL in IEM area of knowledge is so needed and why it might be considered a successful teaching and learning practice?

PBL is a pedagogic approach that allows students to tackle real industrial/business problems while developing commitment in administering the fields of knowledge acquired in several courses, and stimulating students' meaningful competences: making inquiry, creativity, personal and critical reflection, hypothesising. The development of PBL projects in industrial context constitutes an exceptional opportunity for engineering students to develop competences expected by the labour market and usually companies have been very pleased with the results of this type of University-Business Cooperation (UBC). Indeed, according to the perspective of The European Union, "Universities must also provide knowledge and skills geared to the needs of the labour market" (Lima, Carvalho, Sousa, Arezes, & Mesquita, 2017).

Students of the University of Minho have the opportunity to be part of an Institution that is a pioneer in the implementation of practical teaching techniques (Lima, Dinis-Carvalho, Sousa, Alves, et al., 2017)}, implementing it since 2005. The UMinho PBL model was originally inspired in the model of Powell & Weenk (2003), which was introduced by a team of university lecturers after training presented by Professor Powell and promoted by the University of Minho's rectory. Following each semester, teachers always develop a workshop in order to obtain the feedback from the students and teachers involved, which gives important data about the challenges and difficulties registered by the different project's stakeholders and allows the construction of a suggestions system for future improvements (Lima, Carvalho, Flores, & Hattum-Janssen, 2007). The main objective of the project developed in semester seven of the Integrated Master in IEM is offering the opportunity to create a bond between industrial and academic worlds by emphasizing the interaction between companies and students.

The main purpose of this paper is to give a more closely vision of the students' experience while realizing the PBL project during the first academic semester, who took the duration of 5 months, in which the authors of this article integrate a team of IEM students focus in solving the real problems of a company dedicated to the production of textiles for tires. The research methodology was based on a qualitative approach in order to obtain a deeper understand of students' perceptions about university and industry cooperation in PBL's context. Following these line of reasoning, technical solutions developed by students were analysed and a general overview about the process (e.g. challenges, difficulties, improvement suggestions) was realized, considering the perceptions of the students involved. These perceptions were collected with narratives.

This paper is divided in five sections. Following this first section designed as introduction, where was given an theoretical context of the academic context studied and where the main objectives were exposed, the second section refers to the PBL Context and Projects' and Stakeholders' Presentation, the third reveals the technical solutions suggested/implemented by the students, the fourth is related to the Students' Testimony of the Experience and the last one is reserved for conclusions.

2 Description of the PBL approach

In this section a special focus will be given to the description of the specific PBL approach implemented in this program. This description will be focused in the presentation of the general context, followed by the description of main details of the projects proposed by one company to one specific team. Finally, it will be presented the main stakeholders of the project.

2.1 PBL Context

The PBL approach examined in this paper is implemented in the 7th semester of the Integrated Master on Industrial Engineering and Management (IEM) program, and it is formalized in the curriculum through the Integrated Project on Industrial Engineering and Management II course (IPIEM II). It is particularly important to reinforce the necessity to respond to the University's and the company's requirements for the specific projects that will be enlightened in section 2.2 and section 2.3. Thus, during the project, teams of 9 to 11 students try to respond simultaneously to several different stakeholders from the university and the company, dealing with a challenging and enriching learning process. Developing a project like this requires a close cooperation between industrial and higher education organisations. The main phases of the project are: (i) exploration, (ii) analysis and diagnosis of the company's production system and (iii) development of improvement proposals (Figure 7). During the exploration phase, students are assigned to teams and projects in a process influenced by their references about their colleague's performance and by their personal preferences. After that phase, the first visits are made and teams immediately start analysing and subsequently understanding the company production system in a generic way, and ultimately defining the objectives of the project. During the rest of the project, students make the diagnosis of part of the company's production system and propose several improvements to overcome the identified and formulated problems.

