Project-based Experiential Learning in Designing Truss Structure for First Year Chemical Engineering Students

Article history
Received
7 April 2024
Received in revised form
23 June 2024
Accepted
24 June 2024
Published online
30 June 2024

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Abstract
The successful integration of a novel and dynamic project-based learning (PBL) methodology, grounded in experiential learning principles, within the pedagogy of the first-year Chemical Engineering program, yielded transformative outcomes in the teaching and learning of the Statics course. This endeavour involved a project-based experiential learning approach, wherein students actively engaged in the conceiving, designing, constructing, and testing a truss structure. This strategic shift from conventional teaching methods to a student-centred approach aimed to empower the learning experience. Facilitated by project-based experiential learning, students collaborated in groups to conceptualize, build, and evaluate the truss structure, fostering self-directed learning skills and enhancing 21st Century 4C skills. The project was designed based on constructivist learning theory, emphasizing experiential learning and scaffolded activities to support students in achieving the project's outcomes. Throughout the project journey, students consistently demonstrated proficiency in applying free-body diagram concepts, which aligns with the constructivist approach to learning. This evidence was documented in student-prepared vlogs, showcasing their ongoing application of theoretical knowledge to practical challenges. At the project's conclusion, a survey was conducted among 124 students in the first semester of the 2022/2023 academic year to assess project outcomes. The results indicated high levels of agreement among students, with 96% agreeing to collaboration elements, 90.4% to communication, 91.2% to critical thinking, and 90.4% to creativity. Moreover, 88.8% of students agreed that their knowledge in designing basic truss structures improved, 96.8% felt more confident in analysing truss structures, and 81.6% found creating montage videos beneficial. Through our innovative methodologies, we contribute to the advancement of engineering education and ensure that our students are prepared to face the challenges of the future with confidence and creativity.

Keywords: Experiential learning; project-based learning; student-centred learning; statics; truss design

Introduction

Constructivists view learning as a journey of uncovering meaningful information. According to constructivist theory, learning occurs when individuals build new understanding through the interplay between their prior knowledge and new experiences. They believe this approach can alleviate learning difficulties with the support of teachers and knowledgeable peers (Jumaat et al., 2017). One compelling application of Constructivist Theory in the classroom is Project-based Learning (PBL). This learner-centred approach empowers students to conduct research, integrate theory and practice, and apply their knowledge and skills to develop viable solutions to defined problems (Sadikin et al, 2019). One of the key elements to have effective and successful PBL is the students take responsibility for their own learning.

Experiential learning, rooted in constructivist theory, is characterized as 'learning by doing.' In this approach, the learner actively engages in the educational process, achieving understanding through an ongoing cycle of inquiry, reflection, analysis, and synthesis (Mughal and Zafar, 2011). Experiential learning, a core component of constructivist learning theory, emphasizes the importance of students actively engaging with and reflecting on their experiences to construct knowledge. Constructivism asserts that learners build their understanding through hands-on experiences and critical thinking, rather than passively receiving information. PBL aligns with this theory by placing students in real-world scenarios where they must apply their knowledge to solve complex, ill-structured problems. This active engagement fosters deeper comprehension and retention of the material (Staehle et al., 2023).

In the context of this study, the PBL methodology not only embodies the principles of constructivism but

Sarkawi, M.S., Mohamed, M., Shamjuddin, A., Alias, H., Mohamad, Z. (2024), Project-based Experiential Learning in Designing Truss Structure for First Year Chemical Engineering Students, *ASEAN Journal of Engineering Education*, 8(1), 49-55.

also leverages experiential learning. Students are encouraged to integrate theoretical knowledge with practical application and collaborate with peers to design and analyse project. This project requires students to apply engineering concepts, engage in iterative problem-solving, and reflect on their learning process, thereby reinforcing their understanding through direct experience. By incorporating experiential learning into PBL, this approach ensures that students are not merely passive recipients of information but active participants in their educational journey. This dynamic method of instruction equips students with the skills and knowledge necessary for real-world applications, fostering both personal and academic growth (Ghosheh Wahbeh et al., 2021).

