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Connecting theory to application: A team-based project in principles of chemical engineering

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Abstract
First-year Chemical Engineering students often encounter significant difficulty in mastering Principles of Chemical Engineering or Material and Energy Balance subjects, core course in the curriculum. These courses heavily rely on theoretical frameworks and complex equations, which can be challenging to grasp when presented passively. Such issues lead to low engagement and unsatisfactory performance in assessments. Additionally, industry feedback highlights graduates' limited ability to apply theoretical knowledge in practical contexts, underscoring a gap in theory-to-practice integration in engineering education. In response, a new instructional method was introduced to foster active learning through team-based, hands-on projects. This approach leverages the Five Es Inquiry-Based Learning model, with a strong emphasis on exploration and employs Bloom's Taxonomy at advanced levels to encourage student-driven project design and implementation. A total of 81 students worked in teams to create prototypes using available materials, demonstrating key engineering principles through live presentations and detailed reports. Surveys showed that over 80% of students found this method enhanced their understanding, motivation, and ability to apply course concepts, with improved performance in exams reflecting the positive impact of this approach. This innovative teaching method holds substantial commercialization potential, aligning with goals in the Malaysia Education Blueprint 2015-2025 to enhance graduates' practical and theoretical competencies. In addition, it is scalable across institutions, equipping students with critical practical skills and problem-solving abilities essential for industry readiness and success.

Keywords: Team-based project, principles of chemical engineering, material and energy balance

1. Introduction

Principles of Chemical Engineering (CEB 1043) is created to provide the first year of undergraduate students with the fundamental of conservation of mass and energy. By the end of the course, students should be able to define and analyse conservation equations for various processes, interpret available data, and apply appropriate equations to determine flow rates, compositions, and temperatures within a process flow sheet. Additionally, students will gain competence in performing mass and energy balance calculations for specific processes. These learning outcomes align with program objectives, enabling students to apply knowledge in mathematics, science, and engineering fundamentals, as well as specialized engineering expertise, to solve complex chemical engineering problems. They will also develop skills in identifying, formulating, researching, and analysing complex engineering issues, arriving at substantiated conclusions using mathematical, scientific, and engineering principles. The course outcomes are structured to reflect Bloom's Taxonomy and the Structure of Observed Learning Outcome (SOLO) Taxonomy to ensure depth and rigor in learning.

The class activities are organized for twelve weeks including 2 hours of lecture and 2 hours of tutorial classes per week. The Principles of Chemical Engineering or Material and Energy Balance course is a foundational subject in the Chemical Engineering curriculum, typically introduced to first-year students. This course provides students with essential knowledge, focusing on the application of mathematics, science, and engineering principles. However, many students struggle to grasp the theoretical concepts and equations that underpin this discipline, leading to limited comprehension and engagement. Traditional lecture-based delivery methods often lack interactivity, which can disengage students—especially millennial learners who typically respond better to hands-on, interactive educational approaches. These factors contribute to poor student performance on assessments and, as reported by industry, graduates who are inadequately prepared to apply theoretical knowledge in real-world situations.

Previous research supports this shift toward active learning, highlighting that interactive teaching methods enhance students' understanding and retention of complex concepts. Studies by Prince (2004) [1] and Freeman *et al*., (2014) [2] show that active learning significantly improves student outcomes in STEM fields, while Johnson, D., Johnson, R. and Smith, K., (1998) [3] emphasize the benefits of collaborative learning environments, which can increase motivation and foster deeper engagement with course material. Specifically, for chemical engineering education, Felder and Brent (2009) [4] found that incorporating active, problem-based learning elements resulted in better student performance and a stronger grasp of engineering principles. Furthermore, Inquiry-Based Learning (IBL), as outlined by McDermott (1993) [5] has been shown to boost critical thinking skills, which are essential for solving real-world engineering problems.

In light of these insights, this course redesign incorporates team-based, practical projects to bridge the gap between theoretical learning and real-world application. By integrating the Five Es IBL model which emphasizes engagement, exploration, explanation, elaboration, and evaluation, the students participate in hands-on, interactive activities that are shown to enhance comprehension and retention. This approach also engages students in higher-level cognitive activities, as outlined by Bloom's Taxonomy, fostering an experiential learning environment that promotes active engagement, deeper understanding, and improved retention of core chemical engineering principles.

