Project-Based Learning: A Case Study with Industrial Engineering Freshmen

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1 INTRODUCTION

Nowadays, technological transformations occur faster and faster. Due to this fact, the requirements of work market also change at a similar rate. These changes affect many things, including the formation of engineers, which still shows major deficiencies by being focused on a very traditional teaching style, which is mostly based on the transmission of knowledge from the professor, i.e. instructor to the student, in which the instructor is the active agent and the student, the passive one.

The education engineering must be changed so that future engineers may be able to work in group and face the internal reality at a company, which is each more and more dynamic [1].

More and more, the work market seeks for well-prepared engineers who possess a diverse mix of competences; as well as engineers that are able to solve problems in a quick way, to communicate clearly, to work on a team, to make decisions and to adapt to technological and to the company cultural changes. This competence mix, more and more evaluated by employers, most of the times, is little developed in engineering courses.

UNESCO [2] showed a solid and consistent study regarding engineering, in which it introduces ways, such as: “transform education engineering, curricula, and methods of teaching to emphasize the relevance and an approach to problem solving in engineering”. This same report highlights the importance of engineering curricula being based on relevant activities to the students, among which, teaching activities based on projects and problems are enhanced.

For UNESCO [2], the future of world is in the hands of young engineers and the university must provide them the maximum orientation for them to be prepared to face the future challenges. The compromise of capacitating engineers more and more prepared for these challenges has coming, along the present years, to force universities to use a series of methodologies based on active learning, among which Project-Based Learning is inserted in consonance with UNESCO [2] methods. PjBL has as one of its main characteristics the learning step focused on the student through real problems he or she is submitted to.

Project-Based Learning (PjBL) was implemented in the Industrial Engineering course at the School of Engineering of Lorena, at the University of São Paulo, Brazil, starting in 2013, in similar experiences to the ones present at University of Minho [3] and at the University of Brasília [4]. This work evaluates the evolution occurred with freshmen in Industrial Engineering at the School of Engineering of Lorena, at the University of São Paulo, on their first term, using PjBL.

2 PROJECT-BASED LEARNING

Project-Based Learning is a method of teaching-learning that has been changing, along the last decades, the way students learn. It is an alternative to the passive teaching style, in which knowledge can only be transferred by the instructor and the student acts as a receptor. This method of teaching-learning puts a group of students to work on teams on a project and has as objective to develop technical competences related to the project theme, as well as transversal competences, such as teamwork, time management, communication, creativity, among others [5].

According to PMBOK [6], project is defined as the creation of a product or service during a defined timeframe. For Poweel and Weenk [7], Project-Based Learning aims at the integration of theory with the practice, through a project for which a solution or a final product must be presented. This project must be integrated to a real context of the future profession where the students assume the central role of their own learning, making the instructor to act more as an advisor, i.e., a tutor.

Project-Based Learning, at engineering major, is considered a way of adding value to the student's learning, as well as being renowned as an effective way of preparing the students for professional practice [8, 9, 10, 11]. According to Lu [12], students that participate in Project-Based Learning are more active, communicate better, know how to work in group, and are better professionals because they know how to apply the knowledge to solve a professional problem.

In this learning methodology, the student must learn how to do, and due to this, he or she becomes more motivated and his or her academic record is improved. What differentiates PjBL from other activities performed outside the classroom are: the position of the student at the centre; the utilization of differential tools, technical or behavioural; the achievement of a tangible product at the end of the work; the pursue of necessary knowledge by the students themselves; the evaluation made in function of the group performance and at last, the stimulus to work in group [13].

For Lehtovuori, Costa and Honkala [14], the work market is demanding much of the professional and only the knowledge is not enough; this way, teaching through PjBL provides many benefits to the students and improves their academic development. The following benefits are highlighted: the students gain not only knowledge, they learn to make a project; they can practice their abilities and gain others; they know how to behave in groups; the practice brings the student closer to his or her profession; the projects, most of the times, cover the university and the communities related to it, bringing improvements; the students' evaluation is based on the reality they will find at the work market; it increases communication and union at classrooms.

Improvements on the students' academic performance can be observed when this method of teaching-learning is utilized, but that depends on the project and on the interaction among the students with the work [12].