One of the key novelties lies in our emphasis on learning through real experiences. Rather than relying solely on theoretical concepts, students actively participate in the entire project lifecycle, from conceiving the idea of designing a simple truss structure to its practical implementation and operation (Fadda and Rios, 2017). We have also fostered a seamless integration between manual and computational approaches, encouraging students to explore diverse methodologies and apply both traditional and cutting-edge tools in their design processes. To ensure comprehensive evaluation, we have developed innovative assessment criteria that go beyond conventional metrics.

Our assessment includes the creation of engaging vlogs and the use of demonstration rubrics, which provide a multi-dimensional perspective on students' learning progress. Furthermore, we offer a well-documented project description and manual, backed by tangible evidence, to showcase the students' progress and accomplishments throughout the project. This novel approach aims to empower students with practical skills, critical thinking abilities, and a deeper understanding of truss design, nurturing their passion for engineering and PBL.

Our project introduces a set of ground-breaking ideas and methodologies that truly set it apart from traditional practices, showcasing its novelty in engineering education. The core innovation lies in the seamless integration of the PBL, real-world experience, and a dual approach combining manual and computational methods. By guiding students through the PBL, we create a comprehensive learning experience that mirrors the professional engineering process.

This approach not only equips students with technical knowledge but also hones their project management, teamwork, and problem-solving skills - essential qualities sought after in the engineering industry (Ricaurte and Viloria, 2020). The emphasis on real-world experience takes learning beyond theoretical concepts. By engaging students in the design of a simple truss structure, they confront genuine engineering challenges, make informed decisions, and witness the practical implications of their solutions.

This experiential learning fosters a deep understanding of engineering principles and motivates students to take ownership of their learning journey. While manual techniques offer hands-on experience and develop students' spatial visualization skills, computational tools enable them to analyse complex data and optimize their truss designs efficiently. This integration empowers students to leverage the best of both worlds, preparing them to adapt to diverse engineering scenarios in their future careers. By emphasizing collaboration, communication, critical thinking, and creativity through the 4C skills framework, we instil in students a holistic understanding of engineering practices, encouraging them to think innovatively and approach problems from multiple angles.

This paper explores the innovative use of PBL and experiential learning principles in a Statics course for first-year chemical engineering students at Universiti Teknologi Malaysia. By engaging students in the design of truss structures, this approach fosters a deeper understanding of engineering concepts and enhances practical problem-solving skills. This initiative serves as the backbone of our teaching and learning practices, allowing students to engage in a holistic learning experience. By integrating the PBL, we foster a new generation of engineers equipped with not only technical expertise but also the practical and soft skills needed to excel in the dynamic and ever-evolving field of engineering.

Methodology

Implementing PBL is complex and challenging for both instructors and students, and this is intentional. The depth of engagement required by PBL often means it is neither simple nor easy. Considerations for implementing PBL include providing significant instructional scaffolding for students who are new to this form of instruction. New learners require support in developing problem-solving skills, self-directed learning abilities, and teamwork and collaboration skills. This project would require the students to apply engineering principles, collaborate with peers, and iteratively refine their designs based on feedback and analysis. Such an experience not only deepens their understanding of statics but also equips them with essential skills for their future careers. Engaging students in PBL prepares them for real-world challenges, fostering a deeper understanding and application of their knowledge, and promoting lifelong learning skills.

Learning Outcomes and Course Mapping

This project focussed on three of the course learning outcomes (CLO). The CLOs are mapped to the respective programme learning outcomes (PLO). The project was designed according to the constructive alignment framework as shown in Table 1.

Project Objectives

This project centres on the truss structure topic, necessitating students to employ their comprehension of trusses to fulfil the project's objectives. The objectives of the project are for students to be able:

1. To draw and design the proposed 2D truss structure using AutoCAD software.
2. To fabricate and demonstrate the 2D truss structure.
3. To analyse the forces of the 2D truss structure.

The project consists of five (5) stages which are: (i) Sketch and design, (ii) AutoCAD drawing, (iii) Calculation, and (iv) Fabrication and finally (v) Demonstration. The flowchart of project activities is illustrated in Figure 1.