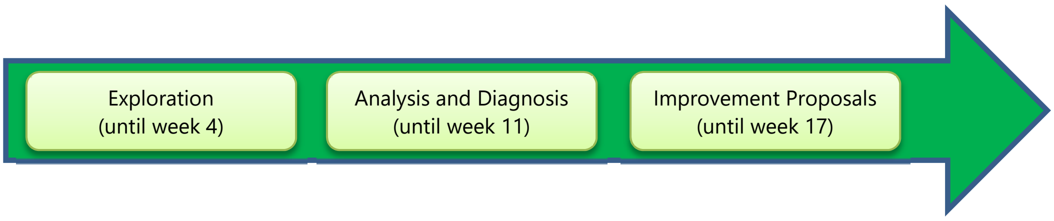


Figure 7. Main phases of the project developed in the IPIEM II course.

In terms of the University's requirements, teachers responsible for the 7th semester require students to make the application of the engineering themes covered by the following courses: (i) Production Systems Organization II (OSP II), (ii) Ergonomic Studies of Workstations (EEPT), (iii) Simulation (SIM), (iv) Production Information Systems (SIP), (v) Production Integrated Management (GIP). These courses and its teachers give support to the teams of students while developing the projects, as illustrated by Figure 8.

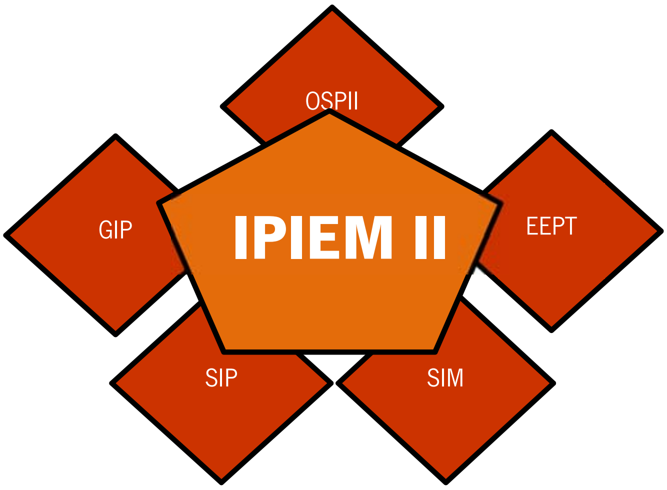


Figure 8. Illustration of the curricular units involved in the IPIEM II.

2.2 Company's Projects

In terms of the company's requirements after some weekly reunions with the engineers responsible for the Department of Industrial Engineering, the team was presented with the following proposal subprojects: (i) Ergonomic Study of the Workstations (ESW), (ii) Implementation of Stock Management Strategies, (iii) Reduction of set-up times, (iv) Overall Equipment Effectiveness (OEE) monitoring and improvement. The mentioned curricular units work as project-supporting courses (Figure 9).

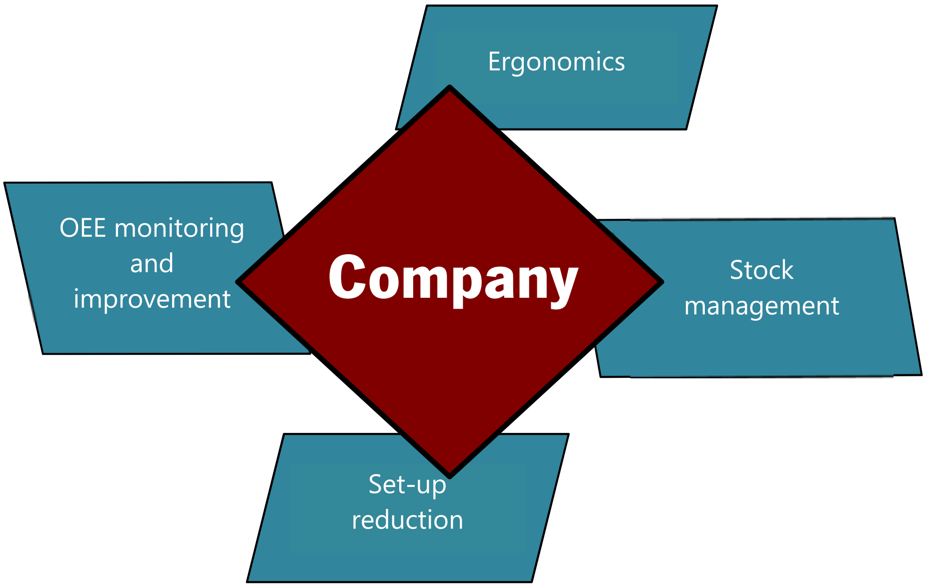


Figure 9. Illustration of the projects proposed by the company.

