Teacher's Perceptions of the Fertility in Implementing Project-based Learning in Engineering Courses

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Abstract. *This paper presents the results of a survey on teachers' conceptual change regarding the use of Project-Based Learnin (PBL). The objective is to investigate the teacher’s perception of the fertility in the use of this strategy within the context of projects offered alongside undergraduate engineering programs. At Mauá Institute of Technology, where this research was conducted, all students are instructed to complete at least two semester projects from a list of projects of their choice. In general, Project Based Learning stands out as a suitable approach for conducting these projects with groups of students. However, adopting the PBL strategy is not always straightforward, as some teachers resist using it or even alter its structure, developing their own models of PBL. Conversely, as instructors increasingly recognize Project-Based Learning as a productive and promising strategy, they begin to employ it with greater enthusiasm, resulting in improved learning outcomes. The primary objective of this study is to provide insights of the effectiveness of Project-Based Learning, show how instructors perceive the outcomes when implementing this strategy, and identify the challenges associated with its application. In this context, "fertility" corresponds to one of the stages of the Conceptual Change Model (comprising Intelligibility, Plausibility, and Fertility), which determines whether a concept is effectively assimilated by an individual. This study draws an parallel between the fertility of the teaching strategy and the positive outcomes observed when using Project Based Learning. If a strategy demonstrates fertility, it is more likely to be adopted by teachers, among other strategy options. Data were gathered through semi-structured interviews with the teachers, and the findings reveal that instructors perceive two types of fertility when employing this strategy. The first relates to student learning, in which instructors felt that students begin to recognize their own educational needs and proactively seek the tools necessary to facilitate their learning. The second type of fertility is associated with the teachers who start to realize Project Based Learning as a versatile methodology, that is effective for both in-person and remote teams, whether they consist of students from the same course or from different programs and academic levels. Nevertheless, this approach also presents challenges, such as the requirement for active student engagement in problem-solving and the time and effort demanded from instructors to create projects and manage teams. On the other hand, there are many opportunities for effectively implementing this strategy, which necessitates ongoing training to maximize its benefits. For oral presentation.*

Introduction

There are various classroom strategies aimed at promoting learning in higher education, ranging from traditional lectures to those employing active methodologies. In expository classes, instructors typically present content verbally or in written form, with limited time for students’ questions. In such settings, the teacher is the focal point of instruction, and students participate passively as listeners. In this situation, while it is true that some educators conduct exemplary expository classes, delivering content with both depth and eloquence, engaging students effectively and promoting comprehension of the subject matter. There are also instances in which these classes integrate active strategies to invigorate the learning experience.

In turn, active learning strategies play a pivotal role by positioning students as active participants in the learning process. Noteworthy approaches include Hybrid Teaching [1], the Flipped Classroom, Peer Instruction [2, 3], Team-Based Learning [4] and Project-Based Learning (PBL) [5], with the latter being the primary focus of this work.

Project-Based Learning (PBL) is a strategy in which the teacher provides a problem to students who, through research and discussions, develop a project aiming to solve the proposed problem [6]. In this method, the student is the protagonist in seeking and providing a solution to the problem, while the teacher participates as a tutor, supporting the student in the search for a solution.

In 2015, the Special Projects and Activities (PAEs, acronym in Portuguese) were integrated into the curriculum of all programs of Mauá Institute of Technology (IMT), a Brazilian Education institution. In the PAEs, activities are conducted primarily through projects, covering a range of topics, accessible to students of all institutional programs (Engineering, Business Administration and Design). Students have flexibility to choose and enroll in PAEs aligned with their interests, shaping a personalized and individualized learning path. This approach allows them to gain additional experiences tailored to their undergraduate field or explore areas beyond their direct specialization. Besides that, PAEs contribute to the development of transversal skills, broadening students' perspectives and equipping them to approach problems from diverse angles. Notably, a single PAE may attract students from different courses and academic levels, fostering a collaborative environment without registration restrictions or prerequisites.

Each student must complete at least two PAEs activities per semester, which lasts approximately twelve weeks. The projects developed in PAEs are not a dessert projects, but a complete project that ask students to present a problem solution, allowed them to develop technical and transversal competences, working in teams [20].

