Design of Project-Based Learning (PBL) in Civil Engineering

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***Abstract*—Project-Based Learning (PBL) is a teaching approach that has been shown to enhance students' learning in higher education. PBL ensures that students develop critical thinking and professional competence in civil engineering education through a well-rounded approach. In civil engineering modules, design projects provide practical design experience to the students. This allows them to apply their knowledge and skills across disciplines. The design of such projects plays a crucial role in their learning journey. Therefore, it is essential to ensure that they are well-designed. This paper presents a framework for designing PBL in a civil engineering module in a joint degree programme in Singapore. This framework for the PBL design is based on the Universal Design for Learning (UDL). A questionnaire was prepared to obtain feedback from students on their PBL experience. Through the implementation of PBL in Foundation Engineering, the students have feedback that the PBL was well-designed and had a positive impact on their learning.**

***Keywords*—Project-Based Learning (PBL), Universal Design for Learning (UDL), civil engineering**

I. Project-Based Learning in Civil Engineering

The joint degree programme between the Singapore Institute of Technology (SIT) and – the University of Glasgow (UofG) in Civil Engineering is focused on an applied learning methodology where students gain profound knowledge by actively engaging in the hands-on application of theoretical knowledge, practical skills, and high-resolution numerical models. To ensure that our students graduate as industry-ready professionals, SIT-UofG integrates scaffolded assessments seamlessly into the curriculum.

At SIT-UofG, we believe in providing a comprehensive educational framework that combines traditional and experiential learning methods. Our contemporary approach to experiential education emphasizes individual or group-based learning processes, which help students hone their unique skills and capabilities. This approach aligns with our educational philosophy of promoting original thinking and fostering diverse cognitive strategies and perceptual skills. This learning mode often goes beyond the conventional methods of book-based learning and lectures, as Williams [1] noted.

Experiential education is a comprehensive teaching approach involving a range of targeted methodologies. Project-Based Learning (PBL) stands out as a prominent and effective strategy. PBL is firmly rooted in three fundamental constructivist principles: 1) learning is contextual, 2) students are actively engaged in the learning process, and 3) learning objectives are achieved through collaborative social interaction and knowledge dissemination [2]. As such, PBL serves as a cornerstone within this educational paradigm.

While university lecturers globally possess extensive expertise in their respective research domains, their prowess in the realm of teaching might not always mirror such depth. A holistic pedagogical knowledge base necessitates a nuanced understanding of learning intricacies, processes, and instructional methods that transcend specific domains—among which PBL holds a pivotal position [3]. Thus, the integration of PBL emerges as a compelling and apt approach to effectively align with the Intended Learning Outcomes (ILOs) within various modules, offering lecturers an avenue to bridge the gap between their expertise and pedagogical delivery. By embracing PBL, educators endeavor not only to impart knowledge but also to refine their instructional techniques, aspiring to elevate themselves into adept and proficient instructors [4]. This method allows for the cultivation of enriched learning environments where educators can guide and nurture students, fostering comprehensive understanding and skill acquisition beyond conventional boundaries.

Studies have consistently demonstrated the exceptional efficacy of Project-Based Learning (PBL), notably within the domain of medical education, where its impact has been profound. PBL has also been shown to improve graduate employability in Ref. [5]. The collated reflections in Ref. [6] depict the project as an effective

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mechanism for developing an array of 21st century skillsets and values. Moreover, PBL finds extensive application within engineering schools, as highlighted by the work of Mills and Treagust [7]. In these contexts, PBL takes the form of expansive projects that span considerable durations, diverging from mere knowledge acquisition to emphasis on practical application. These engineering-oriented projects serve a dual purpose: not solely confined to knowledge assimilation but primarily emphasizing its real-world application.

This distinctive approach underscores the essence of PBL within civil engineering, compelling students not only to grasp information but to intricately interlink and practically implement it. It has also been discussed in Ref. [8] that sufficient methods, tools, languages, and interdisciplinary teamwork must be learned at the undergraduate level to empower students to address the needs of the Construction Industry stakeholders. Herein lies the crux of PBL's suitability within civil engineering education—it necessitates students not just to accumulate information but actively apply it, fostering deeper comprehension and practical insights.

However, the effectiveness of PBL in civil engineering education hinges greatly upon the provision of robust scaffolding and support structures. These mechanisms are indispensable to ensure that students navigate these learning avenues effectively and derive maximum benefit from this experiential learning methodology. As such, it is crucial to ensure that the projects are well-designed for effective PBL. Our research objective is to understand and evaluate the design approaches for PBL, implement the characteristics of these approaches in the design of a module in civil engineering, and evaluate their effectiveness.

