Engineering Students can use the words "Calculus" and "love" in the same sentence: using active learning the impossible can happen

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Abstract

Teaching Calculus can be one of the most challenging practices in the engineering context for a number of reasons, namely: taught at the beginning of engineering courses, introducing to the student in a critical phase of his/her transition between high school and university, not understanding the meaning of some contents in relation to Engineering. The disciplines of Calculus are responsible for high failure rates and students' dropout. Lectures are predominantly used to teach Calculus in engineering context, with rigid contents centered on the blackboard and in the book. Therefore, students have low interaction with teachers and they have difficult to build their own knowledge and to understand the importance of mathematical methods, and procedures. However, project based learning was used to teach Calculus to engineering students. Students were asked to choose a phenomenon of their Engineering area of knowledge and explain why and how it needs integrals and derivatives to be explained. 127 students from six engineering courses were involved in the experiment. The students were organized in teams and tutored by other professors. This paper aims to describe the experience and analyze the outcomes terms of the perception of learning and development of transversal competences. The evaluation was based on content analysis of the reports delivered by the students. 100% of the groups evaluated the experience as positive. The students used adjectives such as "excellent", "extraordinary" to characterize the experience. In addition, students reported the following learning outcomes: knowledge and understanding; analysis; problem-solving; creativity/originality; communication and presentation; evaluation; planning and organization; interactive and group competences. Some groups reported that, in this project, they created prototypes that they will keep on researching and developing to take these ideas to the market. Yet, in this experience, the failure rate of this discipline that previously was 95% dropped to 5%.

Keywords: Active Learning; Project-Based Learning; Calculus for Engineering; Engineering Education.

1 Introduction

The disciplines of Calculus have an important role in engineer training (Flegg, Mallet &Lupton, 2012). This is the discipline that inaugurates students in understanding and managing mathematical procedures, with a language that can help engineering students analyzing and describing the most diverse engineering problems. The truth is that most students do not realize this positive nuance regarding the disciplines of Calculus. These disciplines are considered to be difficult, boring, inflexible and with no practical application.

In some circumstances, the strategies adopted in teaching Calculus in the context of engineering are mostly repetitions of the modus operandi that mathematics teachers (mostly bachelors) have experienced throughout their formation. Thus, these teachers reproduce what they experience as students. In most cases, as mathematics bachelors, these teachers do not have formal training to became a future professor. As a result many Calculus teachers have no references to turn their practice more effective.

Flegg, Mallet &Lupton (2012, p.718) refers, based on several studies, "there seems to be noconsistent, research-informed, view of how, what, when and by whom mathematics should be taught to engineering students". In fact, a traditional way of teaching predominates in Calculus disciplines in engineering context. Lectures with rigid contents centered on the blackboard and in the textbook are the mean stream strategies. Therefore, students have low interaction with teachers and they have difficult to build their own knowledge and to understand the importance of mathematical methods, and procedures in engineering practice. Yet it is important to mention that the disciplines of Calculus are responsible for high failure rates and students' dropout. Dahl (2017) argues that Mathematics fits in Problem-Based Learning approaches. Nevertheless, there is a lack of studies of PBL including mathematics education for engineers.

This paper aims to describe and evaluate an experience of using project based learning (PBL) to teach Calculus to engineering students which took place at the first semester of 2017. The teacher who led this experience teaches Calculus at this university since 2008. His dissatisfaction with the traditional learning process and huge failure rate in the discipline (95%) in past years motivated him to innovate his practice. To be engaged in the PBL approach, students were asked to choose a phenomenon of their Engineering area of knowledge and explain why and how it needs integrals and derivatives to be explained. A survey was developed with the students who attended this discipline and it was possible to understand its impacts in terms of the motivation to study, the perception of learning, the development of transversal competences and approval in the discipline.

