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Project-Based Learning through Web-Based Simulations: Evaluating Learning Outcomes in a Design of Engineering Experiments Course

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ABSTRACT

This study investigated the integration of project-based learning (PBL) and web-based simulations (WBS) in a design of experiments course involving industrial engineering (IE) and mechanical engineering (ME) students. Among 127 enrolled students, 75 valid questionnaire responses were obtained. Students conducted experiments using either a paper helicopter or parachute simulation, followed by data analysis, engineering decision-making, and technical communication. Descriptive statistics and Welch's independent-samples t-test were used to examine perceptions and compare learning outcomes. Both simulations were favorably evaluated, with the parachute simulation receiving the highest ratings. Although IE and ME students differed significantly in pre-project learning outcomes, no significant difference was found after the project. These findings highlight the potential of PBL and WBS to support interdisciplinary, collaborative, and ABET-aligned engineering education.

Keywords: design of experiments, interdisciplinary learning, outcome-based education, project-based learning, web-based simulations

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INTRODUCTION

Project-based learning (PBL) is an experiential and active-learning approach in which students engage in authentic projects that require them to apply disciplinary knowledge to practical problems. In engineering education, PBL can bridge theoretical learning and professional practice by engaging students in inquiry,

critical thinking, problem-solving, collaboration, and decision-making. Previous research indicates that PBL supports both cognitive and professional development, including disciplinary understanding, practical engineering skills, teamwork, and the application of technical knowledge in authentic contexts (Wickramasinghe & Appiah, 2026; Santhosh et al., 2023; Guo et al., 2020; Pérez-Rodríguez et al., 2022; Ruslan et al., 2021; Yang et al., 2021; Pawar et al., 2020; Yadav et al., 2011; Dutson et al., 1997). Interdisciplinary project-based learning can also engage students in authentic, technology-supported challenges that foster critical thinking and problem-solving across disciplinary boundaries (Li et al., 2023). Research on innovative instructional approaches in higher education further illustrates how PBL can be integrated with other student-centered methods to support learning-related outcomes and skill development (Chu & Takahashi, 2024). Collectively, these findings position PBL as a pedagogical framework that supports the concurrent development of cognitive learning and professional competencies, particularly in contexts requiring experimentation, data analysis, collaborative problem-solving, and engineering decision-making.

The relevance of PBL to outcome-based engineering education is further supported by its alignment with competency-oriented assessment. Shafi et al. (2019) highlighted the role of student-outcome assessment and course mapping in supporting ABET accreditation and continuous curriculum improvement. Mills & Treagust (2003) and Prince & Felder (2006) similarly emphasized that project-based, active, and inductive approaches can connect theoretical knowledge with authentic engineering practice while supporting engagement, critical thinking, and professional skill development. Thus, PBL provides an appropriate pedagogical foundation for learning environments in which engineering competencies are developed through authentic tasks rather than through conceptual instruction alone.

Web-based simulation (WBS) can complement this pedagogical foundation by providing an accessible environment for experimentation and application. WBS enables students to design and perform virtual experiments without some of the resource, equipment, and scheduling constraints associated with physical laboratories (Calfa et al., 2017; Chen, 2009). When incorporated into project-based activities, simulation can further connect theoretical concepts with practical engineering applications and provide opportunities for repeated experimentation, observation, and data-based learning (Salazar-Peña et al., 2023; Beneroso & Robinson, 2022; Chua & Islam, 2020). Recent research further demonstrates how simulation-driven project-based learning can integrate engineering design, iterative testing, and competency-oriented assessment within an engineering curriculum (Hegedűs, 2026). In a design of experiments (DOE) context, these affordances are particularly relevant because students must formulate experimental factors, conduct repeated trials, analyze data, interpret results, and make evidence-based engineering decisions. Saikaew (2022), for example, reported that web-based virtual learning materials supported motivation and engagement in DOE project activities by enabling students to apply DOE techniques to practical situations.

Although PBL and simulation-based learning have individually demonstrated educational value, their roles are conceptually different. PBL provides the pedagogical process through which students formulate problems, collaborate, investigate, analyze evidence, make decisions, and communicate solutions, whereas WBS provides the technological environment through which experimentation and iterative data collection can be conducted. This distinction suggests that the two approaches can be complementary rather than redundant. Their integration aligns with ABET student outcomes related to engineering problem-solving, design, communication, teamwork, experimentation and data analysis, and lifelong learning (ABET, 2025), underscoring their relevance to engineering education (Bashir, 2026). Accordingly, ABET provides a competency-oriented framework for examining whether the learning activities supported by the PBL-WBS approach correspond to broader engineering education outcomes.

However, the existing literature has generally examined PBL and simulation-based learning as separate instructional approaches or has focused on individual outcomes such as engagement, conceptual learning, or virtual laboratory use. Comparatively less attention has been given to their systematic integration within a DOE course in which students use simulation to conduct experiments as part of a structured PBL process and subsequently apply statistical analysis and engineering decision-making.