The goal of this instructional innovation is to create a more engaging, effective educational experience that better prepares students for real-world chemical engineering challenges by enhancing their problem-solving skills and understanding of fundamental principles. This project will serve as a model for integrating IBL in chemical engineering courses, contributing to the growing body of evidence on the effectiveness of experiential, inquiry-based learning in STEM education.

2. Methods and Materials

The project was implemented with 81 first-year Chemical Engineering students enrolled in the Principles of Chemical Engineering (CEB 1043) course. The instructional design aimed to promote experiential learning by engaging students in hands-on application of theoretical principles. The methodology followed four main stages including team formation, problem statement and identification, demonstration and report submission as well as peer assessment and survey.

2.1 Team Formation

Students were organized into teams of four to five members, creating a collaborative environment to encourage teamwork and idea exchange. Teams were formed with a mix of skill levels and backgrounds to ensure diverse perspectives, enhancing collaborative problem-solving and communication skills. Each student was assigned a specific role within their team such as project manager, safety officer, and design engineer, to mimic real-world engineering scenarios where multidisciplinary teamwork is essential.

2.2 Problem Statement and Identification: Each team was tasked with designing a working setup using recycled materials, grounded in the conservation laws of mass, energy, and momentum. The problem statement involved constructing a system that demonstrated these principles in a tangible way, challenging students to exercise creativity, engineering judgment, and resourcefulness by sourcing materials from their dormitories or homes. The students were required to analyze a specific engineering challenge, outline relevant conservation equations, and discuss how these principles applied to their chosen system design to ensure a comprehensive understanding of the theoretical framework. Furthermore, the students were provided with a series of preparatory exercises covering mass, energy, and momentum conservation topics. These exercises allowed students to practice applying theoretical concepts in practical contexts, ensuring a solid foundation as they moved toward project execution.

2.3 Demonstration and Report Submission

Upon completion of their projects, each team participated in a live demonstration and presentation session. During this 25 minute session, students showcased their setups and explained the chemical engineering principles and safety features integrated into their design. Each demonstration was followed by a 5-minute question-and-answer session, encouraging active engagement from both peers and instructors.

Following the demonstration, each team submitted a comprehensive report. This report included a schematic diagram of their setup illustrating components and flow paths, theoretical principles applied with clear descriptions of conservation laws utilized, detailed calculations and assumptions supporting their design, a cost analysis accounting for the materials used and budget constraints and hazard assessment identifying potential safety risks and measures to mitigate them. The reports were then evaluated on clarity, depth of analysis, and alignment with chemical engineering principles.

2.4 Peer Assessment and Survey

Peer assessments and anonymous surveys were conducted at the end of the project to capture feedback and encourage self-reflection. Each student evaluated their team members' contributions and teamwork, promoting accountability and highlighting areas for improvement. Additionally, the survey collected feedback on how the project impacted their understanding of course concepts, as well as their views on teamwork and project-based learning. The survey is conducted for 5 questions: (Q1) Team-based practical project motivates me to learn further about principles of chemical engineering and real applications (Q2) The practical project conducted increase my understanding in Principles of Chemical Engineering (Q3) The project activities help me to prepare for Test/Final Exam (Q4) I would like to see this type of activity in more of my courses (Q5) Experience in learning Principles of Chemical Engineering is fun and interesting. Data from the assessments and surveys provided valuable insights into the project's effectiveness, capturing student perceptions of how hands-on learning affected their engagement, comprehension, and confidence in applying chemical engineering principles. These insights were used to refine future course iterations, ensuring continuous improvement in instructional methods.

3. Findings

3.1 Student reflection survey

The analysis of student reflections from the survey on the team-based practical project is presented in Figure 1. According to these survey results, over 80% of students reported that the project significantly enhanced their understanding of key concepts in material and energy balances. This positive response highlights the impact of integrating practical, hands-on experiences into the course. Five specific questions were asked in the survey to capture various aspects of the project's impact on students' learning and engagement. The results for each question indicate strong support for the project-based approach.