To discuss these results, this paper was organized into 6 parts including this introduction. The second part presents the theoretical framework that indicates the challenges and alternatives to turn the teaching of Calculus an interesting journey to Engineering students and the ultimate considerations about project based learning. The third part is the description of the research procedures. In the fourth part the data discussion is presented. The fifth part is the final consideration of the research. In the final part, the references are included.

2 Theoretical Framework

2.1 Teaching Calculus to Engineering students: challenges and alternatives

According to Kyle and Kahn (2009), in United Kingdom most mathematics teaching comprises formal lectures once more innovative methods are used only occasionally. They added that most assessment strategies rely on formal examinations rather than a wider range of assessment methods. Garzella (2013) found the some reality at a Brazilian University where the discipline of Calculus is compulsory to many courses. At this research, Garzella (2013) found evidences that the teaching of Calculus has the following characteristics: a) the content is inflexible, b) lectures are the predominant strategy of teaching, c) the learning process is centred in the teacher, d) the individualism is predominant (lack of interaction among students and instructors), e) divorce between learning and teaching (teaching is teacher´s duty, and learning is exclusively related to students), e) the traditional way of teaching and assessing is the reflection of an authoritarian ideology.

Teaching Calculus has the importance of help students to understand the multiplicity and variability of nature (Boyer, 1959). As integration and derivation are the main contents, it is possible to assume that the better understanding of them would occur in the mist of experiential learning that can derive from projects, problems or the combination of both active learning strategies. Indeed, the challenge is to help students enter into the process of doing Calculus or applying it to the real world in order to provide a more significant learning process (Kyle& Kahn, 2009).

There are evidences that active approaches are useful to make the learning process more effective, as Prince (2004) argues. One possible strategy, applied to Calculus, is a workshop-style approach. It means getting students to debate and justify proofs within a peer group. It can stimulate, not only the mathematics way of thinking but also other transferable competences such as communication, team work, creativity and autonomy.

Problem based learning is other strategy that can be used in this context, which is one of the most used active learning strategy in the Engineering context (Lima et al., 2017). In terms of concrete teaching strategies, real problems are posed so that students that as a group create solutions to the proposed situation (Haryani, Prasetya, & Permanasari, 2014). Furthermore, the students generate their own examples, visualize, connect ideas or unpack symbols when the instructor engage them in the learning process (Kyle & Kahn, 2009).

Similarly, Kyle and Kahn (2009) suggest mathematical modeling which is a formulation of a real-world problem phrased in mathematical terms. Application is often embedded in atypical mathematics course through well-defined mathematical models that can enhance learning and understanding within individual theory-based modules through adding reality and interest. Through this king of active learning strategy the student can develop several competences such as problem-solving, creativity/originality, communication and presentation, evaluation, planning and organization and interactive and group competences. Meanwhile, they get acquainted with mathematical ideas and techniques.

All these active learning practices mentioned above can clearly enhance students' engagement and understanding in Calculus learning process. Nevertheless, project based learning was chosen in this teaching experience as the active learning approach tool and it will be better explained in the next session.

2.2 Project Based Learning

Projects are finite endeavours with defined goals that rise from a problem, a necessity, an opportunity or interest of a person, a group, or an organization (Barbosa & Moura, 2013). When this concept is used as a pedagogical resource, project based learning (PBL) rises as an AL strategy that allows a student to learn by applying these ideas and concepts (Krajcik & Blumenfeld, 2006).

The PBL is a form of situational learning based on the constructivist findings where the student gains a profound comprehension when he or she gets involved in their knowledge development (Krajcik & Blumenfeld, 2006). This approach has been gaining ground especially in applied science universities due to the student´s necessity to develop several learning competences for the professional environment. It is a technique that provides multifaceted learning experiences as opposed to the traditional teaching method (Lettenmeier, Autio, & Jänis, 2014). Several studies have proved that PBL is an active learning approach that can be organized in several ways. It is important to mention that PBL have a effective impact in the development of transversal skill and consequently in the professional formation of engineering students (Lima, Mesquita, Rocha, & Rabelo 2017; van Hattum-Janssen & Mesquita, 2011; Lima, Mesquita, Fernandes, Marinho-Araújo, Rabelo 2015; Lima, Mesquita, & Flores 2014).

