



Experimental Evidence of the Problem-Based Learning in Mechanical Engineering Classes and Participants' Perception

Raquel Ramirez-Vazquez^{1,2}, Rosely Maria Velloso Campos³, Júnia Moraes Lage e Silva⁴, Guilherme Rafael Gonçalves⁵, John Carter Oliveira Santos⁵, Felipe Venancio Mitkiewicz Silva⁵, Isabel Escobar^{2,6}, Augusto Belendez⁷, Enrique Arribas^{2,6}

¹ University of Castilla-La Mancha, Applied Physics Department, Polytechnic School of Cuenca, University Campus, Spain

² MORFEO Research Group, University of Castilla-La Mancha, Spain

³ Mechanical Engineering Department, PUC Minas University, Brazil

⁴ Virtual PUC Minas Department, PUC Minas University, Brazil

⁵ Electrical Engineering Department, PUC Minas University, Brazil

⁶ Applied Physics Department, Faculty of Computer Science Engineering, University of Castilla-La Mancha, Spain

⁷ Physics Department, Systems Engineering and Signal Theory, University of Alicante, Spain

Abstract

This article presents a case study of an interdisciplinary project, developed by students, that involved designing and assembling a small autonomous vehicle to participate in a competition with 40 teams during the first semester of Mechanical Engineering at PUC Minas (Pontifical Catholic University of Minas Gerais). This experimental evidence demonstrates the effectiveness of Problem-Based Learning (PBL) in Mechanical Engineering classes. This intervention on the implementation of PBL was carried out in conjunction with measuring the participants' perception of the environment and the evaluation methods used, to understand the impact before and after the activity's implementation. The evaluation of the implementation and the perception of the students (96 students) on this experience was carried out by the University's own Evaluation Committee (CPA) under the guidelines of the Ministry of Education (MEC).

In the Flipped Classroom methodology, students can review the topic before class, and the professor's role extends beyond simply transmitting information. Their main task is to support students in developing their technical skills, as well as their interpersonal skills, such as leadership, project management, and teamwork. In this methodology, lectures are replaced by video lessons, and students acquire the concepts of the class content before the face-to-face class. Later, in the in-person format, they will supervise some group or individual tasks designed to foster the development of their skills.

We studied flipped classroom methodologies and techniques to develop this project. We created teaching materials, documents, and PowerPoint presentations, which students could access at their convenience and review before attending class. The students have demonstrated development in interpersonal skills such as autonomy, responsibility, teamwork, leadership, creativity, conflict resolution, peer assessment, and self-assessment. They have also improved skills such as programming, problem-solving, and digital media literacy.

Keywords: *Arduino and mathematics, participants' perception, peer and self-assessment, Problem-Based Learning, programming and robotics.*

1. Introduction

Much research has focused on the causes of dropout rates in engineering courses. These studies have shown that the main reasons are related to students' mathematical difficulties and the methodologies used. The common passive methodology in which the professor talks, and the students simply listen, is considered outdated. Therefore, the contemporary learning structure requires methods that embrace the paradigm of the digital age; that is, social media, mobile devices, and other technologies must be included, as they can play a fundamental role in updating this status quo.

Consequently, new methodologies have been tested that allow students to develop their critical thinking skills, understand how theory and practice complement each other, and learn through hands-on experience by developing projects. Generally, these new approaches propose active



methodologies, such as the flipped classroom and Project/Problem-Based Learning (PBL). These methods require students to be more active in their learning process, as they are frequently asked to solve problems or build solutions related to their field of work. Therefore, they must be proactive and research diverse topics to understand the scenarios and achieve their objectives in a project. Usually, they use digital resources, such as web channels and e-learning, as a platform for technical knowledge. These methodologies have shown that students are more motivated and can learn concepts more quickly. Specifically, the PLB model has been widely implemented in various educational fields and contexts, as it challenges students to learn by participating in a real-world problem [1]. The educational reform driven by the European Higher Education Area (EHEA) has led to a redefinition of roles and competencies for both teachers and students. The new role of the professor in the teaching-learning process should be that of a mediator for the student in the process of acquiring competencies.