In order to reduce the number of set-ups the company proposed the Stock Management project to optimize the produced quantities and stock. According to the process, the set-up time could be a barrier on the appliance of the Stock Management project, because of the optimization of produced quantities resulting from the study. To get around this obstacle comes up the Set-up Reduction project, which is related with a new way of working for the operators and the insertion of new tools. To ensure an efficient interaction between operators and the changes caused by the Set-up Reduction project, the company proposed the Ergonomic study of these changes. To evaluate the benefits achieved by all these interrelated projects an OEE indicator was developed and implemented.

2.3 Main Stakeholders

As mentioned in section 2.1, PBL has two main stakeholders: on the one hand, the university teachers, and on the other, the company, which in this case is a company dedicated to the textile production for tires. During the project, the industrial engineer from the company, who provided guidance to the team, emphasised the need for the engineering students' team to cooperate with a group of vocational students, from a pre Higher Education level, in order to develop some industrial prototypes. This prototype could have a huge impact in reducing the set-up time of some of the production machines. This will be discussed in section 3.3. The vocational school selected was FORAVE, a private vocational school, who have been involved in large number of projects developed in company. This school's main objective consists of the preparation of citizens for active life who wish to improve or acquire skills to respond to the requirements of the market in the areas of Production Management, Industrial Maintenance, Electronics and Automation and Quality Control.

2.4 Technical solutions suggested/implemented by students

The technical solutions developed by the students were based in the results of the analysis and diagnosis phase. On account of the broad nature of the developed solutions, these will be introduced in the following sections according to a classification into different categories.

2.4.1 Ergonomic Study of the Workstations

In terms of the subproject related to Ergonomics, after a short period of analysis the students identified a task that caused serious problems to employees at the skeletal muscle level, which were related to the operation of placing rollers in the buffers. This operation was performed by two employees, in which they had to place the rolls, weighing around 110 kg, at different levels of the buffer (Figure 10). This operation has different ergonomic risks, varying from level 1 to level 3, depending on the height. Level 3 of ergonomic risk is a result of the operation, in which the employees raise the arms to a height superior to the height of the shoulder.

In order to solve this problem, the authors resorted to mechanical means (stacker), which raised its rollers up to the level of the desired buffer level, and then it would only be necessary to push the roll from the stacker to the buffer. It was necessary to use the ergonomic evaluation method called REBA (*Rapid Entire Body Assessment*). REBA has been developed to fill a perceived need for a practitioner's field tool, specifically designed to be sensitive to the type of unpredictable working postures found in health care and other service industries (Hignett & McAtamney, 2000). The selected method was used to evaluate the current roll placement process and the proposed process that consists in the use of a stacker as a mean of production aid. The results obtained based on the REBA analysis allowed to conclude that this new proposed method of placing rolls in the buffer allowed to reduce the risk of work-related musculoskeletal disorders in the employees, as well as the reduction of the number of employees needed to perform the task, going from 2 to only 1.

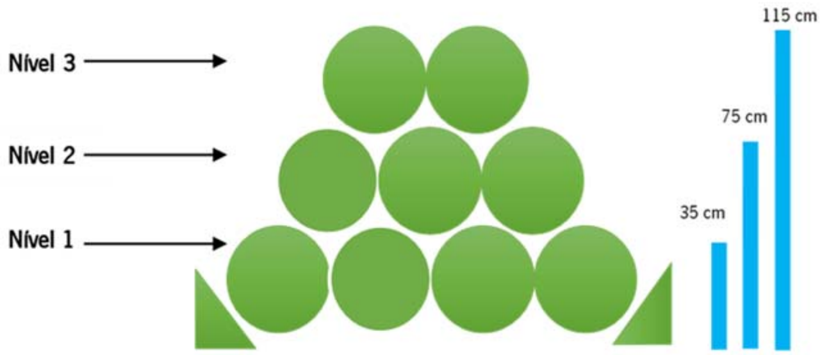


Figure 10. Representation of the stacking of the rolls in the buffer.

