Enhancing Engineering Education through Problem-based Learning

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ABSTRACT

Problem-based learning is a dynamic teaching approach that empowers students to actively address real-world challenges while taking charge of their own learning process. This study focuses on how problem-based learning enhances the retention of engineering concepts and principles, evidenced by higher levels of engagement and satisfaction reported by students. Through rigorous analysis of student feedback and project outcomes, this research investigates the effectiveness of problem-based learning in the context of engineering education. The results highlight the substantial positive influence of problem-based learning on both student engagement and their grasp of engineering fundamentals.

INTRODUCTION

Problem-Based Learning (PBL) serves as a pedagogical paradigm that transcends traditional education norms (Barrows and Tamblyn, 1980). It functions as a cognitive approach, blending theoretical foundations with practical applications. Within this dynamic realm, the instructor's role evolves from the traditional conveyor of information to that of a guide, empowering students to navigate their educational path. PBL is a teaching methodology that promotes experiential learning by challenging students to solve real-world problems. This active method of teaching and learning transfers the responsibility of the learning process to the students themselves (Savin-Baden, 2003; LaForce et al., 2017). The method involves analysing a problem and identifying the sources of conflict by applying prior and newly acquired knowledge. This cognitive harmony resembles an intellectual furnace, where the fusion of critical ideas transforms into practical solutions. In this capacity, students aren't passive receptors of predetermined solutions; instead, they actively create resolutions that mirror real-life complexities (Hmelo-Silver et al., 2004); students have an active role in creating the problem, analysing and developing solutions, and exploring different viewpoints and a variety of fields (Luecht et al., 2005).

RATIONALE

The purpose of this study was due to the significance of embracing a project-based learning approach in the context of engineering education. The capacity of PBL becomes evident in fostering profound learning experiences within an active environment. Unlike traditional methods that rely on pre-packaged content, this approach encourages students to gradually construct their understanding, fostering a more comprehensive grasp of concepts. Through engaging in projects, students refine their thinking and problem-solving skills, encompassing tasks such as evaluation, analysis, synthesis, and logical reasoning (Sharunova et al., 2018; Helerea et al., 2008). Moreover, this approach enhances intellectual understanding and clarifies concepts and theories. Additionally, the independent execution of projects enables students to learn from both failures and successes, promoting skill development, strategic thinking, and reflection. This iterative learning process amplifies motivation and engagement, creating a dynamic educational experience (Klegeris and Hurren, 2011). The exchange of spoken dialogic feedback between module leaders and students further enriches this approach, providing a platform for constructive criticism and addressing misconceptions.

AIM AND OBJECTIVES

This study aims to elucidate the potential benefits and challenges associated with incorporating PBL methodologies within engineering education. The specific objectives include:

1. Investigating the dynamics of implementing PBL in engineering education.
2. Evaluating its effectiveness in fostering critical thinking, problem-solving skills, creativity and teamwork among students.

METHODOLOGICAL APPROACH

This study has been carried out on projects undertaken by undergraduate students over a span of three years; the research was conducted ethically in adherence to university regulations. The projects which have been used for this work include Self-balancing robot using MATLAB/Simulink and Arduino, Low-pass audio filter design using simulation software and digital prototyping tools, and Analysis of 2D & 3D structures: comparison of numerical simulations with analytical solutions. These serve as good examples of PBL where aspects such as the level of complexity, the degree of authenticity, and the relevance to current engineering challenges were considered. Students, grouped in sets of approximately five, were provided with a problem statement and the necessary materials. Their task involved devising designs, implementing models or systems, and formulating their algorithms and solutions. Upon project completion, students were provided with a survey form aimed at evaluating the efficacy of PBL employed throughout the project. They were encouraged to rate various aspects of their experience on a scale of 0 to 5 in response to different questions on the form, or alternatively, choose from three response options: agree, disagree, or neither.

THE ENGINEERING EDUCATION PROBLEM AND INTERVENTION

In the domain of engineering education, a persistent challenge lies in fostering comprehensive learning experiences that bridge theoretical concepts with practical applications. This challenge arises from the gap between acquiring textbook knowledge and effectively applying it in real-world scenarios. The conventional educational approaches often fail to provide students with the holistic understanding required to excel in the intricate field of engineering. The result is a mismatch between theoretical insights gained in classrooms and the practical skill sets demanded by industries. This discrepancy underscores the imperative need for an intervention that can harmoniously merge theoretical learning with practical skills. It's in this scenario that PBL emerges as a transformative strategy, aiming to not only equip students with practical competencies but also to cultivate a profound comprehension of engineering concepts. This intervention effectively tackles the engineering education challenge by providing a dynamic educational framework that bridges theory and practice.