II. Design Approaches of PBL

In order to achieve the goals of PBL, two design frameworks, i.e., the ABC framework and Universal Design for Learning (UDL), were chosen. In this section, a comparison study was conducted to prepare PBL in the Foundation Engineering module.

The ABC Framework and Universal Design for Learning (UDL) are two distinct design frameworks used in education, particularly in the design of instructional materials and learning environments. The ABC framework is a model that focuses on designing curriculum and instruction based on authentic activities that students are meant to be engaged in. It is clear that the ABC framework emphasizes real-world application and problem-solving [9]. The PBL we are going to develop is also closely related to real-world applications. Therefore, the ABC framework is considered a design framework. The UDL is a model that aims to create inclusive learning environments that can be easily accessed, understood, and used by students, including those with diverse abilities and learning styles [10]. The UDL emphasizes creating curriculum and instructional materials that are designed from the outset to be inclusive and accessible to all learners [11]. In addition, it encourages the use of multiple means of representation, engagement, and expression to cater to diverse learning needs. Therefore, the UDL is well-suited for the PBL, particularly tailored to international and/or local students with a keen interest in Foundation design.

It is also true that the ABC framework is a task-centred approach where the curriculum is designed around authentic activities. Therefore, assessments in the ABC framework are closely tied to the authentic learning process, often in the form of performance assessments, projects, and practical application of knowledge and skills. From the UDL perspective, it promotes varied and flexible assessment methods that accommodate different learning styles and abilities with the incorporation of demonstrating and understanding knowledge, such as written assignments, oral presentations, and multimedia projects [12]. Therefore, we concluded that the UDL places a stronger emphasis on student-centred approaches in the sense that it recognizes and embraces learning variability. It seeks to remove barriers to learning and aims to engage all students by providing them with multiple pathways to learning and demonstrating their understanding. However, this is not a criticism of the ABC framework but we hope to also incorporate the good features of UDL in our design. In terms of its approaches and assessment, the ABC framework encourages active and experiential learning. It truly values the acquisition of practical skills and knowledge and often involves students in collaborative problem-solving activities.

The PBL will be prepared by an interdisciplinary team of colleagues; therefore, we need to focus on inclusivity that emphasizes creating an inclusive learning environment for diverse learners [13], rather than on real-world relevance and problem-solving. In addition, the UDL starts with designing the curriculum and instructional materials with inclusivity in mind. While the PBL still demands that students are ready for real-world tasks, the top priority for this module is to guarantee accessibility and engagement for all learners, given that the interdisciplinary team addresses fundamental concepts in various learning styles [14].

In summary, while both the ABC Framework and UDL share a commitment to effective education, they have different starting points and primary goals. ABC emphasizes authentic, task-based learning, while UDL prioritizes inclusivity and flexibility to accommodate diverse learner needs. With the consideration of the educational context and goals for the PBL, our team went with UDL for the development of our PBL.

The UDL can be effectively shared across interdisciplinary teams that include educators, special education professionals, curriculum designers, and other experts. It can serve as a common framework for collaboration, fostering a shared understanding of how to meet the diverse needs of all students. In addition, the application of the UDL has been shown to have a positive effect on students in Science, Technology, Engineering, and Mathematics (STEM) programs, even on students with disabilities [15]. By adopting the UDL principles, team members can create consistent approaches to curriculum development, lesson planning, and assessment, ensuring that every student receives equitable access to education because it is possible to institute the UDL training for educators. Training in the UDL on lesson plan development for special and general instructors was provided [16].

Levey [12] stated that barriers to the utilization of UDL were an absence of the ability to collaborate with other teachers to share their experience and expertise with this approach and an absence of a model lesson to support their understanding of how UDL could be utilized. It means that implementing UDL effectively can be complex, requiring careful consideration of a wide range of design principles and accessibility standards, which would be time-consuming, as it involves creating multiple options for content delivery and assessment [17]. However as mentioned earlier, it is necessary for educators to be familiar with the UDL by providing general instructions, principles, and guidelines, to utilize the UDL effectively. To successfully complete the design using the UDL across interdisciplinary teams, it is important to provide training, resources, and ongoing support to ensure that all team members understand and can implement the UDL effectively. This may include professional development workshops, access to UDL resources, and opportunities for collaborative planning and reflection [18, 19].