According to Barbosa & Moura (2013), there are three categories for this approach: (i) Constructive project: it aims to build something new by introducing innovations or proposing a new solution to a problem or situation. It has a function, form, or process in the inventiveness dimension; (ii) Investigative project: research development on a matter or situation by applying a scientific method; and (iii) Didactic (or explanatory) project: tries to answer questions such as "How does it work?, "What is it for?, and "How was it constructed?". It seeks to explain, to illustrate, and to reveal the scientific principles of functioning of objects, mechanisms, systems, and so on. To Krajcik & Blumenfeld (2006) , PBL is an overall approach to the design of learning environments. Learning environments that are project-based have the following five key features:

1. They start with a driving question, a problem to be solved; 2. Students explore the driving question by participating in authentic, situated inquiry, which are processes of problem solving that are central to expert performance in the discipline. As students explore the driving question, they learn and apply important ideas in the discipline; 3. Students, teachers, and community members engage in collaborative activities to find solutions to the driving question. This mirrors the complex social situation of expert problem solving; 4. While engaged in the inquiry process, students are exposed to learning technologies that help them participate in activities normally beyond their ability and 5. Students create a set of tangible products that address the driving question. These are shared artefacts, publicly accessible external representations of the class's learning.

Considering all these PBL characteristics, it is possible to conclude that this strategy is broadly used to obtain learning results. For this to happen, it is believed that the teacher must constantly check whether the students have the appropriate theoretical basis for developing a project. As Hibberd (2011) argues, project activities are widely identified as a valuable component of a mathematics teaching. According to him, the potential for enhancement of competences, peer learning and assessment are considerable together with greater efficiency on staff resources. In this way, it is important that the teacher acts as a tutor by following the intermediary results, and by verifying the progress of the work group. Thus, PBL is presented as an alternative to knowledge development that can be shared internally and externally by the university.

3 Research Procedures

This is a descriptive research (Gonçalves & Meirelles, 2002) which is the most appropriate modality to describe the impacts of project based learning strategy in terms of the motivation to study, the perception of learning, the development of transversal competences and approval in the discipline. In order to know in depth the results of the activities performed, the quantitative strategy was used that according to Gonçalves & Meirelles (2002) is more adequate for the quantification and analysis of the behavior of a given population.

To achieve the objectives of the study, a case study was developed that, as Yin (2005) states, can be useful for testing theories and elucidating situations. The case studied was the pedagogical experience of teaching Calculus to Engineering students at the Federal University of Itajubá - campus of Itabira. In this case the project based learning was used with the objective of enhance learning results in terms of the motivation tostudy, the perception of learning, the development of transversal competences and approval in the discipline. It was proposed to students to develop a project in which they should choose a phenomenon of their Engineering area of knowledge and explain why and how it needs integrals and derivatives. In this study, 127 students from six engineering courses were involved in the experiment. The students were organized in teams and tutored by other professors.

Data collection was done through reports the students had to handle at the end of the semester. At this report, the student had to describe: a) how they choose the components of the group; b) how they search for the collaborating professor; c) how they choose the research theme; d) how the choose the Leader and Vice leader, the group organization and the activities; e) Action plan with the research and the presentation (there were 3 presentations in class); f) Conclusion about the project and g) Conclusion about PBL strategy organized by the teacher saying positive aspects and suggestions.

To analyze these data, a content analysis was made in order to identify the impacts of this active learning strategy in the students.