The professor should be a facilitator of student learning. Active methodologies are based on exchange processes for collaborative problem-solving and knowledge construction, both individually and collectively [2,3]. This methodology is based on developing student autonomy in learning, transferring responsibility for their learning to them. They have good support; generally, they can achieve their learning objectives through different learning platforms, such as videos, PowerPoint, YouTube, and Instagram. It is important to mention that this methodology also provides collaborative environments and opportunities for sharing experiences.

Problem-Based Learning (PBL) is a pedagogical approach that allows students to learn actively through meaningful problems, giving them the opportunity to solve them authentically through collaborative learning [4]. It is an inductive learning approach that starts with a specific observation, question, or problem and leads to abstract knowledge as it is addressed [5]. Students identify their learning needs, explore and learn new content, developing skills to apply their knowledge to real-world problems through experimentation in a project. Therefore, PBL can be considered a cyclical process consisting of three phases, which are shown in the Fig. 1 [6].

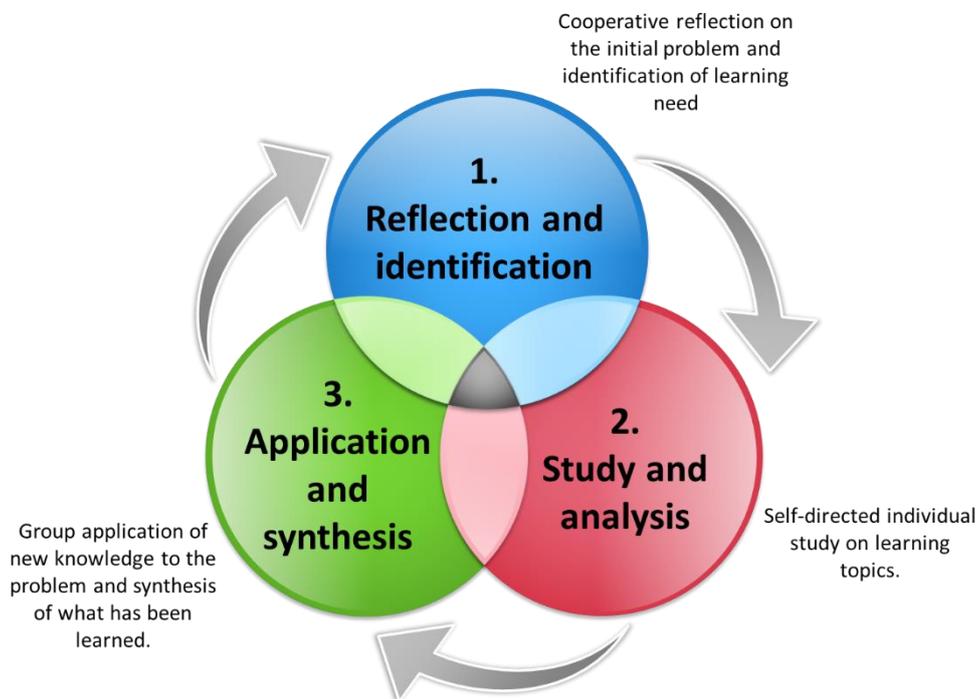


Fig. 1. PLB Cyclical Process

In the flipped classroom methodology, students can view the topic before class, and the teacher's role extends beyond simply transmitting information. Their primary task is to support students in developing their technical skills, as well as their interpersonal skills, such as leadership, project management, and teamwork. Generally, in this methodology, lectures are replaced by video lessons, and students acquire the concepts of the course content before the in-person class. Subsequently, in the face-to-face class, they will undertake tasks, either group or individual, that will help them develop



their skills. Consequently, time can be used more effectively by participating in active learning activities facilitated by the professor, who is considered an instructor [7].