Thus, Project-Based Learning is a method that places the student at the centre of the learning experience. He or she, the student, receives a theme and needs to create a project and show a solution in a determined time. During the project development, he or she acquires competences that he or she would not have on a traditional learning experience; thus, he or she learns how to work in group, to dialogue; he or she develops abilities as leadership; he or she must seek his or her own knowledge, as well as separate what must be learned for him or her to be able to finish the project, among other abilities. The traditional "classroom" also changes, since it becomes an interactive learning environment. The instructor role changes as well, since its position becomes a tutorial one, stimulating the student to seek knowledge.

3 METHODOLOGY

The method of research utilized was case study [15] that consists of a strong method, once it allows, from exploratory studies, the development of ideas and research questions, to the development of new theories and a comprehension increase of current theories. This research method shows inductive focus on analysis of obtained data and a descriptive one for results presentation.

A case study is generally organized around some questions referring to "how" and "why" of such investigation, and it can be decomposed to its most relevant components. There are four essential steps for a case study. They are: (i) – delimitation of the case-unit: it is regarded to the precise delimitation of the constituent unit in the case, as well as the presentation of the minimal sufficient data

for an adequate comprehension of the study object; (ii) – data collection: it refers to quantitative and qualitative tools responsible for the data and obtained data about the researched object; (iii) – selection, analysis and data interpretation: analysis and data interpretation are performed in function of the research goals and the obtained data limitation, and (iv) – report writing: based on the obtained data, the necessary reports for an adequate comprehension of the theme and the studied object are elaborated.

3.1 Delimitation of case-unit

The main goal of this research was to evaluate the occurred evolution of freshmen in an engineering degree on their first term using Project-Based Learning. Regarding the nature of the addressed variables, this research is characterized as a qualitative research with a descriptive exploratory feature, once during the research, little was known about the real application of the methodology with freshmen in an Industrial Engineering course.

The research was performed with the registered students in “Introduction to Industrial Engineering”, based on the major of Industrial Engineering, at the School of Engineering of Lorena at the University of São Paulo. The class was composed of 46 students, having 40 of them as incoming freshmen in 2013. The other six started their course in past years, having three of them changed their major, via internal transferring, and three of them taking this course as an elective one for their major program.

A “Project Guide” [17], elaborated by the course professor alongside with the tutors, was handed to all the students in their first class. This guide consisted on the instrument that would explicit the main objectives to be followed throughout the term, as well as the responsibilities of the students and the tutors. It presented the technical competences that were hoped to be developed with the students during the project, as well as a group of transversal competences (Figure 1), that made up the great differential in their formation, particularly by being freshmen in an engineering course.

Project Management	Team work	Personal Development	Communication
Research capacity Decision making Organization capacity Time management	Autonomy Initiative Responsibility Leadership Problem Solving Interpersonal relationship Conflict management	Creativity/ Originality Critical Thinking Self-evaluation Self-regulation	Written communication Oral communication

Figure 1: Desired competences [17]

The proposed theme for the project was an open problem that would not have one single solution. The proposed question was: “Sustainable University Campus”.

Each group utilized three supporting tools: a blog, where they would publish the work evolution on the web; the minutes of meetings, where they would register the meeting discussions; and a communication protocol, throughout which they would make the internal group communication.

Six teams were formed, with 6 or 7 components, a professor as tutor, and a student as consultant. The tutor was a professor at the School of Engineering of Lorena, that had the responsibility of mentoring the group, but he or she would not be able to interfere in the decision making. The consultant was a veteran student that would support and motivate the group. Each group had a leader and a secretary. The leader had as roles the team coordination, the meeting scheduling and task distribution. The secretary had as role the writing of the minutes of meetings.