In this context, this research focuses the fourth stage in a series of studies that has been assessed the implementation of projects in the PAEs. As the previous works, the Conceptual Change Model (CCM) by Posner et al. [10] is used as reference framework.

In the initial study [7] teachers' dissatisfaction with expository classes was examined by comparing them with active learning strategies and PBL. The subsequent study [8] focused on intelligibility, exploring teachers' understanding of PBL and its structural components. In the third step [9], the plausibility of PBL was assessed, considering its alignment with teaching-learning beliefs and its applicability in Special Projects and Activities (PAEs). In this work, the fourth stage of CCM is discussed, the fertility in the use of projects, as the main method or associated with other strategies, that is, the results related to fertility that the use of project in PAEs provides from the teachers view.

Literature review

Two main references were considered in this work: The Conceptual Change Model (CCM) [10] and Project Based Learning [5].

Conceptual Change Model

Posner et al. [10] propose a four-step process for scientific conceptual change in individuals. The initial step involves dissatisfaction with an existing model and established concepts. This dissatisfaction paves the way for the exploration of a new scientific model, which, to be accepted must pass through three subsequent stages: intelligibility, plausibility, and fertility. In 2006, Mattasoglio Neto and Pavão [12] transposed the Conceptual Change Model in the context of the teaching process, establishing four conditions to the Strategy Change Model. These conditions can be interpreted as follows:

- *dissatisfaction*

To change to a new model, an initial dissatisfaction with the current teaching strategies is necessary. This dissatisfaction turn teacher permeable to looking for a new strategy to use in class. Anomalies, such as a lack of positive response from the current methods, can serve as catalysts for dissatisfaction, rendering the current approach less meaningful.

- *intelligibility*

Once there is dissatisfaction, one of the necessary conditions for a new strategy to be accepted is its intelligibility. Intelligibility refers both to understanding the structure of the strategy and its conduct, also the evaluation mechanisms and the learning concepts that underlie the strategy.

- *plausibility*

The new strategy should align with the teacher's knowledges, including beliefs, epistemological commitments, other theories or knowledge, and previous experiences. It should facilitate the analysis of the applicability of the new method and its efficiency in addressing the shortcomings and anomalies of previous strategies. Additionally, the new strategy should seamlessly integrate with technics used by the teacher, serving as a consistent complement to the methods already familiar to the teacher.

- *fertility*

As the fourth step, the introduction of new strategies should pave the way for novel discoveries and offer participants, both teachers and students, fresh insights in teaching and learning experiences. Proposing and solving new problems not only fuels the expansion and development of the method but also deepens its comprehension and enhances its overall effectiveness.

This work will evaluate the fourth stage of the Strategy Change Model, the fertility, in the use Project Based Learning as projects in the PAEs. Fertility is a crucial condition to the change, pointing out the potential to face issues encountered in traditional education and bringing confidence that future challenges can also be effectively tackled with the new strategy.

It must be considered that an analogy is being made between the Conceptual Change Model applied to learning in science and the Strategy Change Model, in the use of teaching strategies by teachers. It is understood that the four stages of the Conceptual Change Model are perfectly suitable for analyzing adherence to the use of strategies in the classroom [12].

The study investigating teachers' satisfaction and dissatisfaction with traditional teaching methods, Silva & Mattasoglio Neto [7] concluded that teachers incorporate active learning methods as PBL, either to develop specific skills and competencies in students or to diversify their classroom teaching strategies. Despite being a new method for many teachers, they express confidence in applying it in the classroom. However, a significant number find the preparation process for these classes to be laborious. Additionally, some teachers choose not to adopt active methods, as they believe they already achieve positive results with traditional approaches.

In the study conducted by Barberini & Mattasoglio Neto [8], the focus was assessing the intelligibility of PBL. It was found that teachers possess a comprehensive understanding of PBL and generally agree on its functioning. However, there is some disagreement among teachers regarding the sequence of stages in the project process. Additionally, the evaluation of students'

performance in projects varies among teachers, including methods such as seminars, oral presentations, and project reports. Teachers expressed that they view PBL as an engaging teaching tool, as it fosters student autonomy and aligns with the challenges encountered in their careers and the job market. It is seen as instrumental in developing the skills needed to take initiative, conduct research, and gather information to solve complex problems, drawing on transversal knowledge.