Furthermore, limited research has explicitly connected this integrated learning process with ABET-oriented competencies across students from different engineering disciplines. This gap is important because an instructional approach that combines PBL and WBS should be evaluated not only in terms of students' perceptions or conceptual learning, but also in relation to how the learning activities connect experimentation, statistical analysis, collaboration, communication, and engineering decision-making.

Based on this conceptualization, the present study proposes an instructional framework in which PBL and WBS serve complementary roles within a DOE course. PBL provides the student-centered learning process, while WBS provides a technology-supported environment for engineering experimentation. These components are aligned with ABET-oriented competencies, integrating pedagogy, technology, disciplinary application, and competency development within a unified instructional framework.

Accordingly, this study aims to (1) develop and implement the proposed PBL-WBS instructional framework in a DOE course, (2) examine students' learning outcomes and perceptions of the simulation-supported learning activities using descriptive and inferential statistical analyses, and (3) compare the learning outcomes and perceptions of IE and ME students to examine the applicability of the framework across different engineering disciplines.

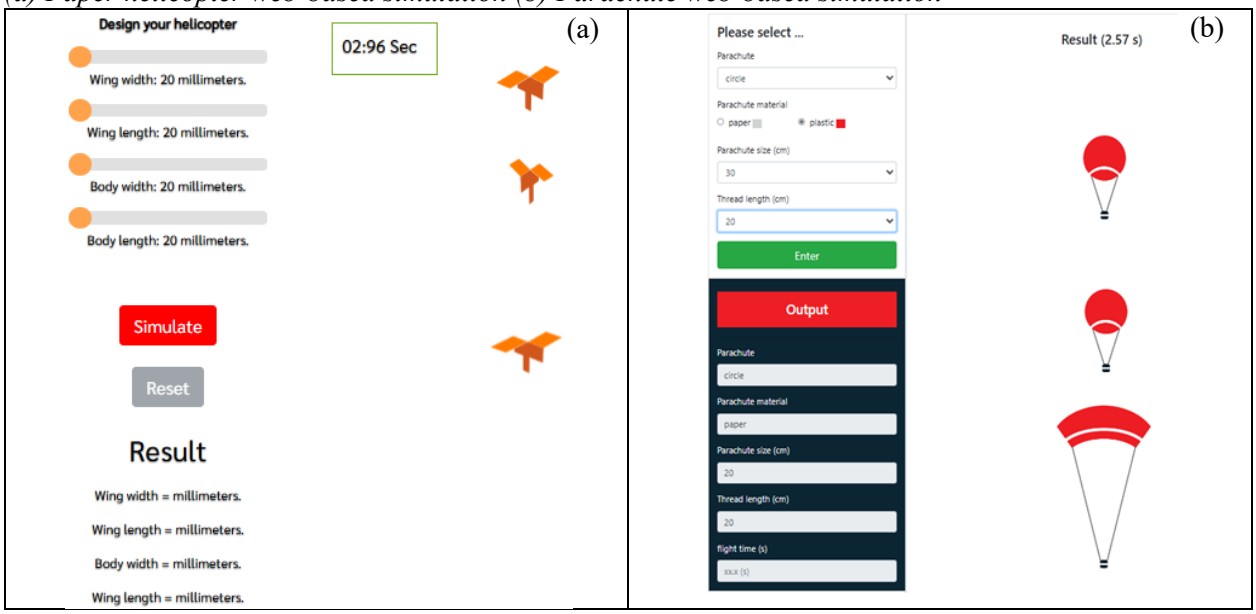
RESEARCH METHOD

PBL-WBS Learning Activities and Experimental Procedure

The study involved undergraduate students enrolled in the DOE course, comprising 53 IE students and 74 ME students. Students worked collaboratively in groups of approximately five members and completed a project-based learning activity supported by WBS. Each group selected one of two web-based simulations, namely the paper helicopter simulation or the parachute simulation, as shown in Figure 1.

Figure 1

(a) Paper helicopter web-based simulation (b) Parachute web-based simulation



Note. thinnaphats.github.io/pre-project/simulation-en.html

Note. https://kanda.in.th/simulation/index.html

Both web-based simulations were developed and implemented by the authors. Each group of students conducted brainstorming sessions to select one factor with at least three levels for the previously

chosen WBS. They then performed experiments to collect data. For example, if the group selected the paper helicopter, they might choose wing length as the factor, with varying levels of 20 mm, 60 mm, and 100 mm. The group then measured flight duration as the response at each factor level, repeating the experiment 4-5 times per level to obtain the experimental data. The students analyzed the collected data using analysis of variance to determine the effect of the selected factor on the response. This was accomplished through calculations performed using a calculator and software tools such as Microsoft® Excel or Minitab®. Additionally, they compared the average responses across factor levels using multiple comparison methods such as the least significant difference method, Tukey's test, Duncan's multiple range test, and the Newman-Keuls method. Based on the results from one of the multiple comparison methods, the students brainstormed to select the appropriate factor level by considering the optimal response and the lowest production cost for the selected simulation, assuming real-world production conditions.