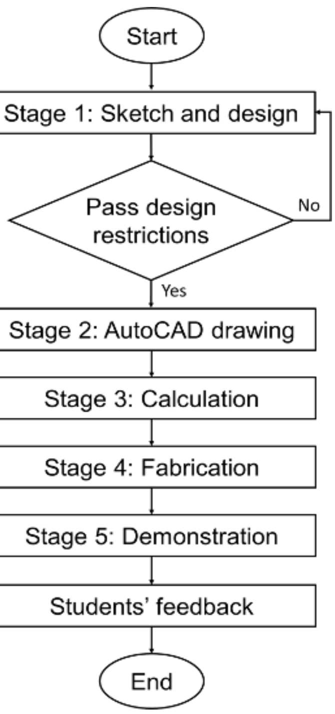

Figure 1. Flowchart of project activities

Design Restrictions

The design parameters for the truss structure encompass specific constraints:

1. The design should encompass a minimum of 5 and a maximum of 15 sticks.
2. Each truss member must not possess a double layer.
3. The alteration of a stick's length to form smaller truss parts is prohibited.
4. Creating a truss frame is disallowed; joining members exclusively occurs at the stick's end.
5. The truss structure's minimum horizontal distance (x-axis) must be 30 cm.
6. Deployment of solely one bolt and one nut per joint is stipulated.
7. Adhesive agents such as glue, paste, cello tape, nails, threads, or strings are strictly prohibited in securing or fastening joints.

The illustration of the five stages is shown in Figure 2. The scaffolding activities were provided throughout the project to support and guide students. Initial project instructions were given to outline the project execution. Sketches and drawings underwent validation based on design restrictions before proceeding to Stage 2. AutoCAD drawing activities were supervised by trained personnel to ensure accuracy and proficiency. Calculations were refined during class activities to reinforce learning. Lastly, the fabrication process was facilitated by technical staff in the workshop, ensuring students had the necessary support and resources to complete the project successfully.

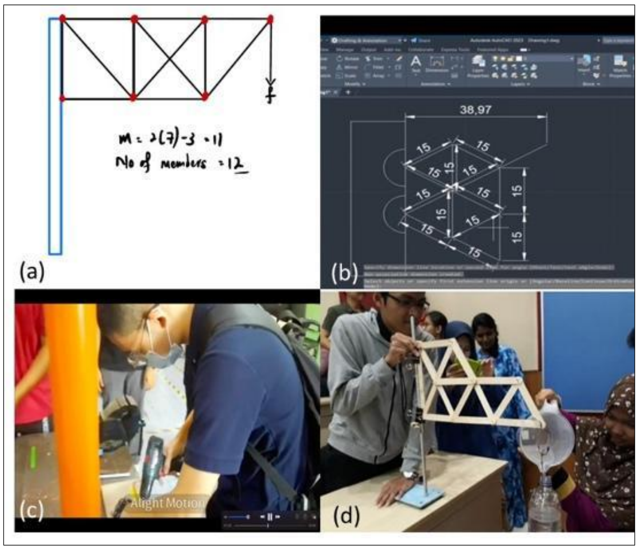

Figure 2. Stages of project activities

Assessment Method

The assessment methodology for the truss structure project is meticulously designed to ensure comprehensive evaluation of both the constructed structure and the group's collaborative efforts. The central criterion is the truss's capacity to sustain a minimum 0.5 kg load without failure, underscoring its functional integrity (Table 2). The rubric was crafted to evaluate two key criteria, making the assessment both comprehensive and engaging. First, it measured students' ability to apply theoretical knowledge to the project, focusing on creativity, structural design, and the loading capability of the trusses. Second, it assessed students' generic skills, particularly their teamwork abilities. This assessment process is documented through the creation of a comprehensive video, capturing all group activities from initial discussions to the final demonstration. Reports and videos must adhere to specified submission guidelines. A peer evaluation system operates at each project stage, underlining the importance of cooperative group dynamics. The culmination involves a live presentation in front of expert panels where the design is showcased, assembled, and tested. The assignment mandates a designated group member to record the demonstration.

Distinguished by their highest load-bearing capacity, each section's top performer will be awarded, with a "Best of the Best" accolade encompassing all sections. The project report entails a detailed account of the group's composition and roles, an introduction to the truss structure, comprehensive free-body diagrams, 2-D AutoCAD drawings, meticulous calculations, and references. The submission should adhere to specified guidelines and be channelled through the respective e-learning section. Incorporating multimedia, the video report mandates the use of original footage or images to construct a 5 to 10-minute montage. While adaptation from external sources is permissible, direct copying is restricted. This video, required in MP4 format within a maximum size of 450 MB, must comprise the list of members' tasks and chronicle the entire project process from discussions to final demonstration. Evaluator assessment hinges on a rubric encompassing Loading, Design, Demonstration, and Creativity criteria for both the structure and the video report. This meticulous evaluation process ensures a comprehensive assessment of students' efforts and their truss structure designs. A survey has been conducted using online Google Form to solicit feedback from students regarding the impact of the project on their learning outcomes.