This UDL educational approach to recognizing and addressing variability allows students to achieve success in the classroom by reducing barriers to learning. This approach benefits all learners and assures learning, which is the primary goal of the PBL. There are many aspects to understanding and assessing the design methods, such as their definition, approach, assessment, and learner focus. The important thing is that all students learn and understand the information that is being presented to them. We adapted this method for all students due to the flexibility it offers in accommodating various learning perspectives. Therefore, educators must be aware of individuals' backgrounds, cultures, and languages to be successful in their development [12].

III. Implementation of PBL

The implementation of PBL has been extensively discussed to uncover the critical facilitators that contribute to its successful integration within educational contexts. We have reviewed relevant research papers mostly associated with engineering education, in particular, civil engineering education. Kokotsaki *et al.* [2] and Efstratia [20] have discussed the factors in the implementation of PBL instruction as follows.

- Effective use of technology
- Kolb's cyclical model: Concrete Experience to reflective observation to abstract conceptualization to active experimentation
- Effective scaffolding of students' learning, motivation, and support.
- Balance of instruction with in-depth inquiry
- Authentic assessment focusing on reflection, self and peer evaluation
- Student engagement: autonomy, relatedness and competence
- Group collaboration of high-quality

One crucial facilitator lies in the creation of authentic, real-world projects that resonate with students' interests and align with the learning objectives. When projects are relevant, engaging, and reflect the complexities of actual problems, they inherently motivate students to delve deeper into the subject matter and take ownership of their learning [21]. Another pivotal factor is the role of the facilitator or educator. Effective facilitators in PBL act as guides, providing necessary support, scaffolding, and mentorship while allowing students to explore and discover solutions autonomously. Their ability to pose thought-provoking questions, offer guidance, and create a conducive learning environment significantly impacts the success of PBL implementation [22]. This approach, when integrated into high-quality educational experiences, enables students to take small yet meaningful steps toward success.

Collaboration and teamwork stand out as key facilitators within PBL. Encouraging students to work in groups fosters diverse perspectives, enhances communication skills, and promotes peer learning. Effective group dynamics, where students collaborate, share ideas, and collectively solve problems, contribute significantly to the success of PBL [23]. Therefore, we emphasized the importance of scaffolding students' learning and fostering high-quality group collaboration in our Civil Engineering curriculum.

Embedded within the civil engineering curriculum, the Foundation Engineering module is delivered by lectures and tutorials—delving deeply into the fundamental theories and methodologies that underpin industrial design principles. This course is conducted in the third trimester of the academic year 2022–2023 and is open to students who have successfully completed two prior modules focusing on geotechnical engineering, namely, Engineering Geology & Soil Mechanics and Geotechnical Engineering.

A total of 95 Year 2 students in Foundation Engineering were divided into three small classes. Each class consisted of groups of 4 to 5 students. These students participate in PBL-deep foundation design using pile load tests under the guidance of academic staff as facilitators. At its core, the assessment structure of this module is designed to encompass project-based evaluations. This deliberate approach grants students the invaluable opportunity to apply their accrued knowledge and hone their problem-solving acumen to grapple with authentic real-world challenges. By immersing themselves in project work, students traverse beyond theoretical boundaries, engaging actively in practical applications that mirror the demands of the industry.

A distinctive facet of this module lies in its encouragement of collaborative efforts among students. Emphasizing teamwork, students are tasked with collaborating within groups, synergizing their collective strengths to navigate the intricacies of their assigned projects. The culmination of their endeavors manifests in the submission of a comprehensive technical report, complemented by the delivery of a compelling presentation that encapsulates their project's progress and findings.

This multifaceted approach within the Foundation Engineering module epitomizes an immersive learning experience, blending theoretical foundations with practical applications and collaborative engagement. It not only equips students with technical knowledge but also fosters teamwork and communication skills crucial for their future roles within the civil engineering domain.

In our research study, a survey has been devised and hosted through an accessible link. In the survey form, participants are fully informed about the purpose of the research, what their participation involves, how their data will be used, and their rights regarding participation. The protection of the privacy of participants is kept confidential. This includes anonymizing data and not disclosing personally identifiable information without explicit consent. The survey link and QR code were shared in the lecture to participate. The participant should voluntarily agree to take part in the research without any form of coercion.

The views and feedback received from the students regarding the PBL were qualitatively collected. This feedback will be used by the course instructor to reflect on their teaching and learning activities, and to decide whether any modifications should be made to the course. In order to explore the issues related to the implementation of PBL, such as student's learning experience and workload, a questionnaire was used to address specific items and questions, as shown in Table I. Some of the questions are adapted from [24].