The main events along the term were: (i) – in the first class, in which the students received the “Project Guide” [17] with instructions about PjBL; the groups were made; and the choice of leader and secretary for each group was performed; (ii) – in the second class, each of the groups made a preliminary presentation about the project theme; (iii) – in the thirds class, the students attended a speech about the importance of team work for the professional life; (iv) – in the fifth class, a librarian made a speech about how to perform research in scientific databases; (v) in the seventh class, the students handed a preliminary project report and they replied an evaluation questionnaire; (vi) – in the ninth class, each one of the groups changed the leader and the secretary; (vii) – in the tenth class, the librarian made a second training about research using databases; (x) – in the twelfth class, each one of the groups made a presentation about a published article in the “International Journal of Sustainability in Higher Education”; (ix) – in the fourteenth week, the students replied to an identical

questionnaire to the one in the seventh class and they handed the final project report, and (x) – on the fifteenth class, the students defended the final project orally.

3.2 Data collection

Data was collected through three questionnaires applied in distinct moments during the course and through interviews made with each one of the tutors.

A closed questionnaire, “Assessment Questionnaire of PjBL”, was applied in two different moments: in the seventh and in the fourteenth classes, in order to investigate: (i) – the students’ opinions regarding the used methodology and its application; (ii) – the motivational degree of each student and his or her team as a whole; (iii) – the degree of participation of the leader, the consultant and the tutor; (iv) – the acceptability of PjBL utilization; (v) – the efficacy of the work accomplished in group; (vi) – the integration among the project and the other courses that were being taken, and (vii) – the utilization of supporting tools to the project. This questionnaire was consisted of 23 questions related to the project. Students answered it using an interval scale from one to five, in which 1 means “totally disagree” and 5, “totally agree”.

A closed questionnaire, “Peer Review Questionnaire”, was applied in the last class of the course. The objective of this one was to allow the student to evaluate the teammates, as well as him or herself, regarding the effective participation of each member of the group in the project. The questionnaire had the name of each group component. The used scale had 7 intervals (-3 to +3, in which -3 indicated the least contribution to the project execution, and +3, the highest). Each student filled out this questionnaire, grading him or herself and his or her teammates from -3 to +3 and the score sum should totalize zero.

An interview was performed, separately with each one of the six tutors, between the fifth and the sixth class of the course. This interview was made using an open questionnaire with 7 questions, aiming the evaluation of the PjBL method itself, the positive and negative aspects of its application, the analysis of the tutor role on the project conduction and the tutor’s perspectives related to the project that would be reported by the groups.

Some other tools were also used as information source, such as the minutes of meeting and the team blog, as well as reports made through the course and the oral presentations of each team.

3.3 Data analysis

Quantitative data were obtained using the “Assessment Questionnaire of PjBL”, applied in two distinct moments, and the “Peer Review Questionnaire”, applied in the last class of the course. For both, basic descriptive statistics calculations were made to obtain simple arithmetic and pondered means. Using this, a demonstrative display was created with the obtained raw results that allowed a general view of the collected data. Preliminary conclusions were obtained, in some cases, in a direct way from a single questionnaire, and in other cases, from the joint analysis of answers from these questionnaires.

Qualitative data were obtained from the interviews with tutors, as well as from the further supporting tools to the project (blogs, the minutes of meeting and reports). All these data were transcribed, in a very thorough way, to specific documents, what brought a systemic view of the occurred dynamic along the term, from both the students’ and the tutors’ standpoints. This way, it was possible to evaluate the project evolution, to evaluate the integration of participants in their groups, to infer about the written communication capacity, and to observe the utilization of communication protocols in each group during the project development. Beyond this, these data were very rich for evaluations related to the development of the students’ transversal competences.

Using the multiple sources of evidences (the three questionnaires, the interviews with the tutors, blog analysis, meeting minutes, and the reports), the triangulation technique was applied; this technique consists on an interaction among these sources to sustain propositions and hypothesis, from the observation of convergences or divergences. This concept not only constitutes, for some, one of the ways to combine several qualitative methods among themselves [18], but also articulates qualitative and quantitative methods [19]. To Flick [19], method triangulation is not only a methodological tool, or a strategy to validation, but a strategy to validate results obtained from data analysis.

4. RESULTS

4.1 PjBL: The course differential

The “Assessment Questionnaire of PjBL”, answered by the students in the middle and at the end of the term, allowed the analysis of Project-Based Learning acceptance as method of teaching-learning. Mean scores of 4.51 and 4.71 (on a scale from 1 to 5) were obtained, in the seventh and fourteenth class, respectively, related to the PjBL utilization as a course differential. Therefore, it can be inferred that, throughout the students’ standpoint, the PjBL application was a significant course differential.