Table 1. Constructive alignment framework of the project

Course Learning Outcome (CLO)	Stage of project activity	Program Learning Outcome (PLO)	Learning Activity	Assessment
Apply the free-body diagram for analysis of various equilibrium force systems (CLO2).	Stage 1 - 3	Engineering Knowledge: Apply knowledge of mathematics, natural science, computing and engineering fundamentals and chemical engineering to develop solutions to complex engineering problems (PLO1).	Calculate external and internal forces for all truss members.	Project report
Demonstrate truss design project to class audience (CLO4).	Stage 5	The Engineer and Society: Apply reasoning to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to professional engineering practice and solutions to complex engineering problems (PLO6).	In-class demonstration and competition	Strength of truss
Work in a team to propose a truss design (CLO5).	Stage 1 - 5	Individual and Teamwork**:** Function effectively as an individual, member or leader in diverse teams and in multi-disciplinary settings (PLO10).	Brainstorming, drawing, calculation, fabrication, and demonstration	Peer rating and observation during demonstration

Table 2. Project assessment rubrics

Area Assessed	Excellent (4)	Good (3)	Fair (2)	Poor (1)
Loading	Truss is able to support loads beyond 1.5 kg	Exceeds minimum loading requirement of 1kg (1-1.5 kg)	Supports minimum loading requirement (1 kg)	Cannot support minimum loading requirement (< 1 kg)
Design	Truss is well designed. All truss members and joints are neatly constructed	Comply with design requirement. Most parts are neatly constructed	Comply with design requirement. Some parts are neatly constructed	Did not comply with design specification (minimum horizontal length 30 cm & number of truss member 10 – 30). Presence of frame.
Demonstration	Every group member contributes to project material & demonstration	Most group member contributes to project material & demonstration	Few group members contribute to project material & demonstration	Only ONE member contributes to project material & demonstration
Creativity	Design is well thought off and very creative	Design has acceptable creativity	Design is presented with minimal creativity	Design has little creativity

Results and Discussion

Project output

In our endeavour to implement the PBL and foster innovative teaching and learning practices, creativity emerged as a cornerstone of our approach. Central to this was the design of the truss structure, which presented students with a specific set of specifications and limitations. While these constraints served as guiding principles, they also ignited the spark of creativity within our students. One of the defining features of our project was the flexibility it afforded students in designing their truss structures. Rather than prescribing rigid templates, we encouraged students to explore their imaginations and apply engineering principles to create unique solutions. This approach not only allowed for diverse truss designs but also gave students a sense of ownership and autonomy in their learning journey. To attract students' interest and empower them toward self-directed learning, we integrated elements that actively engaged their creativity. Our PBL practices included innovative learning activities, assessments, and materials meticulously crafted to foster problem-solving skills and critical thinking. For instance, students were tasked with designing truss structures capable of supporting specific loads, requiring them to apply theoretical knowledge in practical contexts (Figure 3). They had to think creatively, often reimagining traditional engineering concepts to meet project objectives. Furthermore, we incorporated hands-on activities such as truss construction and load testing, promoting active engagement and kinesthetics learning. These activities challenged students to think on their feet, make real-time adjustments, and apply creativity to optimize their designs. In addition to these broader methodologies, our project featured several specific examples that underscored our creative approach. Students were encouraged to develop novel joint configurations, experiment with materials, and explore innovative load distribution techniques. These instances not only enriched their understanding of truss design but also ignited their passion for engineering. our project's creative elements were woven throughout the teaching and learning process, from the initial design phase to the hands-on construction and testing. By offering flexibility, hands-on experiences, and a platform for inventive problem-solving, our PBL practices not only enriched the educational experience but also nurtured a culture of creativity, critical thinking, and self-directed learning among our students.

