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Evaluating the Impact of Problem-Based Learning and Digital Models on Civil Engineering Education

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Abstract

To address the increasing complexity and sustainability challenges facing civil engineering, an educational approach that integrates theory with practical experience is needed. Traditional methods of teaching often fail to equip students with the skills needed by the industry which later on hampers their job readiness and the development of infrastructure. This study investigates the use of Problem-Based Learning as an integrative feature of BIM in a civil engineering module for the purpose of increasing engagement, problem-solving skills, and comprehension of complex concepts. The research included both pre- and post-class surveys that were directed toward the students and the professor. The pre-class surveys were used for the examination of the anticipated expectations, perceived difficulties, and awareness of PBL and BIM, while the post-class surveys were designed for the estimation of the shift in perceptions, confidence levels, and contentedness. The gathered data were also examined through descriptive statistics and thematic coding. The two approaches, PBL and BIM, were the most positively rated, where instead of discussing the effectiveness of these methods, 62.5% of students mentioned that BIM was the most beneficial tool for deepening structural concepts. The instructor particularly made mention of successful alliances with industry and sustainable direction but pointed to delays in permits and logistics maintenance as big threats. The integration of PBL and BIM in the civil engineering curriculum is found to be a significant aim of improved teaching as students are more motivated to complete course objectives and are more confident when they are exposed to real-life problems of the industry. It is proposed that PBL sessions be held in advance and that new digital resources be designed. Further research should be conducted to find out the effect of such methods on career readiness in the long term.

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1 Introduction

Civil engineering education faces unique challenges, as students must acquire a blend of theoretical knowledge and practical skills to succeed in real-world applications. Traditionally, lecture-based approaches have formed the core of engineering programs, focusing on conceptual knowledge and formulaic problem-solving. However, these methods often fall short of equipping students for the complex, unpredictable conditions of actual engineering projects [3]. In recent years, the field has witnessed increasing demand for an education that not only covers foundational knowledge but also fosters the ability to navigate real-world challenges such as sustainability, project constraints, and collaboration with various stakeholders. Addressing this gap, Problem-Based Learning (PBL) has emerged as a transformative approach, gaining traction in civil engineering programs worldwide. PBL situates students in the midst of complex, real-world problems that require interdisciplinary thinking and collaborative effort [2]. Rather than presenting a fixed set of facts, PBL engages students in problem-solving, where they must analyse situations, explore potential solutions, and evaluate outcomes. This approach not only deepens technical understanding but also cultivates critical thinking, adaptability, and teamwork—skills essential to civil engineering practice. Recent studies have shown that students in PBL-based courses demonstrate increased engagement, improved problem-solving abilities, and a greater capacity for handling multifaceted engineering tasks [5]. Building Information Modelling (BIM) has become a cornerstone in the integration of digital models within civil engineering education, enhancing the learning experience by offering interactive, visual representations of structural elements. BIM's dynamic, multi-dimensional modelling allows students to visualize and simulate engineering processes, transforming abstract concepts into concrete experiences [1]. By interacting with digital models, students gain insights into the structural and environmental implications of their decisions. Studies have found that combining PBL with BIM fosters a learning environment that closely mirrors professional practice, offering students a hands-on, realistic experience [4]. The addition of digital tools in PBL not only reinforces technical knowledge but also prepares students to work with the technologies and methodologies they will encounter in their careers. This study evaluates the effectiveness of integrating PBL and BIM in a civil engineering module to enhance student engagement, confidence, and understanding of complex engineering concepts. Pre-class and post-class surveys were administered to gauge student expectations, perceived challenges, familiarity with PBL and BIM, and the impact of these methods on learning outcomes. The professor's perspective was also gathered, providing insights into the instructional and logistical challenges involved in delivering a module cantered on PBL and digital models. Analysing this data provides a comprehensive view of how integrating PBL and BIM can impact civil engineering education, bridging the gap between theoretical knowledge and practical application, and fostering skills relevant to today's engineering challenges.

2 Study Design and Methodology

This study aimed to assess the effectiveness of integrating PBL and BIM into a civil engineering module. The focus was on evaluating student engagement, problem-solving skills, and comprehension of complex engineering concepts. To investigate the impact of these teaching methods on students' learning experiences and to identify the challenges faced by the instructor, a mixed-methods research design was employed. This approach involved the collection and analysis of both quantitative and qualitative data.