Another question present in the “Assessment Questionnaire of PjBL” aimed to investigate if the students thought that PjBL should be used in further courses along their coursework. Regarding this question, students attributed mean scores of 4.15 and 4.18 (on a scale from 1 to 5) in the seventh and fourteenth class, respectively. Thus, students showed a good interest in continuing to work with the methodology in other courses in their curricula.

4.2 The integration of the project with supporting courses

Some questions aimed at analyzing if the students were able to see any kind of integration among the project and the other courses they were taking concomitantly on the first term of their engineering degree. These questions were in the “Assessment Questionnaire of PjBL”. The obtained responses, on a scale from 1 to 5, for the degree of integration among the project and the analyzed courses are on table 1.

Table 1. Degree of integration among the project and the courses

Course	Seventh Week	Fourteenth week
Calculus I	2.13	3.00
General Chemistry	2.58	3.36
Production of Academic Texts	4.74	4.86

It can be seen that the integration with the course “Production of Academic Texts” was excellent throughout the entire course. This was a very positive result, since this a course that brings little interest to the students on their first terms in an engineering degree.

Regarding the other two (Calculus I and General Chemistry), that are basic courses for freshmen in engineering, it was observed that in the middle of the term that the students disagreed more than agreed that there was integration. The perception of integration among these courses and the project, though little, evolved on the second half of the term, the period in which they gave the final format of the project.

4.3 Leader change

The leader change occurred in the ninth class, aiming at a role rotation among the group components. The obtained data from the “Assessment Questionnaire of PjBL”, referring to the effective contribution of the leader to the group success, presented a mean score of 2.77 and 3.43 (on a scale from 1 to 5) for the first and the second leaders, respectively. This way, in general, the leader change was beneficial. However, when the groups were analyzed one by one, it was noticed that for two groups the leader change was very relevant. For other three groups, this role rotation was relevant, in a smaller intensity, and this leader change was not beneficial for one single group.

Another question at “Assessment Questionnaire of PjBL” evaluated if the group leader had conducted the whole team in an efficient way. It was observed, on a scale from 1 to 5, a mean score for all the groups regarding the efficiency of the leader conduction: (i) – the mean score of 3.15 for the first leader, and 3.61 for the second one. This result reinforces what was determined before, i.e., that leader change, in a general way, was beneficial for the project execution.

These two results revealed that choosing the second leader seemed a more mature act from the group, since this choice was made in the middle of the term, when all the students knew each other for about two months.

4.4 The development of transversal competences

The interviews with the tutors allowed to infer that all of them noticed, on a larger or on a smaller scale, the students' evolution in regard to the transversal competences. Two of the tutors highlighted that, in their opinion, this was the most significant gain on utilizing PjBL.

4.4.1 Project Management

The competences related to Project Management that were aimed to be enhanced at the students were: research, decision, organization capacities and time management. Initial expectations related to project management were that the groups followed the times pre-established on the Project Guide, that they reached the proposed objectives at the course beginning and that they delimitate the acting area for each proposal.

It was expected that the students managed, in an optimized manner, the time separated for performing project-related activities and that they also organized them in a way of following a previous elaborated plan. This, in fact, occurred and it was observed through passive observation of group meetings. It was also observed that, most of the times, they followed the pre-established deadlines present on the Project Guide.

The analysis on the minutes of meetings revealed that: (i) – there was a good organization of the ideas and (ii) – the groups used to look for proposals that were coherent and escaped a little from the problem focus.

4.4.2 Team work

One of the great objectives of the PjBL utilization is the possibility for the students to develop transversal competences, overall, those related to team work, such as: autonomy, initiative, responsibility, leadership, problem solving, interpersonal relationship, and conflict management, previewed on the Project Guide.