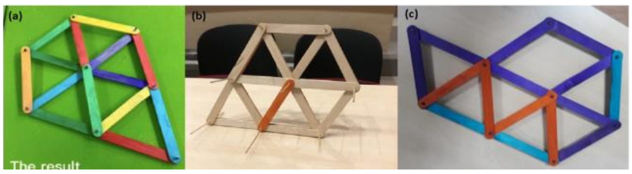

Figure 3. Actual truss designed by students

Students' feedback

A survey was conducted among 124 students enrolled in the Chemical Engineering program, who were taking the Statics course during the first semester of the 2022/2023 academic year, to gather insights into the project's outcomes. One of the survey questions pertained to the project's goal of integrating Education 4.0 / 21st Century 4C's Skills (Collaboration, Communication, Critical Thinking, Creativity) into students' learning experiences. Students were asked to rank their proficiency in these four skills after completing the project, using a scale from 1 to 5, indicating their level of agreement. Please note that 1 = Strongly Disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly Agree. The results (Figure 4a) showed that 96% of students provided a percentage agreement exceeding 80% for the collaboration element, 90.4% for communication, 91.2% for critical thinking, and 90.4% for creativity. The second statement posed to students was, "Please tick the following if you feel the Statics Project has helped to enhance your knowledge in these fields: 1. knowledge in designing basic truss structure, 2. knowledge in analysing truss structure, and 3. knowledge in creating montage videos." The findings (Figure 4b) demonstrated that 88.8% of students indicated an agreement percentage exceeding 80% for the enhancement of knowledge in designing basic truss structure, 96.8% for analysing truss structure, and 81.6% for creating montage videos.

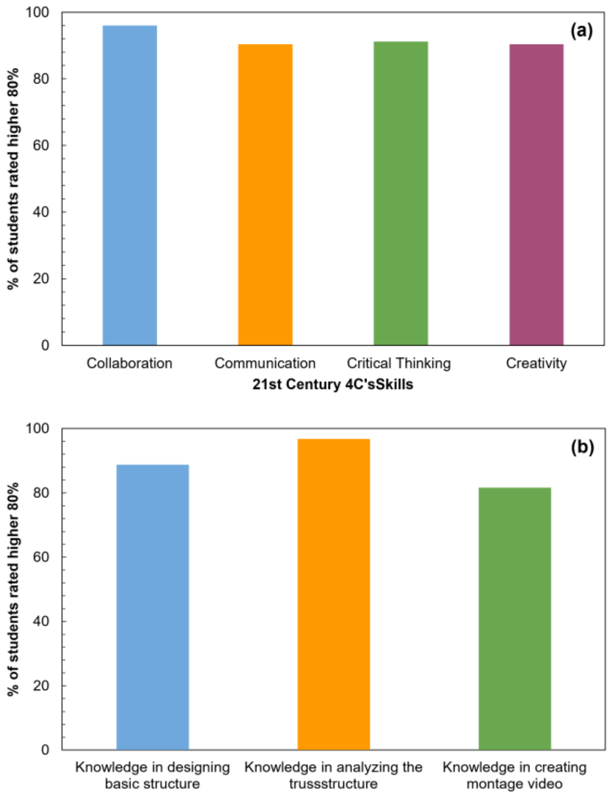

Figure 4. a) Students' experience on 21st Century 4C's Skills; b) Students' knowledge enhancement

Impact on students' learning experiences

Through the implementation of our innovative teaching and learning practices, we have witnessed profound impacts on students' learning experiences, with a focus on engagement and empowerment. One significant outcome has been the promotion of essential 21st-century 4C skills - Collaboration, Communication, Critical Thinking, and Creativity - among students. By working in collaborative teams throughout the project, students learn to effectively communicate ideas, engage in critical discussions, and foster a creative mindset to solve complex engineering challenges. This emphasis on 4C skills equips them with invaluable competencies required in their future careers (Kokotsaki et al, 2016). Our approach has nurtured a positive and strong relationship between students and lecturers. By encouraging open dialogue and close mentorship, we have created a supportive learning environment where students feel comfortable sharing their thoughts and seeking guidance. This personalized interaction has empowered students to take ownership of their learning and seek continuous improvement, fostering a sense of mutual respect and trust between students and faculty. Another remarkable impact has been the boosted confidence that students gain as they progress through the project. By actively engaging in the entire design process and witnessing their ideas materialize, students feel a sense of achievement and accomplishment (Chikkamath et al., 2016). This newfound confidence transcends the project and spills into other aspects of their academic journey and beyond. Lastly, our approach has led to a significant increase in students' engagement with the learning process. As they work on real-world projects with tangible outcomes, students become more invested in their education. The hands-on experience and practical relevance of the project foster a genuine interest in engineering and encourage students to explore beyond the classroom curriculum. Our innovative teaching and learning practices have a profound impact on students, emphasizing engagement and empowerment. By promoting 21st-century 4C skills, nurturing strong relationships, building confidence, and encouraging active involvement in the learning process, we have successfully created a transformative educational experience that prepares students for future challenges and opportunities.