In the study conducted by Bortolozi & Mattasoglio Neto [9], which assessed the plausibility of PBL, it was observed that, despite having a good understanding of PBL, many teachers tend to revert to traditional methods in challenging situations, particularly when students face difficulties. For instance, when a student is struggling to comprehend the material, rather than encouraging team discussions, some teachers take the lead in explaining the subject in an alternative manner, thereby diminishing the student's role as the protagonist. When questioned about whether students essentially learn by listening to the teacher, there emerged a sense of uncertainty among teachers regarding the method, and approximately one-third of them neither agreed nor disagreed with the statement. For those who do not use PBL, difficulties were noted in create projects, correlating theory and practice, or believe that PBL might lead to a shallower understanding. However, overall, teachers believe in the advantages of PBL, recognizing its ability to promote essential skills for life in engineering and the demands of the job market.

Project Based Learning (PBL)

Project Based Learning is an active teaching strategy centered on collaborative problem-solving through projects. There are different ways to fit PBL [19] and, in general mode this approach facilitates the development of student's socio-emotional skills as they navigate various experiences with their team, including leadership development, enhanced communication, and project management. Moreover, PBL contributes to increased student engagement in classes [20]. The acquiring technical knowledge can be effectively accomplished through PBL, emphasizing that the use of this strategy encompasses both soft skills and technical proficiency.

According to Silveira et al. [5], PBL has the following structure (Chart 1):

Chart 1 – Project Based Learning steps.

Step	
1	Receive or choose the project theme.
2	Collect facts to understand the proposed project (initial research) and formulate the problems.
3	Create ideas to develop or elaborate the project.
4	Learn the content necessary to achieve it.
5	Discuss solution proposals and project implementation, their feasibility, and the conclusion of a solution to be implemented.
6	Develop and implement the project.
7	Carry out tests through data collection and verify the results obtained.
8	Prepare a written report and a seminar (oral presentation) containing the objective, the project description, the methodology applied, the results and analyzes carried out and, finally, the team's conclusion regarding the project.

Source: (Silveira *et al.*, 2008) [5]

Each of the PBL stages brings the uniqueness of promoting the learning of skills that will help shape the professional future, such as step 3, which promotes the development of project

creation skills, a skill that is indicated in the National Curricular Guidelines (DCNs) established by Ministry of Education and Culture (MEC) of Brazil, for Engineering programs [13].

Skills developed with Project Based Learning

Sesoko & Mattasoglio Neto [11] outlined the benefits of employing Project Based Learning (PBL) in comparison to traditional teaching. They highlighted:

1. The student learns to seek tools and methodologies to address problems and undertake projects.
2. The student learns to work collaboratively within a team, encompassing skills such as listening to diverse opinions, presenting ideas, committing to tasks, taking responsibility, generating activity reports, demonstrating leadership and adaptability, managing projects, adhering to schedules, and navigating interpersonal differences.
3. Embrace interdisciplinary perspectives and comprehend the correlation between theoretical content and practical application.
4. Exposure to contemporary issues.
5. Understanding the role of an engineer and developing awareness of economic, social, and environmental responsibility.
6. Getting closer to reality, where you encounter a problem first and then seek theory to solve it.
7. Activation of the student's existing knowledge.
8. Facilitates the transfer of principles and concepts, allowing students to recall and apply previously learned concepts to adapt to different problems, enabling effective problem-solving.
9. Enhanced retention of knowledge.
10. Taking ownership of one's own learning.
11. Intrinsic motivation to learn.;
12. Enhanced relationships between students and teachers, increased interaction among students, and improved internal communication among faculty members.
13. Development of critical analysis skills.

All these competencies have a direct connection with the National Curricular Guidelines (DCNs) [13] in 2019, as well as with the stages of PBL. Several essential transversal competencies are associated with leadership, teamwork, communication skills, and entrepreneurship—all highly valued in the job market [18].

Methodology

This study aims to assess the Fertility of PBL. To achieve this goal, a literature review was conducted on the Conceptual Change Model (MMC) proposed by Posner et al. [10] to comprehend its stages and validate the transposition of Conceptual Change Model to Strategy Change Model. The primary focus is on the final stage of the process, namely Fertility.