3.1 Description of the activities developed in the discipline

The discipline Calculus 1 is part of the curriculum of the undergraduate courses in the 9 Engineering Courses available at the University of Itajubá - campus of Itabira. The discipline consists of 96 semester hours. The objectives of the discipline are: a) generate the understanding of mathematic concepts of the program, especially analytical and numerical calculations of derivatives and integrals of functions of a variable and its applications, b) develop geometric, algebraic and numerical competences and c) show problem solving tools within the context of engineering courses. Two classes of students were involved in this experience which summed 127 students.

At the begging of the first semester of 2017, the teacher explained the objectives and teaching procedures of the discipline (strategies, activities and assessment procedures). The teacher showed to students how the discipline would occur with the project, lectures and in class activities. Students were asked to choose a phenomenon of their Engineering area of knowledge and explain why and how it needs integrals and derivatives to be explained. The students were organized in teams and tutored by other professors. The phases of PBL approach as described as follows (Table 1).

Table 1. Phases of project based learning used in the discipline Calculus 1

Phase	Discription
Formation of groups 1st class	There were 5 teams in each classroom, from diferent Engineering courses
Choice of Leaders and vice-leaders 1st class	Each team chose a leader and a vice-leader, they had the role of organizing the taskes and solving conflicts. They had the responsability of avaluated the students of his or her group. Each group receive 250 credits which were divided among the members of the teams according their collaboration to the results (as peer avaluation)

Choice of Collaborative Professors 2nd week	Each team contact a professor which was a collaborative member of the team. The colaborative professor was responsable for guiding the group during the development of the project - indicated the theme of the project
1st Presentation 15 class	A 5 minute long presentation designed to atract athention and interesting of the audience about the chosen theme. A report of the tasks developed until this point of the project was asked to the students.
2nd Presentation 28 class	A 5 minute long presentation about the theme of the project. The group should explain the theme derivates related to the project. A report of the tasks developed until this point of the project was asked to the students.
3rd Presentation 44 class	A 5 minute long presentation about the theme of the project. The group should explain the theme derivates and multiples integrals related to the project. A report of the tasks developed until this point of the project was asked to the students.
Final Presentation 49, 50, 51 classes	A 18 minute long presentation about the theme of the project. The group should explain all the job done during the project. A report of the tasks developed until this point of the project was asked to the students.

At this experience, the teams run an investigative project because they were supposed to make a research about an engineering phenomenon by applying derivates and integrals. 28 professors acted as collaborative members of the group, 6 sophomore students and a university technician made the some role helping the teams in the projects.

Half of the discipline grade was due to the project, which was divided in a peer evaluation mode because the leaders chose how they would distribute the 250 credits among students according the collaboration of each member of the team. The other credits were divide in three exams (10 credits in the first test, 20 credits in the second one and 20 credits in the third test). The strategy of linking only 10% of the credits to the first evaluation shows to the students the teacher evaluation style. Thus, a possible bad performance in this first evaluation, would not be a discouraging factor for the continuity of their activities in this discipline. The student can take into account the other possible 90% of the remaining credits.

After each presentation class, the instructor that conducted the discipline gave clear feedback to the students about the communication techniques and about the content of the projects. It was conducted with the clear objective of increase the self esteem of the students. It was important to increase their ability to communicate the results of the project. Another tactic used by the instructor was schedule the presentations after the exams in order to make the presentations in a less tense period.

3.2 Presentation of collected data

Considering the two classes, there were 127 students organized in 23 teams which applied derivate and integral to explain the following phenomena:

1. Optimization of canning process: from the factory to the shelves
2. Shazam Operation: mobile application that recognizes music
3. Support Vector Machine - learning machines technique
4. Vibrations in Machines with Accelerometer
5. Heat Transfer Through Fins
6. RLC - Resistor, Inductor, Capacitor Circuit
7. PID (proportional–integral–derivative) controller 1
8. PID (proportional–integral–derivative) controller 2
9. PID (proportional–integral–derivative) controller 3
10. PID (proportional–integral–derivative) controller applied to Motor Speed Control
11. Calculation of curve area generated by vibrations in an open pit mine explosion through integrals
12. Drone Control Functions
13. Machining of materials