The development of these competences was inferred based on the "Assessment Questionnaire of PjBL", as well as from the observation of the students' behaviour along the classes and presentations. The analysis of a question related to relationship among team mates and the integration among them allowed to be inferred that the students agreed more than disagreed on forming an excellent team: 3.98 and 3.57 (on a scale from 1 to 5), on the first and on the second utilizations of the questionnaire, respectively. A slight decrease on the second application was shown. It might be based on the natural relationship tear among mates on a team along the time.

Another question present in the "Assessment Questionnaire of PjBL" aimed to evaluate if the PjBL methodology contributed to the improvement of interpersonal relationships. Mean scores of 4.73 and 4.68 (on a scale from 1 to 5) were obtained on the first and second applications of the questionnaire, respectively. This high degree of concordance suggests that interpersonal relationships among the students, in general, occurred in a very favourable way. Since it is related to freshmen it is positive, that most of them got to know each other in the first day of class.

Beyond this, it was possible to observe at the meetings among students that they developed higher flexibility to problem solving and decision making, once they started to be the main mentors and executors in seeking knowledge. In short, many competences related to collaborative work that would not be so enhanced by the use of conventional learning methodologies, were potentially improved from the moment PjBL was applied.

4.4.3 Personal Development

The related competences to the personal development expected to be upgraded by PjBL utilization were: creativity/originality, critical thinking, self-evaluation and self-regulation. The supporting tools to the project (blogs and the minutes of meetings), the oral presentations and the questionnaires regarding the project execution allowed to find how the active learning procedures were favourable to these competences development.

The application of "Peer Review Questionnaire", in the last class of the term, allowed to evaluate the real contribution of each team member on the project execution and organization. The given answers to this questionnaire revealed a good maturity level coming from the students, when they evaluated the work made by the teammates, compared with the work made by themselves. This way beyond the maturity, the adequate usage of the critical thinking on the performed evaluation was found.

4.4.4 Communication

In different moments during the course, the students were challenged to elaborate reports about the project execution, and to present, orally, how they were executing the work. The main objective of these challenges was the development of the capacity of oral and written communications.

Four oral presentations were performed in distinct moments during the course. It was found that, along the presentations, the students that were shy at the beginning evolved and became more confident to speak in public. Furthermore, it was observed that had students already spoken in public in a more natural manner, even gained more confidence to do so. The final project presentation was made to a panel with three professors, having the group tutor as one of them. In this presentation, all the students participated and, in a general way, they outcome their oral presentation made in the second week of class.

Regarding written communication, the analysis of both reports revealed a substantial evolution in relation to their argumentation capacity, theoretical and scientific foundations, expression of ideas and text organization. Beyond this, at the end of the course, students also handed a report, on the format of an academic article, with the required standards and methodologies of a scientific work.

4.5 Indirect result

One of the teams submitted their project to a University funding source to order funds for the project to be executed and they were successful. The presented project showed scientific basis and an excellent idea organization, as well as a proposal design to be executed. This group proposed that conventional distillers, present in the chemistry labs, were substituted by reverse osmosis distillers. The group proposal was based on the reduction of potable water consumption, if the project was approved; what happened indeed. This was a very positive indirect result because, beyond the gains that were brought to the laboratories, the responsible students were able to work in the project implementation on the following term.

5. CONCLUSIONS

In engineering, those students that are able to devote intensively themselves to their studies will achieve significant development of their technical competences, which are important for their professional qualification. However, the development of transversal competences achieved, and has been achieving, significant room in the engineering market place, once they are the responsible skills to differentiate the good technical professionals.

In this case study, the most relevant results obtained were: (i) – the increase in the development of the students' transversal competences, among which teamwork, project management and communication were highlighted, and (ii) – the contribution to upgrading the students' personal and professional developments.

One of this study's limitations is due to how hard it is to measure quantitatively the development of transversal competences, especially considering the time length of a single academic term. It has been noticed that such development from diverse qualitative evidences that were in this research scope could be interpreted by other means by other researchers.

A suggestion for future PjBL applications is to seek for a tangible product at the end of the project [7, 13], what has not happened in this case; not taking the merit away of this case of PjBL application though, once it was a pioneering strategy in this course.

Lastly, it is important to highlight that even with these pointed limitations, the application of PjBL became a significant differential in this course, especially over the students' standpoint.

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