2.1 Research Design

A pre- and post-course survey was employed for students, along with semi-structured interviews conducted with the course instructor. The surveys were designed to assess changes in students' perceptions, confidence levels, and the effectiveness of the teaching methods. Furthermore, feedback from the instructor was obtained through structured surveys and in-depth interviews to examine instructional challenges, the effectiveness of the course, and potential improvements in the integration of PBL and BIM. This mixed-methods approach facilitated a thorough understanding of the impact of PBL and BIM on students' learning outcomes, as well as the practical challenges encountered during course implementation.

2.2 Mixed-Methods Approach

To enhance student participation, we crafted an accessible survey using Google Forms. Prior to the course commencement, we provided a QR code linking directly to the survey. This allowed students to easily scan the code and complete the survey on their phones right before the first class, offering us a snapshot of their expectations, initial confidence levels, and perceived challenges. After the module concluded, we shared the QR code once more to gather follow-up feedback. By employing the same questions in both surveys, we were able to track any shifts in their perceptions throughout the course. To gain insights from the professor, we adopted a slightly different approach. In addition to completing a structured Google Form similar to the one used by the students, the professor also engaged in informal interviews both before and after the module. These discussions allowed us to delve deeper into their experience with course delivery, addressing everything from anticipated challenges to observations about student engagement. During the pre-course interview, the professor articulated their teaching goals and identified potential logistical concerns. The post-course interview offered an opportunity to reflect on what worked well and areas for improvement. Overall, these interviews provided valuable insights that extended beyond the information gathered in a standard survey.

2.3 Participants

The students in this study were all undergraduates enrolled in the part of the Civil Engineering program at the University of Cambridge. This group came from varied academic backgrounds but was united in their focus on sustainable construction—a key theme of the course. Including the professor's perspective as both an instructor and observer allowed us to understand the teaching dynamics and challenges involved in introducing PBL and BIM in a foundational civil engineering module. This combined view of student and instructor experiences helped to capture a fuller picture of the module's impact.

2.4 Data Collection and Analysis

We collected all survey responses through Google Forms, which allowed us to maintain an organized approach. The QR code facilitated convenient access, enabling most students to complete both surveys and providing us with valuable pre- and post-module data for our analysis. To evaluate the quantitative aspects, we employed descriptive statistics, including mean and percentage calculations, to measure changes in student confidence, perceived difficulty levels, and effectiveness ratings of PBL and BIM. This methodology offered us a clear insight into the shifts observed within the group. For the open-ended survey responses and the professor's interviews, we employed thematic analysis using NVivo software to identify recurring themes. Student responses emphasized aspects such as "building confidence," "real-world application," and "collaborative learning." The professor's interview responses were coded independently, highlighting themes like "logistical challenges," "effective teaching strategies," and "observed student growth." By integrating these various data sources, we achieved a more comprehensive understanding of how both students and the professor experienced the course, combining structured statistics with insightful reflections.

3 Results

The results of this study present a comparative analysis of student expectations and outcomes before and after completing the module, alongside the professor's perspective on its implementation. This section summarizes the key findings in three areas: initial expectations and perceived challenges, effectiveness of the PBL and BIM methods, and shifts in confidence and learning engagement.

3.1 Initial Expectations and Perceived Challenges (Pre-Class Survey)

Prior to the beginning of the module, students expressed a blend of enthusiasm and apprehension regarding the anticipated challenges of the course. The pre-class survey indicated that 57.1% of students perceived the module's expected difficulty as moderate (level 4), while 35.7% deemed it slightly challenging (level 3). This reflects a diverse range of expectations among the students. Only 7.1% of respondents anticipated a low level of difficulty (level 2). These findings suggest that the majority of students expect the module to present moderate challenges, particularly with respect to complex topics such as environmental risk management and structural analysis. Students exhibited a moderate to high level of confidence in their ability to confront these challenges. Notably, 57.1% rated their confidence at level 4, and 35.7% rated it at level 5 (high). With an average confidence score of 4.3 out of 5, this indicates a strong belief in their capacity to succeed, even in the face of anticipated difficulties. The pre-class survey also captured students' perceptions of which subjects were most crucial for their success in the module. Construction Engineering and management emerged as key subjects, with high importance ratings indicating students' recognition of their foundational role in solving engineering problems. In contrast, subjects such as cost planning and health and safety were rated as less critical, suggesting these areas may not engage students as strongly as the core technical subjects as shown in Figure 1.