KEY FINDINGS

Figure 1 illustrates the outcomes of students' feedback on the Self-balancing robot project. The survey involved 90 participants. The scores, which are out of 5, indicate that in terms of the assessed skills, critical thinking received an average score of 4.16 with a standard deviation (SD) of 0.63, problem solving achieved an average score of 4.32 with an SD of 0.54, project management yielded an average value of 3.95 with an SD of 1, creativity obtained an average score of 3.75 with an SD of 0.75, teamwork received an average value of 4.32 with an SD of 0.54, and engagement obtained an average score of 3.66 with an SD of 0.76. This study suggests that the project contributes to a favourable student experience, with students enjoying active engagement. A selection of additional comments shared by students is as follows: 'PBL project was better than the traditional lecture; it was more interesting because it promotes self-learning', 'PBL project allowed me more freedom, more enjoyable, but our team needed better time management' and 'Being thrown in the deep end, it can be difficult to find your feet at first, lack of a clear direction can be demoralising'.

Figure 1. The effectiveness of PBL in enhancing students' skills, obtained from the feedback of the Self-balancing robot project

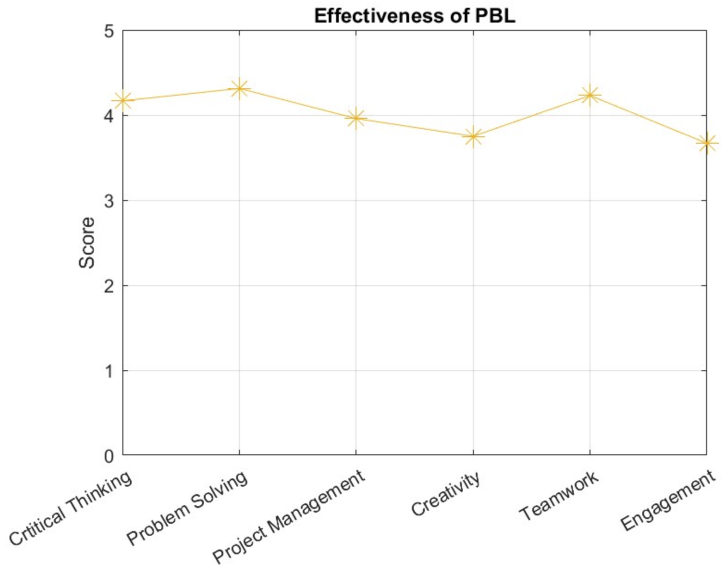


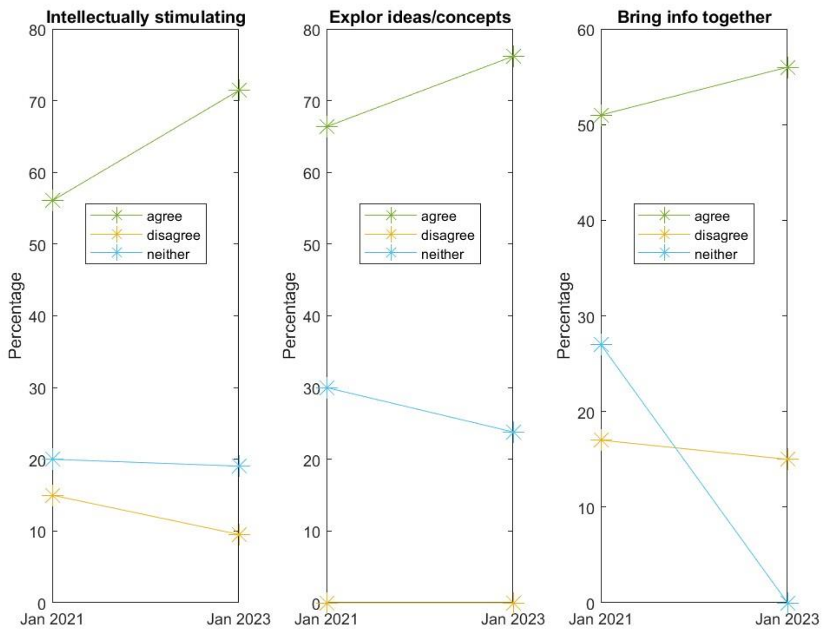
Table 1 displays a subset of questions extracted from the feedback summary of the Low-pass audio filter design project, implemented within a project-based module format. The project's structure included an outline and a briefing sheet, providing minimal guidance. The presented table outlines the average values and an SD for 46 participants. Notably, questions 1 and 2, pertaining to critical thinking and problem-solving, obtained average scores of 4.2 and 4.5. Conversely, scores slightly decreased to 3.9 and 3.7 for questions 3 and 4, related to the provision of learning materials and support. The results indicate that while some students excel with clear instructions and well-defined guidance akin to traditional lectures, others favour the challenges and independence offered by project-based learning. Students offered a few additional comments as follows: 'The group project was very fun. It helped a lot in the process of independent learning', 'Teamwork skills have been boosted during the learning in the module. More lab support sessions can be helpful' and 'The project was given out with vague instructions, meaning the group was confused on how to go into different points'.