The Flipped Classroom (FC) is an inductive learning approach that starts with a specific observation, question, or problem and leads to abstract knowledge by addressing it [8]. Unlike traditional classes, students face real, open-ended, and unstructured problems and work in teams to solve them [9]. Since class time is not used to transfer knowledge to students through lectures, the professor can interact with them through other learning activities. Therefore, the professor is responsible for promoting practical activities that engage students in problem-solving or self-proposed projects, conflict resolution, hands-on activities, and guidance. Students may be more satisfied with the flipped classroom method, and it can be more cost-effective than traditional instruction. This methodology optimizes learning and integrates educational life into the student's daily life and its specific needs. Another very interesting methodology is just-in-time learning, where students complete some of their activities outside the classroom at their own pace [10].

2. Methodology

2.1. Case Study Analysis

According to Barbosa [11], one of the problems in engineering programs is the low motivation of students and their training, which translates into poor academic performance and increased dropout rates.

Traditionally, there has been a gap between what students have learned and the skills they have acquired at university and what companies demand when hiring new employees. Despite having identified this gap, many universities continue to use traditional, teacher-centered rather than student-centered learning methodologies, hindering the development of essential competencies required in the workplace [12].

Problem-based and project-based learning can contribute to an innovative way of teaching, leading to a more dynamic, current, and motivating engineering education. Furthermore, this methodology is better suited to the current demands of the job market.

This article presents results of student participation in the knowledge construction process through active methodologies, such as interdisciplinary project-based learning, blended learning, and the flipped classroom. This paper presents a case study of an interdisciplinary project, developed by engineering students, that aimed to design and assemble a small autonomous vehicle to participate in a competition with approximately 40 teams during the first semester of Mechanical Engineering at PUC Minas. Each team had a project manager who worked with practical management concepts. In addition, the students used the virtual environment of the e-learning platform to learn technical topics through videos, PowerPoint presentations, YouTube links and resources, as well as completing online activities. In practical classes, the students programmed an Arduino UNO to use sensors. Besides programming logic, they also had to design and draw the vehicle's chassis, for which they used a laser cutter to shape it. They utilized a computer lab and a hackerspace lab, both equipped with the necessary tools to work on the project from both a theoretical and practical perspective. Overall, upon completion of the project, the students demonstrated development in interpersonal skills such as autonomy, responsibility, teamwork, leadership, creativity, and conflict resolution. They also improved technical skills such as programming, problem-solving, and digital media skills.

Therefore, this type of project can encourage students to rethink their activities (reflection-action), thereby improving their knowledge and the methodologies they use to overcome problems. Furthermore, it can enhance the interaction between the university and the market. In this study, we used five methodologies (Fig. 2)



Fig. 2. Methodologies used.

1. Flipped Classroom Methodology

To develop this project, we studied flipped classroom methodologies and techniques. We created teaching materials, documents, and PowerPoint presentations, which students could access at any time and review before attending class.

2. Active Learning Methodology

In this stage, the objectives of each class are defined where the student or a group of students must solve the problems and proposed activities, to present their results at the end of the class.

3. Project-Based Learning Methodology

In addition to the theoretical component presented to the students, this stage involves working with a practical kit, where students implement what they have learned in the theory classes.

4. Just-in-Time Methodology

In this project, the student gradually puts into practice the theory available and discussed at the beginning of each class. After the theoretical discussion, part of the class is reserved for assembling the system, using a breadboard, wires, an Arduino board, LEDs, ultrasonic sensors, DC motors, switches, an H-bridge, and other components. They also use a space called HACKERSPACE to fabricate the chassis and build the car. The final project consists of assembling an autonomous car, with the students participating in a competition.

5. Interdisciplinarity

There is a point in the project's development where the students design the chassis of an autonomous car, which constitutes the final project, using tools such as AutoCAD, SolidWorks, or CATIA, which they learned during the project's development period. This allows them to work in an interdisciplinary manner. They also use methodological approaches for sensor calibration.