The students prepared a report and presented their findings to the class. The instructor provided feedback, recommendations, and grades. A questionnaire was then distributed to all students, asking them to indicate their preference for a particular WBS using a Likert scale (1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, and 5 = strongly agree). The students also responded to questions about how their perceptions differed before and after completing the project, also using a Likert scale. All descriptive and inferential statistical analyses were conducted using the valid questionnaire responses.

Instructional Alignment with ABET Student Outcomes

Table 1 summarizes the proposed alignment between the course activities and the ABET Student Outcomes addressed in this study (ABET, 2025). The instructional activities closely align with ABET outcomes related to experimentation, teamwork, communication, and engineering problem-solving. Students conducted experiments, analyzed and interpreted data, presented technical findings, and collaborated to make engineering decisions. These activities reflect the competencies expected in internationally accredited engineering programs and demonstrate the potential of simulation-supported PBL for outcome-based engineering education. Specifically, SO1 refers to the ability to identify and solve complex engineering problems, while SO2 focuses on applying engineering design under realistic constraints. SO3 emphasizes effective communication, SO5 relates to teamwork and leadership, SO6 concerns experimentation and data analysis, and SO7 involves acquiring and applying new knowledge through appropriate learning strategies.

Table 1

The alignment between the course activities and specific ABET Student Outcomes (SO1-SO7)

Course activity	ABET Outcome
Conducting designed experiments, analyzing and interpreting data, drawing conclusion	SO1, SO6
Group presentations	SO3
Team collaboration	SO5
Selecting the appropriate operating condition of the significant factors	SO2
Independent problem solving using WBS	SO7

Statistical Analysis

Descriptive statistics, including the mean and standard deviation, were used to summarize students' learning-outcome scores for the IE and ME groups. Based on the research objectives, two hypotheses were formulated for inferential statistical analysis:

H_1: Pre-project learning-outcome scores differ significantly between IE and ME students.

H_2: Post-project learning-outcome scores differ significantly between IE and ME students.

To test H_1 and H_2, Welch's independent-samples *t*-test was employed separately for the pre-project and post-project scores. Welch's *t*-test was selected because it does not require the assumption of equal population variances and is appropriate for comparing independent groups with unequal sample sizes and potentially heterogeneous variances (Du et al., 2026). Two-tailed tests were used because the hypotheses concerned whether the learning-outcome scores differed between IE and ME students without specifying a priori which group would have higher scores. For each comparison, the mean difference between the IE and ME groups, Welch's *t*-statistic, Welch-Satterthwaite degrees of freedom (df), and two-tailed *p*-value were calculated. A significance level of 0.05 was adopted for all inferential tests. The magnitude of the between-group difference was additionally evaluated using Cohen's (*d*), with absolute values of approximately 0.20, 0.50, and 0.80 interpreted as small, moderate, and large effects, respectively. Statistical conclusions were based on the *p*-value together with the magnitude and direction of the effect size.

RESULTS AND DISCUSSION

Descriptive Results

The questionnaire was distributed to all 127 enrolled students. However, only 75 valid responses were included in the analysis., comprising 42 responses from IE students and 33 responses from ME students. Figures 2 and 3 and Table 2 summarize students' evaluations of the two web-based simulations (WBS). Overall, both simulations received favorable ratings, with mean scores ranging from 3.76 to 4.24 on the five-point scale. Across both departments, the parachute simulation received higher mean ratings than the paper helicopter simulation. ME students generally reported higher ratings than IE students for both simulations and also showed a higher proportion of maximum ratings (score = 5).

Figure 2

Students' preferences of WBS applied in PBL for IE students (a) paper helicopter (b) parachute