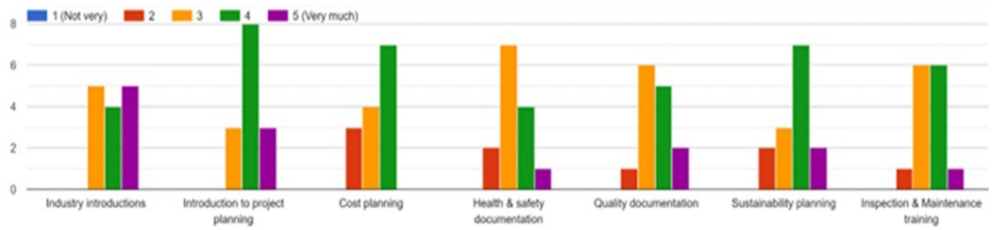

Figure 1: Results of the Pre-Class Survey for Relevant Subjects

This prioritization indicates potential areas where instructional strategies could be tailored to increase student interest and understanding of less popular topics.

The professor's pre-class survey responses underscored the module's objective of providing students with practical, real-world experience through industry collaborations and sustainability topics. The professor rated the clarity of these objectives at 5/5, emphasizing that an essential component was engaging students through authentic industry scenarios, including introductions to industry practices and collaborative group projects. Sustainability was also highlighted as a focus area, aligning the module with broader societal needs and academic research goals. In terms of instructional challenges, the professor anticipated high-risk areas in logistical issues, permitting delays, and project management (all rated 5/5), reflecting a realistic outlook on potential obstacles. Although the professor expressed moderate confidence (3/5) in addressing these challenges fully, they felt confident (4/5) in guiding students through them, underscoring a commitment to student support despite external constraints.

3.2 Effectiveness of the Module (Post-Class Survey)

The post-class survey revealed a notable change in student perceptions regarding the module's difficulty. By the end of the course, 55.6% of students rated the difficulty level as moderate (level 4), while 22.2% considered it slightly challenging (level 3) and another 22.2% rated it as low difficulty (level 2). This decrease in perceived difficulty indicates that the module's structured support and PBL approach effectively alleviated initial concerns, allowing students to navigate complex topics with greater ease. Feedback on PBL and BIM was particularly favorable. Approximately 62.5% of students reported that BIM was highly effective in visualizing and understanding structural concepts. The interactive features of BIM enabled students to engage with real-world simulations, thus enhancing their grasp of abstract engineering principles through practical, hands-on experience. Furthermore, 50% of students identified PBL as a vital tool for improving their problem-solving skills, highlighting its collaborative and practical aspects. Open-ended responses reinforced these findings, describing BIM as invaluable for understanding technical concepts and PBL as essential for developing real-world problem-solving abilities. Confidence ratings collected after the course demonstrated a positive shift, with 44.4% of students rating their confidence at level 5 (high) and another 44.4% at level 4, reflecting consistently strong confidence levels. These ratings affirm the module's effectiveness in equipping students with the skills and confidence needed to apply theoretical knowledge in practical situations. The professor's post-class feedback indicated that the module met its primary objectives, achieving an overall rating of 4/5 for its effectiveness in providing students with hands-on, practical experience. While several challenges anticipated in the pre-class survey did arise—including logistical delays and weather-related disruptions—these were managed through adaptive strategies. The professor reported a particular instance where adverse weather (high winds) impacted crane operations, temporarily halting student activities. Such challenges underscored the realistic nature of the project-based module, exposing students to the unpredictability inherent in engineering projects. The professor rated the PBL approach as highly effective (5/5) for engaging students in real-world problem-solving, confirming its role in enhancing student involvement and collaborative skills. However, digital tools such as BIM were rated at 3/5, suggesting that while beneficial, their potential may not have been fully realized. The professor noted that with additional training and support, BIM could be better integrated to support student learning in future iterations of the module. In terms of resource availability, the professor initially rated digital support low (2/5) but increased this rating to 4/5 as resources were adjusted throughout the course. This adaptive response highlights the importance of real-time adjustments in educational delivery to ensure a supportive learning environment.