Table 1. Summary of feedback on selected questions along with their corresponding average scores and standard deviations, obtained from the feedback of the Low-pass audio filter design project

	Survey Question	Average	Deviation
1	This module was intellectually stimulating	4.2	1
2	The module has provided opportunities to explore ideas or concepts in depth	4.5	0.6
3	Learning materials (handbook, study guide, teaching materials) have effectively supported my learning	3.9	1.3
4	I have received good study advice and support	3.7	1.4

Figure 2 shows the students' feedback on three selected questions for the Analysis of 2D & 3D structures project. The questions include: 'Module is intellectually stimulating', 'Module has provided opportunities to explore ideas or concepts in depth' and 'Module has provided opportunities to bring information and ideas together from different topics'. In this survey, students were given three response options: agree, disagree, or neither. Each plot compares results from 2021 and 2023. In 2021, the module lacked a project, whereas, in 2023, the project was integrated into the module. Observing the green line on the plot denoting intellectual stimulation, the inclusion of the project results in agreement percentages rising from 56% to 72%, and disagreement percentages dropping from 15% to 9.5%. Similarly, in the plot pertaining to exploring ideas, the green line indicates a rise in agreement percentages from 66% to 76% due to the project's inclusion. The last plot exhibits a 5% increase in agreement in relation to bringing information together. Overall, this figure shows the effectiveness of PBL in enhancing student engagement and agreement with module attributes. Students provided a few additional comments as outlined below: 'The project helped further understanding the content, and it made it easier to link the theory to what FE software does', 'Enjoyed the scope and left the opportunity to explore more', 'The Matlab scripts were a bit difficult to use due to the use of global variables over functions' and 'Some of the questions were a bit vague/not laid out very clearly; content was good and appropriately challenging'.

Figure 2. The impact of project integration on students' feedback, obtained from the Analysis of 2D & 3D structures project



DISCUSSION

This study has revealed the multifaceted impact of project-based learning in engineering education. The insights derived from the outcomes of students' feedback on various projects underscore the diverse nature of student preferences. While some students thrived in the autonomy and dynamic nature of PBL, others expressed a preference for more structured and explicit instructional methods. This duality in responses highlights the necessity for an adaptive and flexible educational approach that caters to a spectrum of learning styles and inclinations. This ensures the creation of a more inclusive and effective learning environment that addresses individual preferences and optimizes the educational experience for all students. The data also shows that PBL has the potential to significantly enhance critical skills such as critical thinking, problem-solving, teamwork, and creative thinking. The findings related to student engagement and satisfaction further affirm PBL's positive influence on the learning experience. The analysis of specific projects, such as the Self-balancing robot project and the Low-pass audio filter design project, demonstrates the multifaceted outcomes of PBL on various skills and attributes. Moreover, the data showcased in Figure 2 clearly shows the quantitative impact of PBL on specific module attributes, underpinning its effectiveness in enhancing student engagement.

CONCLUSIONS & RECOMMENDATIONS

PBL enhances the quality of engineering education by offering students a meaningful learning experience. The multifaceted benefits of problem-based learning underscore its potential to cater to diverse learning styles, promote deeper learning and retention of engineering concepts or principles, enhance engagement, and cultivate essential skills. PBL not only addresses the dynamic needs of education but also equips students with the skills and mindset required to thrive in the professional landscape. A potential path for future research could involve exploring the enhancement of students' learning experiences through the provision of additional resources and support for idea generation and development within PBL projects.

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