2.4.2 Stock Management

The company presented a problem to respond to the variation in demand. Their production is based on forecast, but many times, there is a huge difference between the predicted and the real quantity carried by the client. This problem caused high levels of stopped stock and some stock breaks. The main purpose of this project was to create a new way to manage the production orders based on stock level.

The product studied has a volume of 1.64 m3 and an unpredictable demand. The first analysis on this issue was to understand the actual production strategy in order to get more knowledge about the problem. From this analysis it was possible to get a better knowledge of the demand characteristics of the product. To solve the problem were used a stock management strategy (Casimiro, 2015) to make a new sizing and analyze whether these strategies works and if it's better than the current strategy.

The stock management strategy gives answer to when and how many the companies must produce (Carvalho, 2017). The company provided some data of the history of the demand and production for forty-two weeks of the product under study. The optimum parameters of the stock management strategy were calculated and after that was simulated the application of the model for that period of forty-two weeks and compared to the actual strategy. The simulation results showed that in terms of stock the actual strategy and the level strategy stock levels were almost the same but in terms of production they had a difference that is illustrated by the chart of Figure 11.

According to the charts, the stock level strategy was chosen because it had the best performance. With this strategy the company should produce always 51 rolls when the stock reached 62 rolls. The production would be more leveled and the total production for this period (42 weeks) would be 1785 rolls when the previous is 1733 rolls, from the charts is possible to see that in the current strategy during the 42 weeks there was one in which production was null because the inventory levels were stable and in stock management strategy this happened on seven occasions, which means that the company would be producing more product in a short period of time with the same capacity.

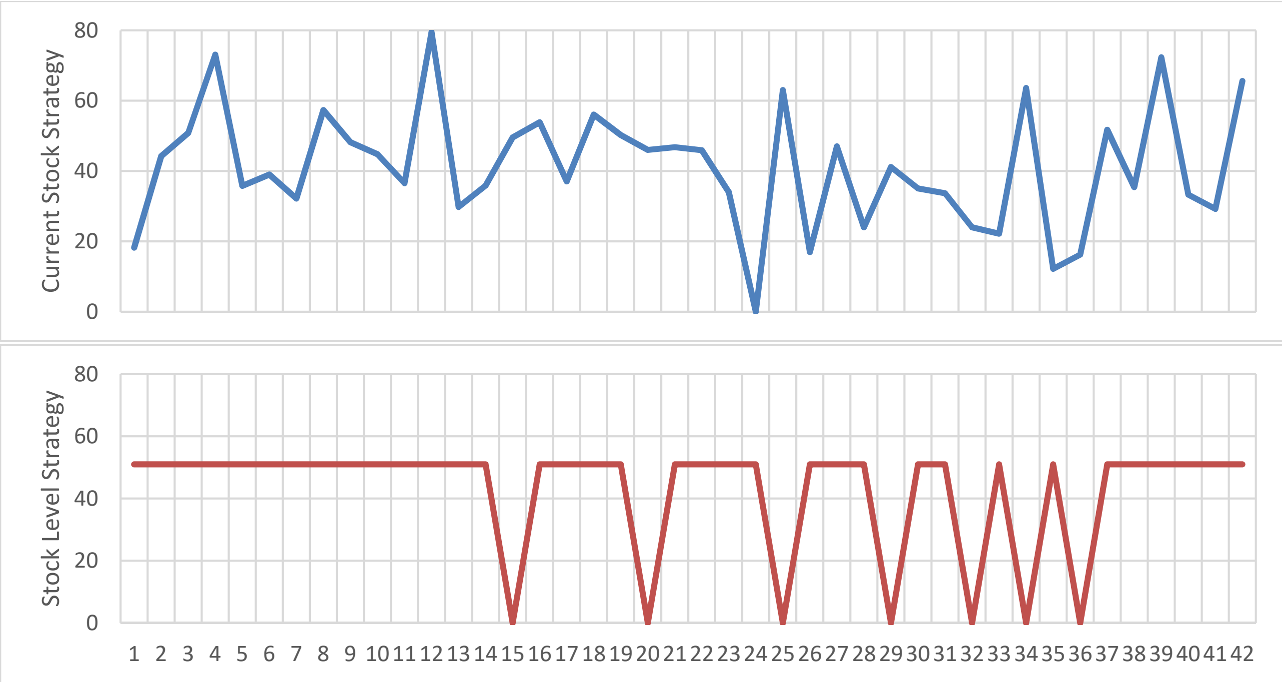
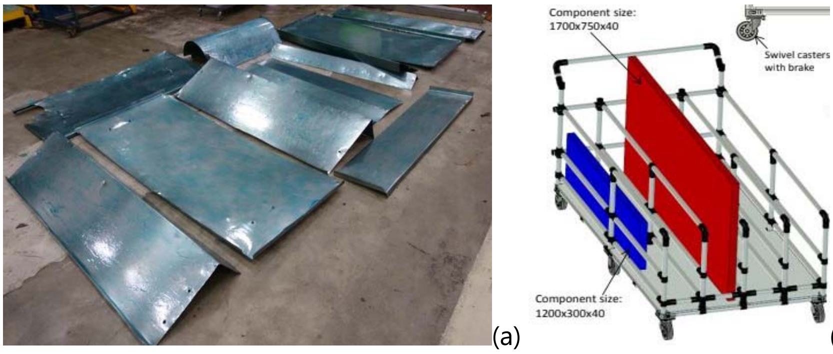