4 Discussion

The findings of this study indicate a meaningful impact of PBL and BIM on enhancing student engagement, confidence, and understanding within a civil engineering module. This section discusses the effectiveness of these methods and their implications for curriculum development, as well as instructional challenges identified through the professor's feedback.

4.1 Impact of Problem-Based Learning on Student Engagement and Problem-Solving Skills

The results of the study show that the Problem-Based Learning (PBL) approach significantly enhanced student engagement and practical problem-solving skills. At the beginning of the module, 57.1% of students expected the tasks to present moderate difficulty, while 35.7% anticipated them to be slightly challenging, particularly in areas such as environmental risk management. By the end of the module, 55.6% of students continued to perceive the difficulty as moderate, with only 22.2% rating it as slightly challenging. This indicates that the collaborative and hands-on nature of the PBL framework effectively alleviated many of the students' initial concerns. The professor's post-class observations confirmed the efficacy of PBL, rating it highly effective for engaging students in real-world scenarios. The industry interactions and collaborative group projects fostered through PBL provided students with practical insights into civil engineering, simulating the professional environments they will encounter after graduation. The alignment between student and professor feedback supports the notion that PBL, when applied effectively, offers an immersive experience that can bridge the gap between theoretical knowledge and professional skills.

4.2 Effectiveness of Digital Models in Enhancing Understanding

The incorporation of BIM significantly improved students' comprehension of complex engineering concepts. Notably, 62.5% of students considered BIM to be highly effective in enhancing their understanding of structural analysis. BIM enabled students to visualize structural elements and simulate project processes, effectively reinforcing their theoretical understanding through practical application. However, the professor rated BIM's effectiveness at 3/5, noting that while beneficial, its full potential was not entirely realized due to limitations in technical support and training. This suggests that future implementations of BIM in similar modules could benefit from additional resources and support, ensuring that students are comfortable

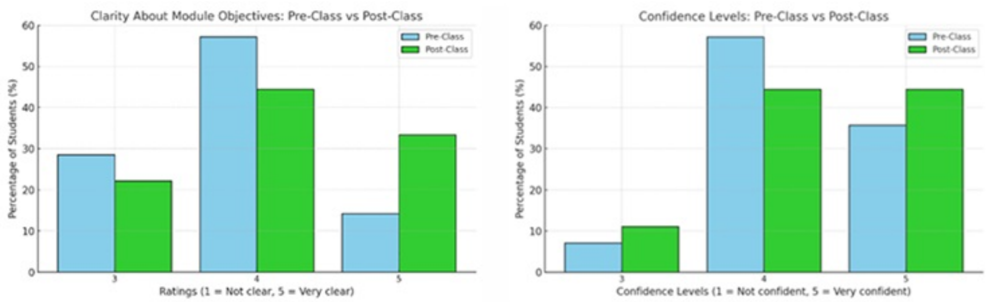

Figure 2: Results of Pre- and Post-Class Surveys

using the software and can fully engage with its capabilities. Incorporating introductory BIM tutorials or increased support could help students maximize the tool's educational potential, further bridging the gap between conceptual understanding and technical skill development.

4.3 Comparison of Pre- and Post-Class Perceived Challenges

The comparison of pre-class and post-class survey data effectively illustrates the success of PBL and BIM in preparing students to confront complex topics. At the outset, 57.1% of students anticipated moderate difficulty, primarily due to concerns related to environmental risk management and structural analysis. By the conclusion of the module, the percentage of students still perceiving the module as moderately difficult held steady at 55.6%. However, there was an increase in the number of students who found the module slightly challenging, rising to 22.2%. This notable shift underscores the module's effectiveness in addressing initial concerns and enhancing students' readiness to tackle real-world challenges. Figure 2 shows the results of Pre- and Post-Class Surveys.

The professor's perspective provided additional context, highlighting how logistical issues and permitting delays impacted the course's delivery. Despite these obstacles, the professor's commitment to adaptive teaching strategies helped sustain student engagement and fostered a supportive learning environment. This reflects the importance of instructor flexibility and responsiveness in project-based courses, where external constraints can influence the learning experience.