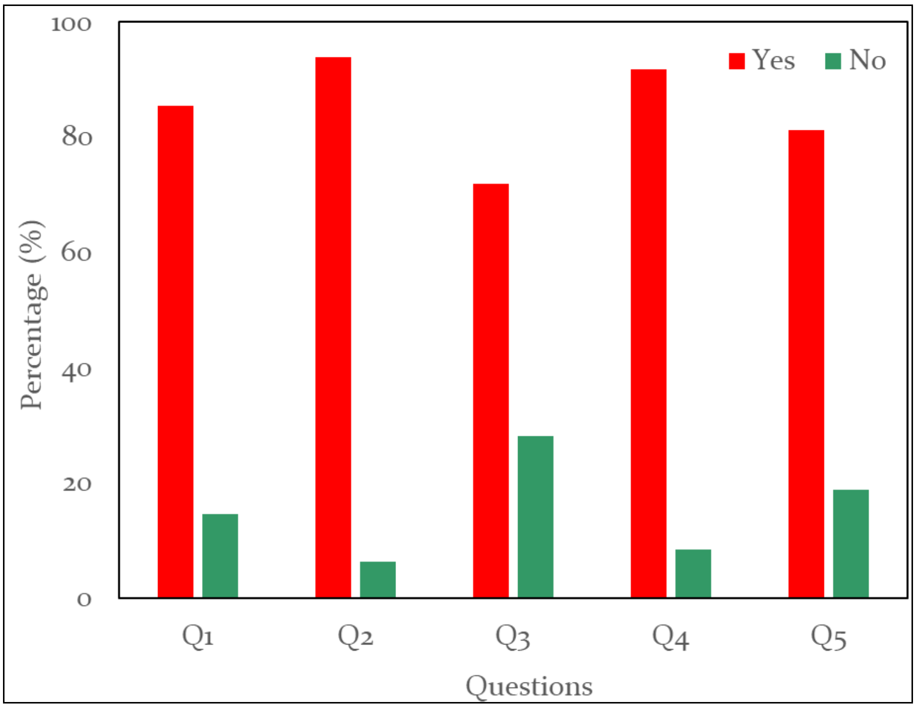

Fig 1: Analysis of student reflection survey on the learning activities

3.1.1 Motivation to Learn Chemical Engineering Principles

A large majority of students (85%) agreed or strongly agreed that the team-based practical project motivated them to delve deeper into chemical engineering principles and their real-world applications. Students indicated that working on a tangible project fostered a sense of curiosity, as they could see the relevance of theoretical concepts in everyday engineering challenges.

3.1.2 Increased Understanding of Core Concepts

Nearly 88% of students felt that their understanding of material and energy balance principles had improved through the hands-on project. This result suggests that interactive, applied learning activities can clarify complex theoretical concepts, making them more accessible and meaningful.

3.1.3 Preparation for Exams

Around 80% of students agreed that the project activities helped them prepare more effectively for tests and final exams. This finding indicates that practical application not only reinforces theoretical knowledge but also improves students' confidence and readiness for assessments, as they are better equipped to tackle problem-solving questions.

3.1.4 Interest in Similar Activities in Other Courses

Over 78% of students expressed interest in seeing similar project-based learning activities in other courses. This feedback highlights a desire among students for more interactive and applied learning approaches across the curriculum, as it aligns better with their learning preferences and enhances their engagement with the subject matter.

3.1.5 Enjoyment and Interest in Learning Chemical Engineering

Finally, 82% of students indicated that the practical project made learning principles of chemical engineering fun and interesting. This feedback suggests that experiential learning activities can foster a more positive attitude toward the subject, increasing student engagement and satisfaction.

3.2 Student performance in summative assessments

In addition to survey feedback, examination results showed a clear improvement in overall academic outcomes compared to the previous semester as shown in Figure 2.