Students' performance on truss knowledge

The PBL methodology grounded in experiential learning principles was implemented in both academic sessions 2022/2023-1 and 2023/2024-1. However, the PBL methodology was not executed during the academic session 2021/2022-1 due to Covid-19 pandemic. The truss structure project took place in the 2022/2023 academic session to enhance students' understanding and application of engineering principles. In the subsequent 2023/2024 session, the decision was made to focus on a different topic, specifically the Pappus-Guldinus theorem, to broaden students' exposure to various engineering concepts. This variation in project topics was intended to provide a diverse learning experience and align with curriculum objectives aimed at comprehensive skill development in engineering education.

Figure 5 illustrates the comparison of Program Learning Outcomes (PLOs) achievements for the academic sessions 2021/2022-1, 2022/2023-1, and 2023/2024-1. There were improvements in the achievement of PLOs 6 and 10 during the 2022/2023-1 and 2023/2024-1 sessions compared to 2021/2022-1. PLOs 1, 6 and 10 achievements were consistent in both academic sessions 2022/2023-1 and 2023/2024-1. The impact of implementing PBL approach, conducted only during the academic years 2022/2023-1 and 2023/2024-1, may have influenced the variations observed in PLO achievement. Notably, the average performance of students on truss structure questions during final examinations in the 2022/2023 session was 81% across all sections, contrasting with 75% in the 2023/2024 session. This disparity indirectly indicates the efficacy of the truss structure project in enhancing students' grasp of the subject matter.

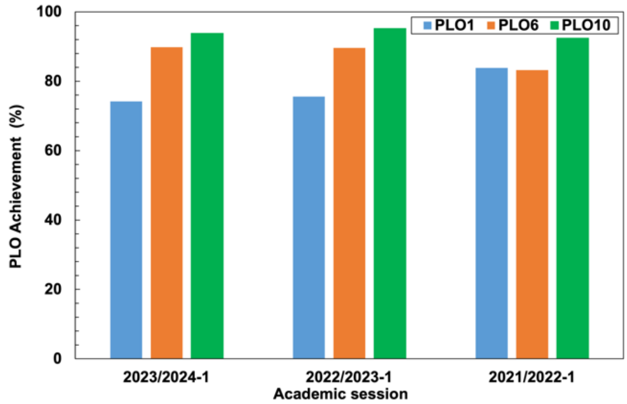

Figure 5. PLOs Achievement comparison

The fluctuations in PLO achievement across the three sessions suggest the influence of various instructional, curriculum, and possibly external factors. Further analysis is needed to understand the specific factors influencing PLO achievement and to determine the effectiveness of interventions such as the truss project. However, the data presented in the bar chart provides valuable insights into trends in PLO achievement across multiple academic sessions and highlights potential areas for further investigation and improvement.

Conclusion

In conclusion, this study underscores the successful implementation of an innovative and dynamic PBL methodology, rooted in experiential learning principles, in the teaching and learning activities of the Statics course for first-year Chemical Engineering students. Through our innovative methodologies, we contribute to the advancement of engineering education and ensure that our students are prepared to face the challenges of the future with confidence and creativity. The outcomes revealed a substantial positive impact on students' acquisition of 21st Century 4C skills, emphasizing collaboration, communication, critical thinking, and creativity. The project's efficacy in enhancing students' knowledge in designing and analysing truss structures, as well as creating montage videos, was evident from the robust survey findings. The transformative effects of this approach are not only confined to the technical realm but also extend to fostering a profound shift in the students' learning attitudes and abilities. This investigation signifies the potential of innovative pedagogical methodologies to enhance both practical engineering skills and holistic cognitive competencies, thereby charting a promising path for future engineering education initiatives.

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