A review was also made of the concepts of Project Based Learning – PBL, its stages and application [5], in addition, it was based on the work of Sesoko and Mattasoglio Neto [11], who listed the advantages that the PBL presents. Furthermore, as it is a continuation of a series of three previous works, so it was based on the article Silva & Mattasoglio Neto [7], on Dissatisfaction, the article Barberini & Mattasoglio Neto [8] on Intelligibility and the article Bortolozi & Mattasoglio Neto, 2021 [9] on Plausibility.

In addition to the literature review, this study incorporates data gathered through interviews with 5 teachers who incorporate PBL in their PAEs. Despite the initial sample comprising 6 teachers, only 5 interviews were conducted. During the academic semester selected for data collection, 89 distinct PAEs were being offered to students.

To assess Fertility, a semi-structured interview was designed to capture the teachers' point of view on PBL, which would make it possible, through the analysis and synthesis of responses, to obtain their perspectives on this strategy.

Quantitative research on the same topic is presently underway, and the results are expected to be concluded soon. However, they have not been incorporated into this article at this time.

Results and discussions

Based on responses from interviews with teachers, the results were analyzed and summarized into three dimensions:

- "Fertility for the student" - aims to evaluate how PBL influences the student's preparation for professional life, examining the skills and competencies that they can develop and how these aspects contribute to their career progression and integration into the job market.

- "Fertility for the teacher and the course" - aims to evaluate the outcomes that teachers obtain in the classroom with students, evaluate how learning is achieved and the problems teaching that PBL can solve. Furthermore, it helps to understand which benefit the teacher obtains by using this methodology.

- "Challenges and Solutions of the Methodology" - aims to highlight potential difficulties that teachers may face using PBL and the corresponding solutions they have identified. This dimension serves to provide educators with insights into key aspects of PBL, offering guidance on addressing challenges for a more effective and efficient teaching experience.

Fertility for the students

The fertility of PBL for the student can be understood as the results achieved and that will generate a future gain, for example in the job market, since for many students, higher education is a means to reach competences before entering a competitive work market, ultimately resulting in increased financial gains, greater job satisfaction, and broader professional opportunities.

In the teachers' perspective, PBL empowers students to identify their own learning needs and independently seek the necessary tools to construct their educational journey. This approach enables students to delve deeper into topics of personal interest, providing a comprehensive view of the professional landscape. Throughout this process, students cultivate critical analysis and improved research skills, fostering independence and proactivity, essential qualities for both professional and personal life. Additionally, the experiential nature of PBL allows students to encounter challenges, problems, or conflicts like those they may face in the corporate world, all within the secure environment of the classroom. This experiential learning model enables them

to solidify knowledge through real-world problem-solving. This sentiment is reflected in the statement from interviewee 1:

> "The student connects the content given with a real problem that can be encountered in everyday life, which helps in the construction and retention of knowledge." [interviewee 1]

Also, in the statement of interviewee 5, there is:

> "The student himself will identify what his learning needs are." [interviewee 5]

From the teachers' perspectives, it is evident that PBL enables students to cultivate transversal skills, in this case social skills, such as interpersonal relationships, communication, negotiation, and teamwork. Engaging in projects also fosters organizational skills and a heightened awareness of meeting schedules, instilling a sense of critical thinking for evaluating and comprehending the essential tasks to be undertaken. Furthermore, students, through PBL, can interconnect knowledge from diverse and unrelated areas, encouraging broader and more creative thinking to address problems, referred to as transversal knowledge.

PBL encourages students to adopt both a systemic and non-systematic approach, fostering an understanding of how various elements are interconnected and contribute to complex systems. Through PBL, students acquire the ability to work with intricate systems, enabling them to recognize physical phenomena, model them, and quantify them. Alternatively, they can construct frameworks that facilitate the extrapolation of understanding from one concept to derive new knowledge. Consequently, as students tackle diverse problems, PBL becomes a valuable tool for navigating changes, empowering them to develop into professional's adept at confronting and resolving challenges. This linkage between PBL and the fundamental nature of engineering underscores its significance in shaping individuals into problem-solving engineers.