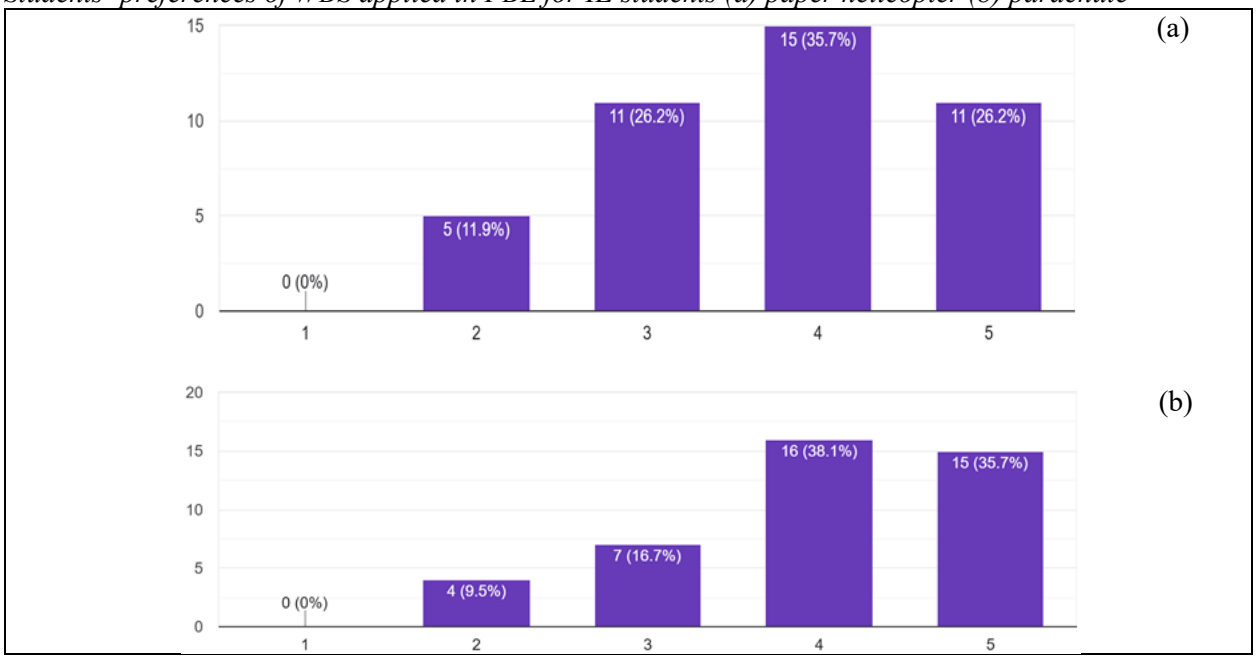
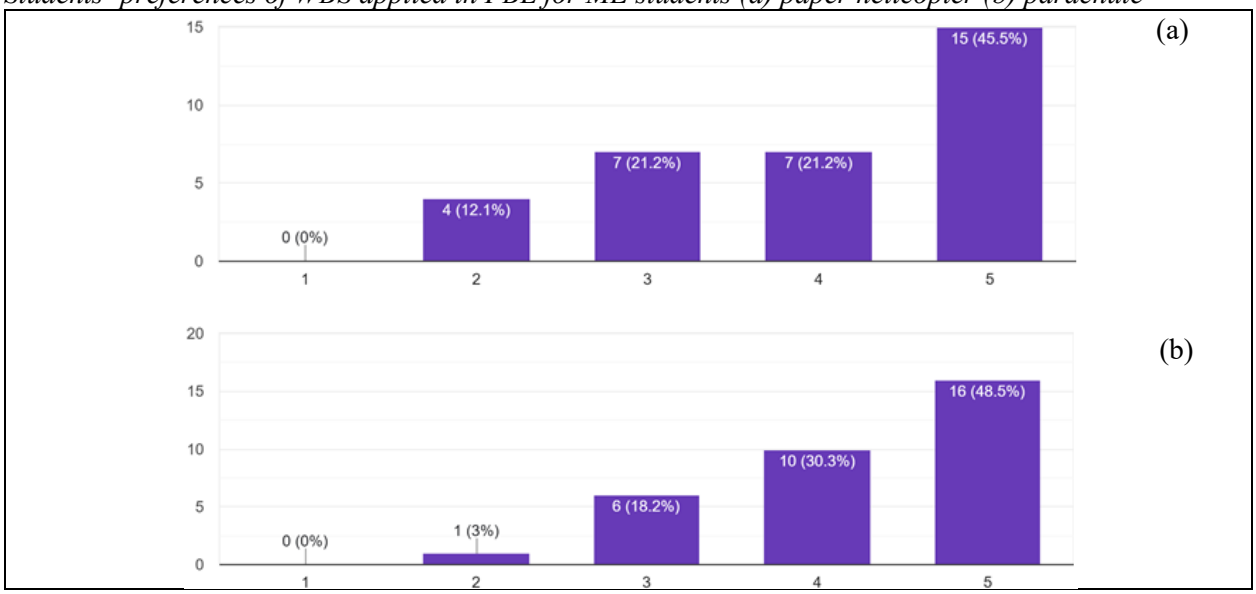


Figure 3

Students' preferences of WBS applied in PBL for ME students (a) paper helicopter (b) parachute



For IE students, the mean rating increased from 3.76 (SD = 0.97) for the paper helicopter simulation to 4.00 (SD = 0.95) for the parachute simulation. Among ME students, the corresponding means were 4.00 (SD = 1.07) and 4.24 (SD = 0.85), respectively. The paper helicopter simulation exhibited greater response variability among ME students than IE students, whereas the parachute simulation showed slightly lower variability among ME students. These results indicate that the parachute simulation was not only more highly rated but also generated relatively consistent evaluations across the two groups.