14. Renewable energy
15. PID (proportional–integral–derivative) applied to temperature control in a coffee maker
16. Billets
17. Transport Phenomena
18. RL (Resistor, Inductor) Circuit
19. Flow machines
20. Information by image filter
21. Machining Removal Rate
22. Material Deformation
23. Strobe light

To identify the results of these experience, the final reports delivered by the students were analyzed - with a content analysis technique. From the final reports, we extracted three kinds of terms related to adjectives the students used to characterize the learning experience, the substantives the students used to characterize the learning results they got through the experience and abilities they learned during the experience. Table 2 presents the groups of nouns used by students to say the results of the learning experience. The number after the terms indicates the number of reports that mentioned this noun or expression.

Analyzing the data, it can be noticed that the experience brought a large range of benefits to the students. In some reports the student said that the project was important and useful to them. In two projects, the students said that this project was a first step towards the development of a new product. The students noticed that this experience brought knowledge and great learning (term used in six reports) that occurred outside the classroom. To reinforce this ideia, one group said that this experience brought aincredible and profound learning gain. At another report the students said that this project showed that they are capable of things that seem impossible.

Table 2. Phases of project based learning used in the discipline Calculus 1

Group of nouns used by students to say the results of the learning experience	Nouns used by students to say the results of the learning experience
Perception of learning	knowledge (2), great learning (6), incredible and profound learning, learning outside the classroom, learning easier to be absorbed, learning about the development of the theme, facilitating learning
Improvement of autonomous learning	encouragement to study, incentive to research, improvement for academic and personal life
Opportunity	Opportunity (2), Opportunity to discover the importance of Calculus and its application (3)
Vision and planning competences	broadening horizons (2), achievement of objectives, possibility of continuing future projects, motivation to pursue extension and research projects
Social Relation competences	engagement with the course, network generation, student and teacher relationship (5)
Technical Knowledge	use of laboratories, knowledge of drone technology, contact with senior themes

It can be noticed that the project improved the autonomous learning because tree reports mentioned that the project encouraged them to study and to research. Yet, it improved their academic and personal life. Five reports used the word "opportunity" to talk about the project. According to them, the project was a better chance to understand the importance of Calculus and its application.

In the reports there were references about how the project help them to envision new possibilities to their academic and professional life. The project was a chance to get to know the opportunities of development during the academic life.

Five reports mentioned that the project was important to generate student and teacher relationship. One of the project generated a paper that will be published in a journal. This same project resulted in research project with the collaborative professor. As some reports mentioned, the project was important to allow students to use laboratories and to contact with senior themes.

At Table 3 it is presented the adjectives used to qualify the learning experience.

Table3 : Adjectives used by students to say qualify the learning experience

Adjectives used by students to say qualify the learning experience
Exciting ; interesting (3); stimulating; important (7); extraordinary; wonderful; perfect; great value; big help; gratifying; good; dynamic; very good for growth; generated many results; encouraged the search for new themes; essential; plausible; difficult

Through the analysis of these data, it was possible to perceive that the students had a positive experience. They used positive adjectives to express how the experience was important (mentioned in tree reports) and interesting (mentioned in seven reports) for them. As they said, the project can be considered an "extraordinary" experience that allowed them to grow as professionals and to get many results. At a report, the students said it was a difficult experience. Literally they wrote:

> "We faced some difficulties and at the beginning it was a bit difficult to understand the purpose of the project and how we would begin to develop. But, throughout the course and during the research with the orientations and explanations of Professor Fadul (collaborative professor) and Professor Gilberto (professor of the discipline),it became clearer and we were more excited with our work."

The reports mentioned several competences that the students learned during the project (Table 4). It is noted that there was enough identification of the students with the project that helped them to understand the challenges of a professional engineer.