In the first five items of this questionnaire, students are requested to select their level of agreement on a scale of "strongly agree", "agree", "neutral", "disagree", and "strongly disagree". Additionally, students are required to choose one of the ILOs that they perceive as having the most benefits to their learning.

TABLE I. QUESTIONNAIRE USED FOR STUDENT FEEDBACK

No.	Questions (strongly agree = 5, strongly disagree = 1)
1	I have a clear understanding of what I am expected to do for this group project.
2	I have a clear understanding of what I am expected to learn from this project.
3	The teaching and learning activities (e.g., lecturing, consultations, peer discussions, case studies, presentations, etc.) have helped me to achieve the module learning outcomes
4	The assessments require me to demonstrate my knowledge, skills and understanding of the subject
5	I understand the criteria according to which I will be graded
6	From the group project, which of the following brought you the most benefits? *LO1: Interpret field and laboratory soil data* *LO2: Understand the analytical solutions of bearing capacity for shallow foundation* *LO3: Understand stress distributions near foundations* *LO4: Overview of deep foundation analysis and design* *LO5: Understand and analyze axially loaded piles and pile groups* *LO6: Understand and analyze negative skin friction and field load tests*

IV. FINDINGS AND LIMITATIONS

Fig. 1 depicts the results of a study that explored the students' learning experience with a subject through Project-Based Learning (PBL). The study collected data from the students, and the findings revealed that the majority of the students (85.7%) agreed that they understood what was expected of them, in terms of learning and project outcomes. Moreover, 71.5% of students agreed that the teaching and learning activities, such as projects, discussions, and presentations, helped them to achieve the learning outcomes of the PBL and module. However, it was observed that the percentage of students who agreed that the teaching and learning activities helped them to achieve the learning outcomes was slightly lower than the percentage of students who agreed that they understood what was expected of them. This can be attributed to the fact that there is often a gap between the students' recognition of the PBL and their ability to apply the knowledge and skills acquired to hands-on activities.

According to recent feedback from students, the assessments in the module have been effective in testing their knowledge, skills, and understanding of the subject matter, with an impressive 85.7% of students confirming their agreement. Additionally, a majority of 71.5% of students felt that they understood the assessment criteria for evaluating their performance. However, some students found the Problem-Based Learning (PBL) approach challenging, especially when working in a group setting. These students would have preferred to work on the PBL exercises individually. This could be mitigated by introducing small research tasks in a group setting, prior to the start of the project, to teach and encourage teamwork. Despite this, most students appreciate the collaborative aspect of PBL and find that it helps them learn better.

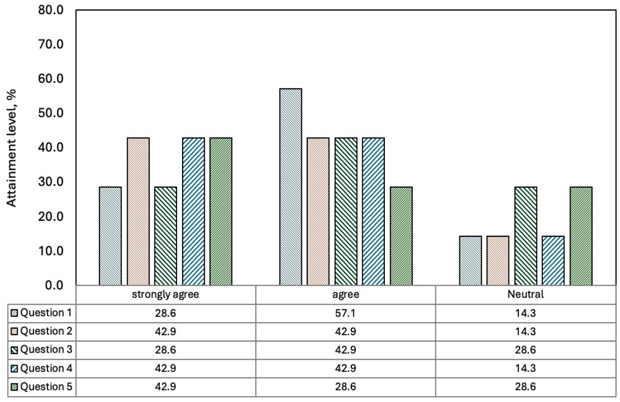

Fig. 1. Distribution of the attainment level for the students' learning experience of the PBL.

V. CONCLUSION

The Foundation Engineering module in the Civil Engineering Programme utilized Project-Based Learning (PBL) that was successfully designed to fit the circumstances of the SIT-UoG joint degree programme and its associated pedagogy. Furthermore, the PBL went through a thorough review process using two design frameworks to ensure alignment with the module and intended learning outcomes. It is evident that the PBL has greatly enriched the students' learning experience. Based on the feedback, the students appreciated the PBL as it helped them to gain a better understanding of design in the industry, familiarized them with the Code of Practices (in particular, foundation design code), and provided practical skills in engineering, such as the use of engineering software. The integration of theory with practice through the implementation of PBL in the course was highly beneficial for the students.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Yongmin Kim and Samiran Das designed this research framework; Yongmin Kim and Li Hong Idris Lim wrote the paper and analyzed the data; Jolly Atit Shah and Li Hong Idris Lim reviewed and edited the paper; all authors approved the final version.

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