Table 2

Students' preferences of WBS applied in PBL for ME and IE students

	IE		ME	
	Paper helicopter	Parachute	Paper helicopter	Parachute
Mean	3.76	4.00	4.00	4.24
Standard deviation (SD)	0.97	0.95	1.07	0.85

Figures 4 and 5 and Table 3 present the descriptive distributions of learning-outcome scores before and after the PBL-WBS activities. IE students' mean score increased from 1.86 (SD = 0.46) before the project to 3.86 (SD = 0.64) after the project, representing an increase of 2.00 points. The post-project distribution was concentrated at higher achievement levels, with 57.1% of students achieving level 4, 28.6% achieving level 3, and 14.3% achieving level 5; no students remained at levels 1 or 2.

ME students showed a similar descriptive pattern, with the mean score increasing from 2.39 (SD = 1.11) before the project to 4.03 (SD = 0.79) after the project, an increase of 1.64 points. The reduction in standard deviation from 1.11 to 0.79 also indicates lower score variability after the project. Most students in both groups achieved level 4 in the post-project assessment, while the proportion achieving level 5 was higher among ME students (24.2%) than IE students (14.3%).

Overall, the descriptive results indicate positive changes in learning-outcome scores in both groups, with IE students showing a larger absolute increase in the mean score and ME students achieving a slightly higher post-project mean and lower score variability.

Figure 4

Learning outcomes for IE students (a) before and (b) after implementing PBL using WBS

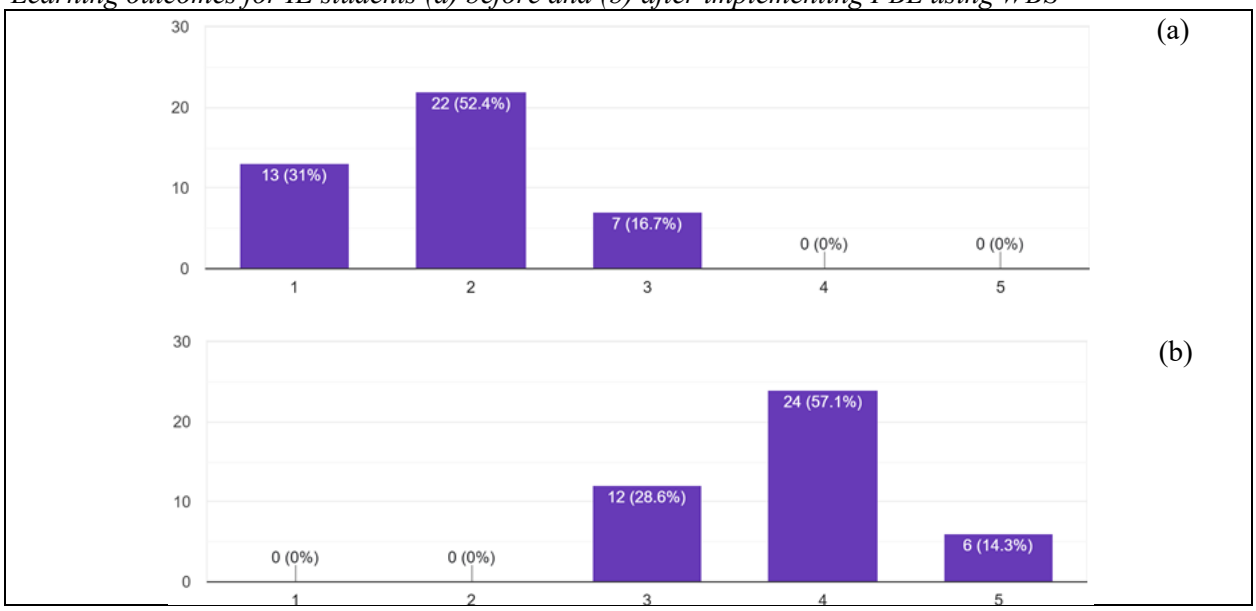


Figure 5

Learning outcomes for ME students (a) before and (b) after implementing PBL using WBS