2.2. Case Study Analysis

In the practical classes, held in the computer lab, students worked on programming an Arduino UNO to use sensors. Throughout the classes, the degree of accuracy of the results compared to initial expectations could be observed; that is, the students' understanding of the content taught and its suitability for their age group.

To this end, two classes were held with the test group. The first class introduced the Arduino platform with an exercise that involved making LEDs blink over time. Finally, they were challenged to simulate a traffic light and use their logical reasoning to solve the problem. To carry out this exercise, it was necessary to teach basic electronics and basic C programming, with an emphasis on commands such as turning the LED on/off and the delay.

The second class consisted of applying the previous concepts, such as digital input/output and timing, as well as new commands. The exercise involved programming a car model that had to navigate a



maze while avoiding collisions with the walls. This situation motivated the groups to improve their projects, leading them to repeatedly modify the program to find the optimal one, which resulted in competition among them. As a result, they became more familiar with programming. It became a competition among approximately 40 teams. Each team had a project manager who applied practical management concepts and used e-learning to learn technical topics, utilizing videos, PowerPoint presentations, links, YouTube resources, and online activities.

The other learning segment of the second lesson was car assembly. The students had to design the car chassis and used the drawing course as a basis for its development. The chassis was manufactured using a laser cutting machine, as shown in Fig. 3.



Fig. 3. Chassis manufacturing in hackerspace.

The hackerspace lab provided all the necessary support, both theoretical and practical, for the students to complete their tasks. The task proved to be an interdisciplinary endeavor, as the students had to design and manage the entire process, from programming to vehicle assembly, as shown in Fig. 4. Specifically, they were asked to develop skills such as autonomy, responsibility, teamwork, programming, leadership, creativity, problem-solving and conflict resolution, and digital media skills.



Fig. 4. Car assembly in hackerspace



2.3. Components of the Educational Kits

The practical classes required students to work on programming with Arduino UNO. Therefore, two different types of kits were used in this program: the first contains eleven elements, Fig. 5.

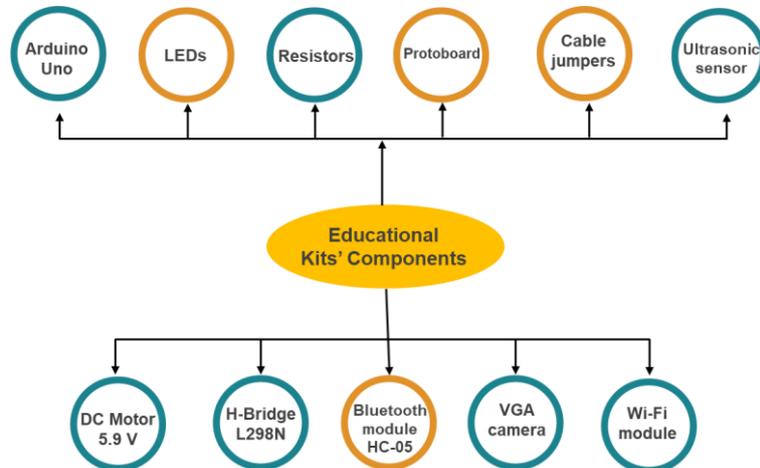


Fig. 5. Components of the first educational kit designed

The second kit was designed to work in conjunction with a car, so it has seven elements, Fig. 6.