This can be seen in the speech of interviewee 5:

> "The ability for you to identify physical phenomena and learn to model them, learn to quantify them in some way, or put together a framework that allows you, based on understanding that concept, to extrapolate that to obtain new knowledge." [interviewee 5]

Still in the speech of interviewee 4:

> "He acquires a vision of the whole, a more systemic vision, not a systematic vision. The systematic view is the view that the guy looks at one after the other. Systemic is when he looks at the system as a whole." [interviewee 4]

Fertility for the teacher and the course

The fertility of PBL for the teacher and the course can be understood as the benefits that the teacher achieves when utilizing the methodology as a teaching tool. The more fertile it is for the teacher, the more sense it makes to continue using this methodology. A methodology that lacks fertility may be discontinued, whether due to difficulties in application, limited use, or low efficiency and effectiveness in transmitting knowledge to students.

The results indicate that teachers view PBL as a versatile methodology, proving effective for teams whether in remote or in-person settings, and applicable to students from the same program and series or across different programs and series. It can be employed in PAEs with a

technical emphasis, utilizing mathematical tools, as well as in PAEs concentrating on the development of socio-emotional skills through debates and case studies. Furthermore, it facilitates both vertical interaction (across different series) and horizontal interaction (within the same series) among students, within or between courses.

Statement from interviewee 1:

> "PBL is interesting for case studies in humanities subjects that address relationships with people, conflicts and leadership, giving problems and starting from the conflict." [interviewee 1]

Interviewee 2's statement:

> "PBL is best suited when you have a hands-on laboratory with equipment to handle." [interviewee 2]

Moreover, PBL proves to be an efficient methodology when there is a reduction in the scope of the course or limited time for the development of skills and competencies. In such scenarios, students take on the responsibility of selecting the necessary information to address the problem at hand. This approach allows students to establish a foundational understanding and delve into topics of greater interest or relevance, transitioning from a macro to a micro perspective. As articulated by respondent 5:

> "Accomplish a reduction in scope without losing a connection with reality and the student's needs." [interviewee 5]

PBL is regarded as one of the most comprehensive methodologies, ensuring interaction and serving well as a strategy for PAEs. With PBL, it becomes feasible to tailor meetings in a personalized manner, while also facilitating feedback mechanisms. Without PBL, a PAE might devolve into a "conventional class," ultimately losing its intended significance.

For interviewee 2:

> "Without an active methodology (as PBL), the PAE becomes another conventional class and loses its meaning." [interviewee 2]

The teachers did not alter the original PBL structure [5], but they introduced adaptations to the problem or the method of explanation, guiding students in the desired direction, all aimed at ensuring a satisfactory structure for use in the PAE.

Teachers express their appreciation for PBL, with some stating that they find it challenging to teach without this strategy. For all these reasons, it can be concluded that PBL is fertile for teachers and courses that incorporate it as a teaching methodology.

According to interviewee 1:

> "I can no longer teach without using this tool (PBL)." [interviewee 1]

Challenges and solutions

Knowledge about challenges and solutions can assist teachers who wish to implement PBL by providing advance awareness, enabling them to overcome challenges and achieve efficient performance. Here, the solutions presented by the interviewed teachers to the challenges they encountered will be outlined.

PBL places demands on both students and teachers. Students are expected to actively engage in projects and problem-solving. Creating projects requires a significant amount of time of teachers, and the process of generating them can be challenging. Finding sources of PBL cases and managing teams in the classroom, such as team creation, is also a difficulty mentioned by teachers.

For interviewee 3:

> "PBL is flexible, allows you to make changes and direct the class in a personalized way, but it demands from those involved, both applicators and students." [interviewee 3]

The student's interest and maturity play a crucial role in shaping the PAE. Student engagement is a key determinant of whether the performance will be basic or exceed expectations. Some students may select a PAE solely to fulfill the required hours without a genuine affinity for the project or an interest in developing the presented skills and competencies. Faced with challenges, some students may choose to discontinue their participation, leading to a low number of participants.

According to interviewee 3:

> "There were students who chose PAE because of the timetable and not the topic and this ends up influencing them. When these students were charged, they simply gave up on the PAE. They wanted to stay passive and keep the hours, almost an entire team that just wanted to keep schedule." [interviewee 3]

PBL, being an active methodology, is inherently unpredictable. After creating a case or problem, it is essential to test it to assess whether the resolution aligns with the desired outcomes. Even after testing, variations in the results may occur, necessitating adjustments during the process. Therefore, it requires the teacher to operate outside the comfort zone, considering that each case is unique, with its own specificities, and each class has its distinct dynamics.