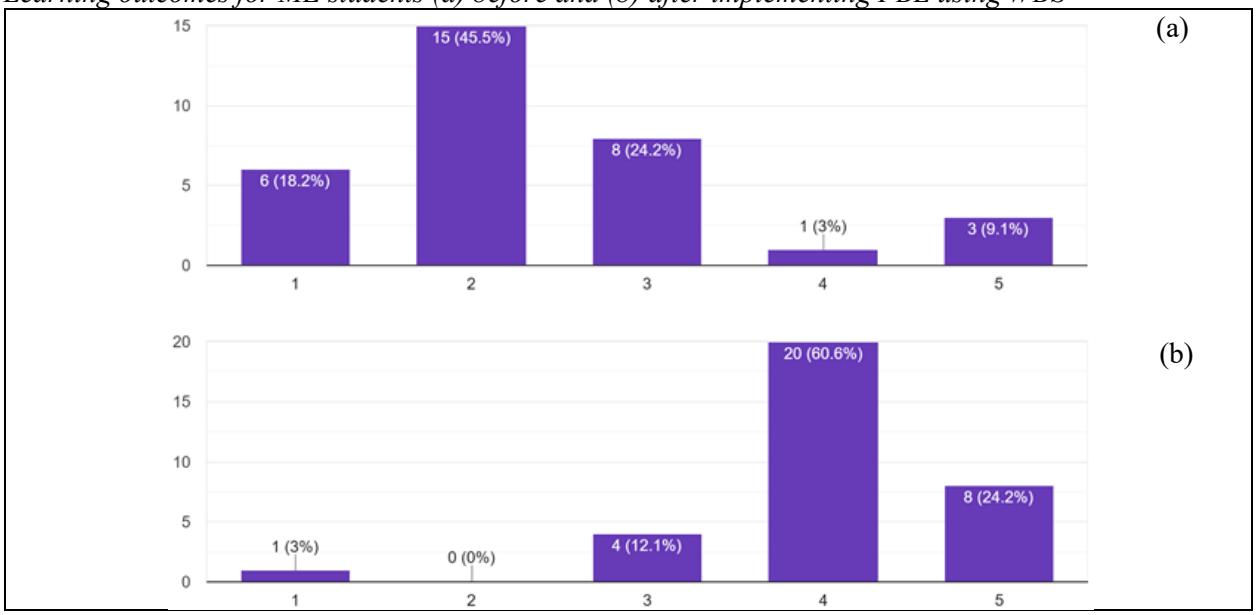


Table 3

Learning outcomes for IE and ME students before and after implementing PBL using WBS

	IE		ME	
	Before	After	Before	After
Mean	1.86	3.86	2.39	4.03
Standard deviation (SD)	0.46	0.64	1.11	0.79

Inferential Results

Table 4 presents the inferential comparison of learning-outcome scores between IE and ME students. The pre-project analysis revealed a statistically significant difference between the two groups, (p = 0.014), with a moderate-to-large standardized effect size ($|d|$=0.66). ME students obtained a higher pre-project mean score than IE students, corresponding to a mean difference of −0.53 points (IE − ME). These findings provide evidence in support of H_1, indicating that the two groups differed significantly in their learning-outcome scores prior to the project.

Table 4

Inferential comparison of IE and ME learning outcomes

Outcome	IE Mean ± SD	ME Mean ± SD	Mean difference	Welch's t-statistic	df	p-value	Effect size (d)
Pre-project	1.86 ± 0.46	2.39 ± 1.11	−0.53	−2.57	40.65	0.014	−0.66
Post-project	3.86 ± 0.64	4.03 ± 0.79	−0.17	−1.00	60.84	0.319	−0.24

For the post-project scores, the analysis showed no statistically significant difference between IE and ME students, (p = 0.319), with a small standardized effect size ($|d|$=0.24). Although ME students achieved a slightly higher post-project mean score than IE students, the mean difference of −0.17 points (IE − ME) was not statistically significant. Therefore, the results did not provide sufficient evidence to support H_2.

The findings also suggest that post-project learning outcomes were relatively comparable across the two engineering disciplines. Although the baseline analysis indicated a moderate-to-large difference between the groups, the post-project effect size was small. This reduction is noteworthy in interdisciplinary engineering education because the PBL-WBS activities required students to engage in shared processes of experimentation, data analysis, interpretation, communication, and engineering decision-making. Such common learning experiences may help mitigate differences associated with students' prior academic preparation. This may partly reflect differences in statistical background, as IE students had studied statistics two years earlier whereas ME students had not previously taken statistics. To address this gap, the instructor provided a statistics lecture in the DOE course, which may have helped narrow the initial difference. Nevertheless, this interpretation should be viewed as a plausible educational explanation rather than evidence of causality, because the present analysis did not include a control group.

Survey Results on Students' Perceptions of WBS and PBL

To examine students' perceptions of PBL supported by WBS, students completed a course questionnaire both before and after undertaking the project. The feedback included the following items:

For IE students: "I was able to gain deeper knowledge and understanding of the content through collaborative learning with my group members.", "Some problems encountered and learned to solve independently while working on the project will lead to a deeper understanding of the content compared to simply reading slides or listening to lectures.", "I could learn to conduct experiments and apply knowledge in practice.", "I was able to learn how to work as part of a team and apply knowledge to practical experiments.", and "I contributed to analyzing the experimental results and identifying the most appropriate outcomes for the experiment.".

For ME students: "I gained a deeper understanding of data analysis.", "I gained an understanding of the differences in results from the same experiment using identical materials but varying structures, which can be explained by natural principles. I also shared knowledge with my team members to ensure the success of the project.", "Teamwork is extremely important, and task division is equally essential. Let each person focus on what they do best. I've come to truly understand this now.", "It helped deepen my

understanding of the lesson.", and "I learned how to determine the optimal value using the least significant difference method, Tukey's test, Duncan's multiple range test, and the Newman method. These techniques help identify the most efficient values to reduce production costs.".