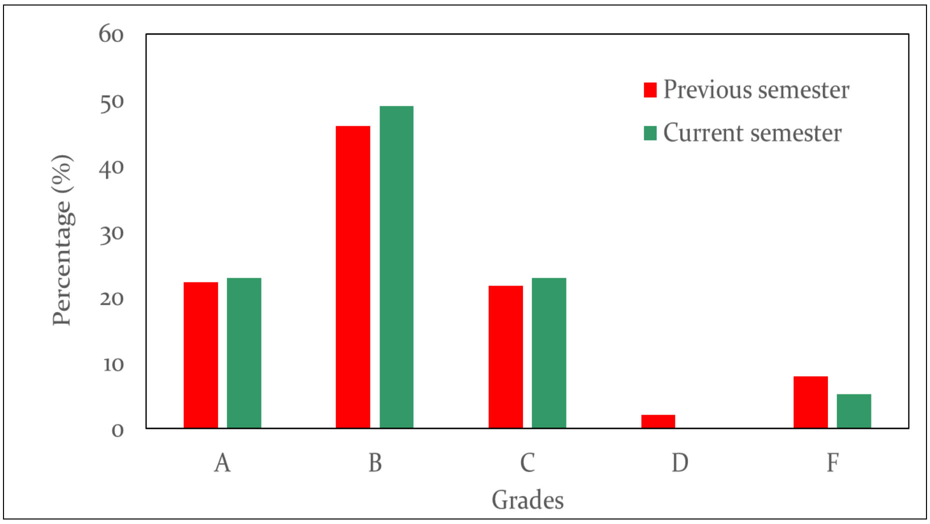

Fig 2: Analysis of student performance in summative assessments

A comparative analysis of course performance data with the previous semester underscores the effectiveness of this approach. The percentage of students scoring an A increased from 22.22% in the previous semester to 22.92%, while those achieving B rose from 46.03% to 49%. Students receiving grade C also showed a slight increase from 21.69% to 22.9%. Notably, there was a significant reduction in lower grades, with the percentage of students scoring grade D decreasing from 2.11% to 0% and the failure rate dropping from 7.94% to 5.2%. This positive shift in grade distribution indicates that incorporating hands-on projects not only enhances engagement but also translates to measurable academic improvements.

4. Discussions

The survey results illustrate that the team-based, practical project had a marked positive impact on students' engagement and understanding. The hands-on nature of the project allowed students to experience how theoretical concepts translate into practical engineering applications, bridging the gap that often exists between academic learning and real-world scenarios. Additionally, the collaborative environment promoted teamwork and communication skills, which are essential for success in the engineering field.

These findings align with prior research on active learning and cooperative learning in STEM education, which consistently show that students benefit from engaging in experiential, project-based activities [1, 2]. The positive response to incorporating teamwork and practical challenges in the learning process reinforces the value of interactive approaches, as seen in Johnson *et al.* [3], which emphasize that collaborative problem-solving can lead to enhanced student motivation and retention of material.

Furthermore, the enthusiasm for implementing similar projects in other courses suggests that students recognize the value of practical, applied learning approaches as a means to deepen their comprehension. This feedback supports a potential shift toward a curriculum that includes more team-based projects, which could cultivate an innovative and active learning environment across various chemical engineering topics. Overall, the survey responses affirm the effectiveness of the team-based practical project in achieving course learning outcomes, preparing students not only for exams but also for future real-world applications. Future studies could explore further optimization of project parameters to cater to diverse learning styles and maximize engagement and comprehension across the student cohort.

In addition, the improved distribution of grades highlights the project's positive impact on student performance. The increase in A and B grades, combined with the decrease in D grades and failure rates, demonstrates that this approach effectively supports students across varying academic abilities. By providing an engaging and collaborative learning environment, the project encourages students to achieve their best potential. This shift also aligns with industry feedback, where the ability to apply theoretical knowledge to real-world situations is a critical competency for engineering graduate.

5. Conclusion

This innovative approach highlights the potential of team-based projects to improve educational outcomes in chemical engineering courses. Emphasizing practical, hands-on experiences alongside theoretical learning fosters creativity, deepens comprehension, and cultivates essential technical skills. Given the positive feedback from students and improvements in assessment outcomes, this approach aligns with the Malaysia Education Blueprint's objectives to enhance graduate marketability by preparing students with fundamental knowledge and practical expertise, contributing to the advancement of engineering education.

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