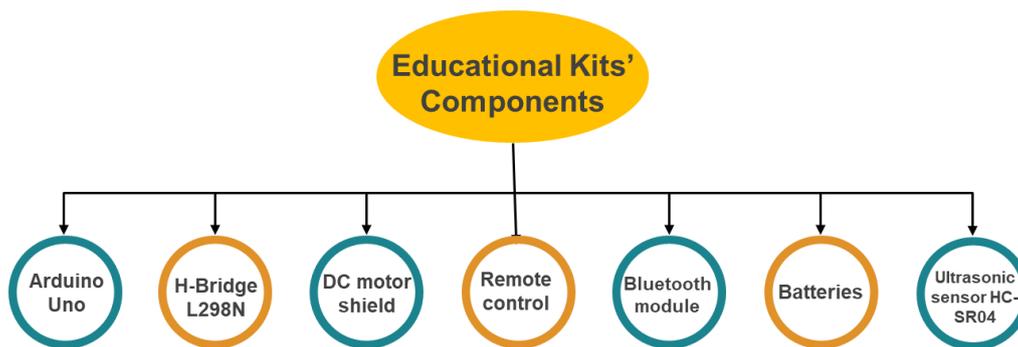


Fig. 6. Components of the second educational kit designed

3. Results

This exploratory, diagnostic, and primarily quantitative research aims to maintain a semesterly record of students and understand their experience with the implementation of PBL. The results of the student experience are shown in Figure 7.

This research is justified by the following points: Problem-based learning helps students improve their entrepreneurial attitudes and increases their motivation to learn. It is true that creating a positive user experience depends on a good understanding of students' perceptions, feelings, and behaviors. Distance education requires a greater effort to gather student perceptions due to the physical distance and the absence of real-time feedback, common in face-to-face learning.

The evaluation of the implementation and students' perceptions of this PBL experience was conducted by the Comissão Própria de Avaliação (CPA) under the guidelines of the Ministry of Education (MEC), the regulatory body of the Brazilian government. Ninety-six students participated.

The analysis of the results was carried out by the commission, and those directly related to the perceptions of its implementation are shown in Figure 7.

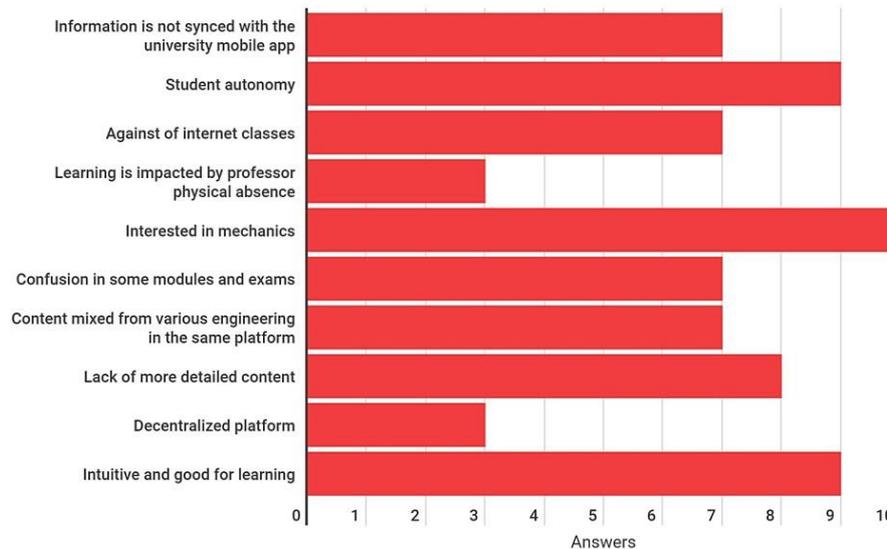


Fig. 7. Results of the student experience with the implementation of PBL.

This methodology makes tangible the work and effort developed by the professor-tutor and by the students, both in terms of the students' academic performance (grades) and their satisfaction with the teaching staff. Furthermore, it allows students to be more independent and take an interest in finding solutions and in learning.

The Problem-Based Learning methodology can be implemented in different areas of knowledge, following and adapting the methodology applied in this work.

4. Discussion and Conclusion

Finally, the use of these methodologies allows the actors involved (teacher/student and content) to experience adaptations and changes in their behavior and structure. In other words, incorporating active learning methodologies allows for the reorganization of the teaching-learning process into innovative and relevant practices.