Figure 6

Development of IE and ME engineering students' learning skills through the PBL using the WBS approach in the DOE course

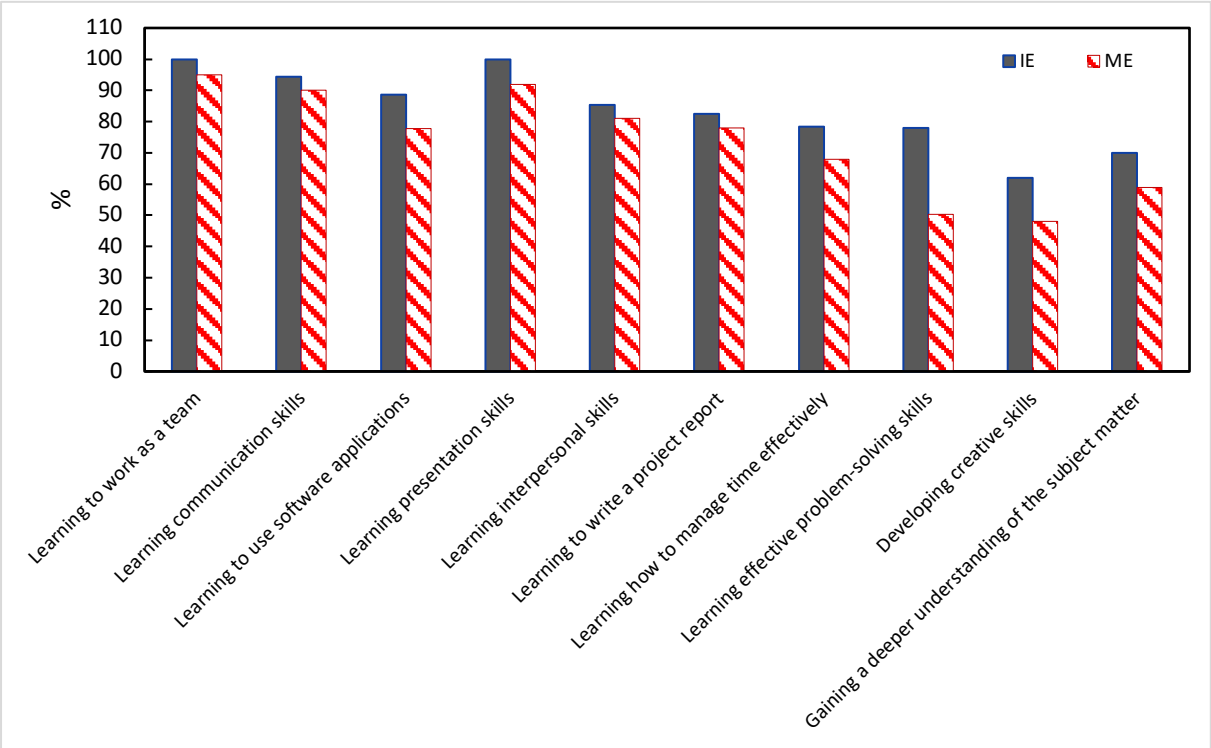


Figure 6 illustrates the development of learning skills among IE and ME students following the implementation of PBL supported by WBS in the DOE course. The data were obtained from a post-course questionnaire in which students identified the skills they perceived to have improved during the learning activities. The results indicate that all IE students (100%) reported improvement in teamwork and presentation skills, suggesting that the instructional activities effectively supported collaboration and communication competencies. Students highlighted that group discussions, collaborative tasks, and technical presentations enhanced their ability to exchange ideas, coordinate within teams, and communicate technical information effectively. The development of communication competencies is also an important consideration in engineering education, where digital learning environments can provide structured opportunities to strengthen students' communication skills (Saienko & Bogdan, 2026). Research on collaborative projects highlights the relationships among teacher and peer feedback, students' perceived quality of their work, psychological ownership, and perceived learning outcomes (Chan et al., 2026). These findings highlight the potential of integrating WBS with PBL to provide opportunities for students to practice technical communication alongside experimentation and data analysis.

In contrast, creative thinking received the lowest ratings, with only 62% of IE students and 48.1% of ME students reporting improvement in this area. This finding suggests that although PBL through WBS effectively promotes structured collaboration and analytical learning, the current implementation may provide limited opportunities for open-ended innovation and design-oriented problem-solving. Future course development may therefore benefit from incorporating more exploratory and hands-on project

activities that encourage students to independently design and develop project materials beyond simulation-based tasks.