Figure 11. Current production strategy and the proposed production with the stock level strategy.

2.4.3 Reduction of set-up times

Another issue addressed to the team, was the study of the setup time of the Single End machine. As it had an 8-hour Setup time, and when observing its operations, it was verified that it could be reduced if the operation of cleaning of the solutes vat passes from an internal operation (operations made with the machine stopped) to an external operation (operations made with the machine in operation). For this to be possible, it was necessary to replicate the Tub Plate Kit (Figure 12a), to have two kits, as well as the creation of a trolley to store that spare plate kit, (Figure 12b). Both projects were then designed by the team and then delivered to outside companies, being under production. It is expected to achieve a saving of about 3 hours in the setup time of the Single End machine.



(a) (b)

Figure 12. (a) Illustration of the plates' kit. (b) Illustration of the trolley for the storage of the plates' kit.

2.4.4 Overall Equipment Effectiveness (OEE)

Overall Equipment Effectiveness (OEE) is a performance indicator designed to measure the utilization of critical equipment in three different dimensions, Availability, Performance and Quality (Hansen 2001). OEE is a golden standard for measuring manufacturing productivity. For this specific project it was necessary to create two different files for different machines of the impregnation area. The purpose of these files is to save the respective data of each shift. These files are very interactive and were developed using specific software like VBA and Excel in order to save and apply the appropriate treatment to data. The OEE's values were obtained in tables and graphs.

3 Quality Analysis of the Students' View of the Experience

This section presents a qualitative analysis of the perceptions of five students that were collected using narratives. The narratives were than analysed by two researchers and cross checked with other researcher to overcome some doubts of interpretation.

3.1 Difficulties and challenges faced during the project

During the project the students faced several challenges that let them excited to release everything that they have been learning at university. Those challenges allowed to put the theory in practice and implementing solutions to solve real industrial problems. They see the difficulties as opportunities to grow up as professional of their areas. Working in teams and communication issues were difficulties that tuned in to opportunities to be developed. The following excerpts present evidences for these difficulties and challenges.