As PBL is implemented in teams, it can mask or overlook disparities among participating students. Despite enabling interaction between students from different courses, years, and knowledge backgrounds, students end up forming groups with students from the same class, moving away from the richness of diversity.

As interviewee 2 indicates:

> "PBL can hide certain unevenness. Because it is teamwork, it is possible to evaluate a team well while there are students who are "hidden" and cannot be evaluated." [interviewee 2]

Interviewee 4 realizes that student's group together for convenience, or because they know each other previously:

> "Students end up forming teams with students from the same class, so there's a group of fourth-year students, a group of third-year students and the first-year students end up alone." [interviewee 4]

To address some of the challenges mentioned, teachers from the same field can form teams to discuss and create PBL cases. Additionally, they can participate in refresher courses on PBL, providing an opportunity to share experiences and learn from colleagues about overcoming challenges in implementing the methodology. This approach not only enables teachers to extract

more from the methodology but also allows them to gain insights and lessons learned from those who already apply PBL.

To prevent students from not completing PAEs on topics that are not of interest to them and avoid giving up, providing freedom of choice for students is crucial. Enhancing the offering, in a more explicit and clear manner, involves creating an attractive showcase that details what will be covered in the workshop, the approach, expectations from participating students, and the gains they can achieve. This way, students can make informed choices, selecting projects that align with their interests and goals.

Actions for teacher training with a focus on PBL

It is crucial for this information to reach teachers who are unfamiliar with PBL, including both those seeking to learn about it for the first time and those looking to update their knowledge about this strategy.

PBL is a methodology that offers benefits to both teachers and students. For students, it provides a stimulating approach that can foster the development of technical and socio-emotional skills while increasing engagement in the classroom. This strategy prepares students for complex environments and challenges, positioning them as protagonists who, through technical knowledge and creativity, can develop innovative solutions.

For teachers, PBL represents an opportunity to conduct more engaging and entertaining classes, leading to more involved students, and making meetings more efficient and interesting. Additionally, it is a versatile methodology that allows the exploration of various topics and areas of knowledge, whether in online environments, laboratories, or traditional classrooms, where students can collaborate in teams.

It is important to highlight that PBL is a methodology that requires training and ongoing efforts to be applied efficiently and effectively. Through proper training, teachers can learn strategies to address challenges encountered in the methodology, such as preventing students from forming groups exclusively with peers from the same course and classroom or fostering the maturity of students to extract more from the methodology. The interviewed teachers proposed that workshops on PBL, hosted by the Teachers' Academy (the institution's teacher training body), would be highly beneficial. Such workshops could facilitate discussions among teachers who are implementing PBL, allowing them to share insights and solutions for addressing the most challenging aspects presented by the methodology.

Final considerations

Teaching poses various challenges, especially in today's heterogeneous classrooms where diversity in thoughts, knowledge depths, study methods, and motivation levels among students can be significant. The traditional expository teaching model, centered on information absorption, may not effectively address the complexities of modern educational needs that demand adaptation and relevance.

Active learning methods, such as PBL, emerge as solutions to meet these demands by engaging students in solving real-world problems and providing a deeper understanding of interconnected knowledge. This study explores the teachers’ perceptions of the fertility of PBL,

emphasizing its significance as an active strategy in engineering education that adds value to students' learning experiences.

The evidence from previous works suggests dissatisfaction with the traditional teaching model, particularly in terms of students' motivation. PBL is recognized as an intelligible strategy, yet its complete adoption may be influenced by teachers' beliefs, indicating a need to align these beliefs for comprehensive adherence. The focus of this study is on investigating the teachers perceptions of fertility in the use of PBL.

Results indicate that PBL is fertile for those who apply (teachers) and appreciate its use, benefiting both the course that adopts PBL and the students who gain valuable insights crucial for their academic, professional, and personal lives.

Additionally, this work shows that PBL presents certain points of attention that may pose challenges or surprises for those implementing it. Hence, it is crucial for teachers to be aware of these aspects, allowing them to prepare and optimize the efficiency of PBL implementation.

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