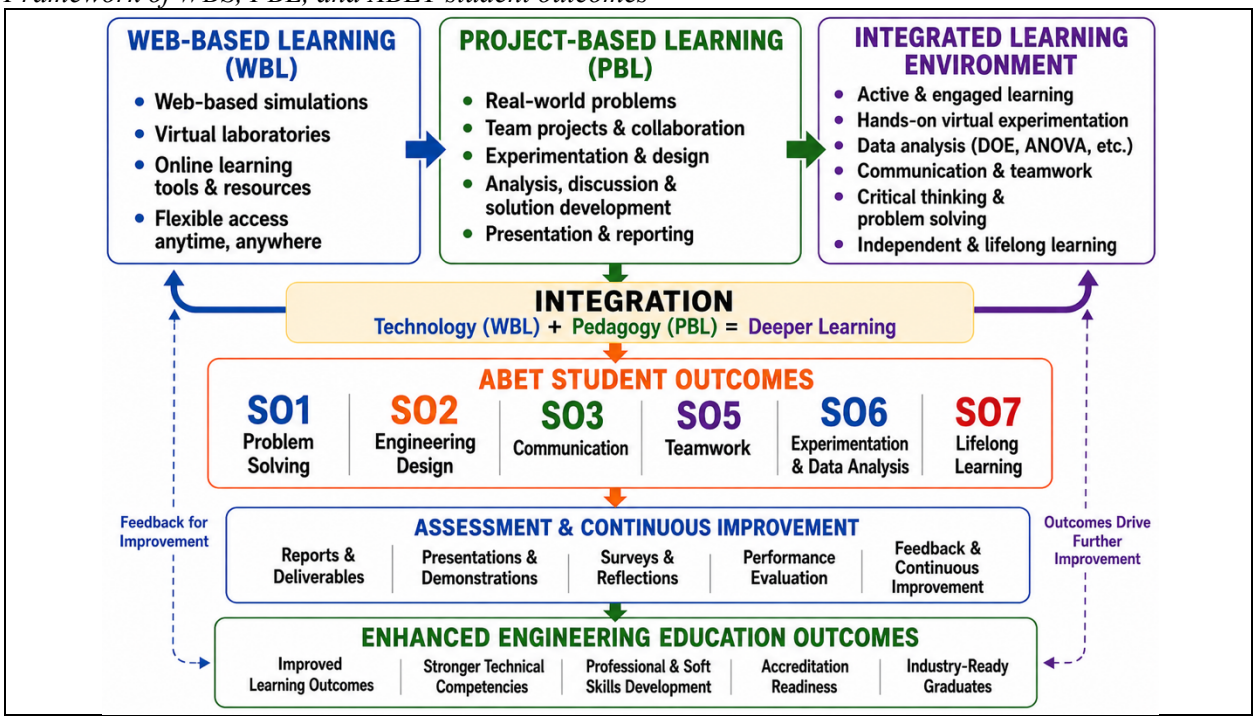
The findings further indicate the development of competencies associated with outcome-based engineering education, including teamwork, communication, experimental analysis, and independent learning. Students' reflections suggest that simulation-supported PBL can support both technical and professional skill development through collaborative and experiential learning activities. These competencies are widely recognized as essential components of modern engineering education and are closely aligned with ABET-related engineering competencies.

IMPLICATIONS

Figure 7 presents a conceptual framework that integrates WBS, PBL, and ABET-oriented engineering competencies within a DOE course. It shows how simulation-supported PBL can combine experimentation, statistical analysis, engineering decision-making, teamwork, communication, and problem-solving in an outcome-based learning process. The reduction in between-group differences further suggests the value of using multiple assessments, such as reports, presentations, reflections, surveys, and performance evaluations, to track student learning and inform instructional improvement.

Figure 7

Framework of WBS, PBL, and ABET student outcomes



From an educational perspective, the framework highlights the potential of integrating WBS with PBL to create a common, flexible learning environment for students from different engineering disciplines. It enables authentic experimentation, statistical data analysis, collaborative decision-making, and technical communication, while supporting competencies aligned with ABET-oriented outcome-based education. As a result, the framework serves as a practical model for incorporating simulation-supported experiential learning into DOE and related engineering courses.

CONCLUSIONS

This study examined the effectiveness of integrating PBL with WBS in a DOE course for IE and ME students. Simulation-supported PBL was positively perceived, and the parachute simulation received the highest ratings in both programs. Inferential analysis showed that, although IE and ME students differed significantly in pre-project learning outcomes, no significant difference remained after the PBL-WBS activities. These results suggest that the approach may support comparable learning outcomes across engineering disciplines while enhancing student engagement, experiential learning, and competency development.

The study contributes to engineering education by proposing and evaluating an instructional framework that integrates PBL, WBS, and DOE within an ABET-aligned outcome-based education context. It also highlights web-based simulations as a useful tool for supporting competency-based assessment and accreditation-oriented instructional practice.

Several limitations should be noted. The study used a pre-post design without a control group, so causal conclusions cannot be drawn. Student perceptions were measured through self-reported questionnaires, which may be subject to response bias. In addition, the study was conducted in a single DOE course at one institution with IE and ME students, which limits generalizability**.**

Future research should validate the framework with larger and more diverse samples from multiple institutions. Studies using control or comparison groups and objective learning measures would provide stronger evidence of effectiveness. Further work should also examine long-term outcomes and the influence of simulation design features on student engagement and learning across engineering disciplines.

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