Likewise, the students were enthusiastic about their accomplishment in programming a car model, which allowed them to improve extremely relevant technical and interpersonal skills. Furthermore, competitiveness generated the need to refine the program, resulting in situations that required critical thinking and logical reasoning to overcome difficulties. Cases like those presented in this work should be explored more extensively during the course, as they have been shown to produce assertive development in individual and group qualities.

In this experience, it was observed how these new active methodologies, used together, can positively influence student performance and motivation. This experience resulted in significant improvements in performance.

Disclosure statement

The authors did not report any potential conflicts of interest.

Notes on contributors

All authors contribute equally.

Acknowledgment

The authors thank CNPq, FAPEMIG and PUC Minas for their support of this work.

REFERENCES

- [1] Munawaroh. The Influence of Problem-Based Learning Model as Learning Method and Learning Motivation on Entrepreneurial Attitude. *Int J Instr* 2020;13:431–44. <https://doi.org/10.29333/iji.2020.13230a>.



- [2] Moya EC. Using Active Methodologies: The Student's view. *Procedia - Social and Behavioral Sciences* 2017;237:672–7. <https://doi.org/10.1016/j.sbspro.2017.02.040>.
- [3] Tadjer H, Lafifi Y, Seridi-Bouchelaghem H, Gulsecen S. Improving soft skills based on students' traces in problem-based learning environments. *Interact Learn Environ* n.d. <https://doi.org/10.1080/10494820.2020.1753215>.
- [4] Batlolona JR, Singerin S, Diantoro M. Influence of Problem Based Learning Model on Student Mental Models. *J Pendidik Fis Indones* 2020;16:14–23. <https://doi.org/10.15294/jpfi.v16i1.14253>.
- [5] Kragulj F, Fahrenbach F, Grisold T, Kerschbaum C, Kaiser A. Teaching Organizational Learning to Undergraduates: Applying Design Thinking in Problem-Based Learning. *European Conference on Knowledge Management; Kidmore End, Kidmore End, United Kingdom, Kidmore End: Academic Conferences International Limited; 2018, p. 414-422, XVIII-XXI*.
- [6] Perrenet JC, Bouhuijs P a. J, Smits JGMM. The Suitability of Problem-based Learning for Engineering Education: Theory and practice. *Teaching in Higher Education* 2000; 5:345–58. <https://doi.org/10.1080/713699144>.
- [7] Hung H-T. Design-Based Research: Redesign of an English Language Course Using a Flipped Classroom Approach. *Tesol Q* 2017; 51:180–92. <https://doi.org/10.1002/tesq.328>.
- [8] Fitriani A, Zubaidah S, Susilo H, Al Muhdhar MHI. The Effects of Integrated Problem-Based Learning, Predict, Observe, Explain on Problem-Solving Skills and Self-Efficacy. *Egit Arast* 2020;45–64. <https://doi.org/10.14689/ejer.2020.85.3>.
- [9] Hmelo-Silver CE. Problem-Based Learning: What and How Do Students Learn? *Educational Psychology Review* 2004; 16:235–66. <https://doi.org/10.1023/B:EDPR.0000034022.16470.f3>.
- [10] Akcayir G, Akcayir M. The flipped classroom: A review of its advantages and challenges. *Comput Educ* 2018; 126:334–45. <https://doi.org/10.1016/j.compedu.2018.07.021>.
- [11] Barbosa EF, Moura DG de. Metodologias ativas de aprendizagem na Educação Profissional e Tecnológica. *Boletim Técnico do Senac* 2013; 39:48–67.
- [12] Murillo-Zamorano LR, Lopez Sanchez JA, Luisa Godoy-Caballero A. How the flipped classroom affects knowledge, skills, and engagement in higher education: Effects on students' satisfaction. *Comput Educ* 2019;141:UNSP 103608. <https://doi.org/10.1016/j.compedu.2019.103608>.