> "*The management of human resources within a work team is not always easy and this project has forced us to apply the soft skills or transversal skills that the labour market demands: conflict management, responsibility, communication, leadership ability, motivation, etc. (...) all these competencies have been tested and applied in order to manage the emotional / motivational component of the team.*" *Narrative A.*

> *"In addition, since it was an extensive project with multiple elements and entities, it also helped me to improve my soft skills, such as interaction with different people and personalities, communication skills, control of emotions, between others." Narrative D.*

3.2 Developed competences during the project

The BPL environment complements the student's formations, in what could be called the union of the two worlds, the university and companies. This environment allows students to develop several competences or either to improve the ones that they already have. They learn many things from university, what they ask many times is where to apply those knowledges and this environment comes to give an answer to this question. This interaction between students and the company was a big step for students to know which competences the market is expecting from them, as mentioned by these students:

> *"I think this kind of methodology lead us to explore deeply the competences that we have been gathering during the years of formation as well as get to know what is missing in us, in terms of competences that the markets really demand. I had the opportunity to practice and apply concepts that I only had in theories, which proved to me that what we learn at university also add a great value in the real world." Narrative B.*

> *"I was able to understand what the job market expects from an industrial engineer and within those competencies demanded by the market, I also realized which of them I have the most competence." Narrative C.*

3.3 What about the experience?

The PBL experience is a mix of many things, is a mix of bad and good experiences. In general, the students go through many situations, which may either let them excited or frustrated with the project. These emotions depend on many factors, including their own personality. But taking in account the main purpose of the project, which is being in a company improving their learning, as well as applying technical concepts from the academy, it makes them overcome every bad personal experience and focus on the solutions to the companies' problems. Ultimately, this gets them highly motivated when something that they have accomplished is being implemented by the company, which turns to be a very good experience for the students. This experience related issues are evidenced by the following excerpts.

> *"Being in a company once or more times a week was a different dynamic and I felt like I was part of something big, a commitment that made me give the best of myself to achieve a common goal." Narrative B.*

> *"PBL project is, in general, quite positive, that's why I strongly recommend the University to maintain this type of teaching more focused on the practical learning methodologies." Narrative A.*

> *"The PBL was a great academic experience. The link between the reality and the academic side was awesome. I was able to understand what the job market expects from an industrial engineer and within those competencies demanded by the market, I also realized which of them I have the most competence." Narrative C.*

> *"In my opinion, the PBL, in the fourth year of the course until the moment, was the best experience and the best moment of evaluation." Narrative E.*

4 Conclusion

The practice of engineering is permanently urging for updates specially in terms of teaching and learning methodologies. This necessity can be enlightened due to the quick changing needs that business, labour market and society requires from their future professionals. In this way, education in engineering needs to quickly adapt the teaching methodologies in order to train engineers with the correct technical and transversal competences to face a world that constantly creates new necessities, new problems, where different and ingenious solutions are required.

This work presented a contribution for the development of a PBL project in interaction with industries, demonstrating that it is possible to create learning environments embracing real industrial contexts. These hybrid environments with a stimulating atmosphere between the academical and the industrial world, create the opportunity for students to identify and define real industrial problems and develop efficient and practical solutions. Additionally, PBL project were developed in a context of curricular integration with five curricular units, which rewards the students' learning that have the chance to solve problems of a higher level of complexity with the assistance of several teachers with many years of expertise in different knowledge areas. The feedback from professionals of the companies involved is extremely positive, and the students develop a great awareness of the professional applications of the Integrated Master in Industrial Engineering and Management. It is extremely important to sustain that students improve their feeling of being well prepared for the labour market after the experience provided by PBL.

The purpose of this article is to present the solutions students were able to develop in such a PBL setting and additionally, to develop a qualitative analysis of the student's view regarding the experience provided. This perspective was categorised in positive aspects, reflecting about some challenges faced and thinking about improvement suggestions in order to support their brilliant view of the this PBL implementation.

To sum up, reflecting about the student's view it is possible to conclude that PBL reveals to be a huge potential tool as a teaching and learning methodology that only needs to be consistently improved.

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