4.4 Correlation Between Familiarity with PBL and Learning Outcomes

The data reveals a positive correlation between students' familiarity with PBL and their overall learning outcomes. Those who possessed a moderate familiarity with PBL prior to the course rated its effectiveness more highly than students who were entirely new to the method. This finding underscores the importance of offering introductory sessions that familiarize students with PBL frameworks early in the curriculum. Such sessions provide students with essential foundational skills and help align their expectations. By implementing preliminary workshops or early exposure to PBL, educators can further enhance student engagement and effectiveness in PBL-cantered modules.

4.5 Resource Utilization and Accessibility

Both the student and professor feedback underscored the importance of adequate resources and real-time support for optimizing the learning experience. The professor's initial low rating of digital support (2/5) improved as resources were adjusted throughout the module, eventually reaching a 4/5 rating. This improvement underscores the necessity of adaptive resource allocation in educational delivery, particularly in modules that heavily rely on digital tools like BIM. Ensuring access to technical support and relevant resources not only enhances the effectiveness of digital tools but also empowers students to experiment with complex simulations and refine their solutions. Furthermore, the professor emphasized broader evaluation criteria such as sustainability and communication skills as essential learning outcomes. By incorporating these criteria, the module aligns with current professional expectations and equips students with holistic competencies that extend beyond technical skills. This comprehensive approach to student evaluation, including both technical and soft skills, ensures that civil engineering graduates are prepared to meet the diverse challenges of their field.

5 Conclusions

This study underscores the advantages of integrating PBL and BIM within a civil engineering curriculum, particularly in enhancing student engagement, confidence, and practical understanding. This approach effectively bridges the gap between theoretical concepts and real-world applications, equipping students with vital technical and collaborative skills. By cultivating these competencies, civil engineering programs can better prepare graduates to navigate the evolving challenges of the industry and make meaningful contributions to the development of sustainable and resilient infrastructure. Traditional civil engineering education, often cantered around lecture-based approaches, can struggle to prepare students for the complexities of professional practice. By immersing students in real-world scenarios and collaborative problem-solving, PBL effectively addresses these gaps, fostering essential skills for tackling multifaceted engineering challenges. BIM serves as an interactive tool that further supports learning by providing visual, hands-on experiences, which deepen students' comprehension of structural elements and project processes. Pre-class and post-class surveys revealed several insights. Initially, 57.1% of students anticipated moderate difficulty, while 35.7% rated the module as slightly challenging. By the end of the module, students' perceptions of difficulty shifted: 55.6% rated the difficulty as moderate, and there was a notable increase in those finding the module slightly challenging (22.2%). Confidence levels were consistently high, improving from an average score of 4.3 to 4.4, with 88.8% of students rating their confidence as high (levels 4 and 5). Furthermore, 62.5% of students rated BIM as highly effective in enhancing their understanding, affirming its value in bridging theoretical and practical knowledge. The professor's perspective supported these findings, highlighting the effectiveness of PBL and BIM in real-world problem-solving while acknowledging logistical and technical challenges. Adaptive teaching strategies, such as improving the availability of digital resources during the module, were essential in maintaining student engagement and achieving the learning objectives. The findings of this study advocate for the inclusion of PBL and BIM in civil engineering education as effective tools for fostering real-world skills. To optimize the benefits of PBL, we recommend introducing students to PBL frameworks early in their curriculum through preparatory workshops or introductory sessions. This groundwork can help align expectations and build foundational skills, leading to more effective engagement in PBL modules. Furthermore, enhancing technical support and resources for BIM will allow students to fully leverage digital models, reinforcing their ability to apply complex concepts and refining their design capabilities. Further research should explore the long-term effects of PBL and BIM on students' knowledge retention and career preparedness. Longitudinal studies tracking graduates' performance in professional settings could provide valuable insights into the practical benefits of these educational methods. Future studies could also investigate how continuous resource adaptation, including technical support and real-time feedback, impacts student learning and engagement in digitally supported PBL modules. Moreover, future studies may consider examining the integration of sustainability and communication skills into student evaluations, offering a more holistic approach to skill development in civil engineering education.

6 Acknowledgments

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