Table 4. Group of competences developed during the learning experience

Group of competences developed during the learning experience	Competences developed during the learning experience
Research and development competences	Data collection and analysis, preparation of scientific work, search (6) application of scientific knowledge, market research, scientific writing and prototyping (3)
Entrepreneurial competences	leadership (3), effort, receiving feed-back, getting out of the comfort zone, initiative, personal growth, striving for knowledge, drawing goals (2), critical view, organization, developing ideas, overcoming challenges (2), confidence, delegation
Communication competence	public presentation (2), demonstration of learning, idea sharing
Creativity	Problems solution, modeling and troubleshooting, creativity
Social relation competences	group work (9), collaboration, interdisciplinary relationship among group members, generation of network of contacts (4)
Engineering Identity	view on the engineer's career, vision of what it's like to be an engineer, knowledge of important tools for an engineer
Derivative and integral application	visualization of the derivative and integral application (11), relate theory and practice (2), understanding complex issues

The impact of the project on the development of transversal competences becomes even more evident analysing the terms used by the students. It can be concluded that they experienced research and development techniques. Several transversal competences were developed as well such as communication, entrepreneurial, creative, social relation and engineering competences (Lima, Mesquita, Rocha, & Rabelo 2017; van Hattum-Janssen & Mesquita, 2011; Lima, Mesquita, Fernandes, Marinho-Araújo, Rabelo 2015; Lima, Mesquita, & Flores 2014). Even their engineer identity was developed as they reported they felt what it is like to be an engineer during the project.The students reported that the visualization of the derivative and integral application was significant for them because it was possible to integrate theory and practice.

4 Data Discussion

This paper aimed to describe the experience of using PBL to teach Calculus in a more effective way and analyze the outcomes in terms of the perception of learning and development of transversal competences.

Given this, it is possible to infer that PBL was able to engage the students who stated that this experience was "extraordinary" and "extremely important" for them. Through all these statements, it can be concluded that the experience was effective in fulfilling the purpose for which it was proposed - engage the students in an active learning experience. Analyzing the statements mentioned above, it can be concluded that this experience was positive and profound helping the students to develop several transversal competences.

Finally, it is concluded that the use of PBL to teach Calculus fulfilled the educational objective of turning the student an active agent of the learning process. The project was stimulating and made it possible for them to reflect on the importance of their personal development.

In general, the application of the active learning strategy PBL had positive impacts on students' learning, which engaged in studying. As presented previously, the great majority of students reported that the project turned the understanding of the content easier to them. It is relevant to mention that the failure rate that in the previews semesters was 95% dropped to 5%. It shows that the focus of the evaluation process is not only the content in the tests but other important aspects to be analyzed as the quality for the presentations and reports, the analysis depth and the team demonstration of knowledge.

Data showed that this pedagogical experience was good enough to help students to learn a very important knowledge that can open their minds as engineers and business professionals. We also notice, by this research, that Calculus can be a significant way of teaching not only mathematical knowledge but also behavioral knowledge to students.

5 Final Consideration

It can be said that the learning process was more effective using the PBL strategy. One of the points that attracted attention was that student reported they developed their professional profile acquiring competences like communication, creativity, social relation among others competences. It was noted that the method used turned the learning of a difficult discipline a more interesting and pleasant journey to students.

Although the experience was very well evaluated, some improvement can be pointed. In order to value the collaborative professors' work it is important to formalize this dedication which can be useful to help this professor to ascent in their career progression. It is important to intensify the participation of senior students which can be important to improve the integration of freshman into the academic community.

As possibilities of future studies we aim to compare results between disciplines, the expansion of this research for the whole campus besides a research with graduates of the university to verify the impact of the disciplines in the life-long learning.

This study showed that engineering students can use the words "Calculus" and "love" in the same sentence. Learning Calculus can stop being a horror experience because of its high failure rate. It can be a profound experience that freshman, since their first day at university, feel like a real engineering applying knowledge in order to solve real and significant problems.

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