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ORIGINAL

Integrating Professional Standards into Project-Based Learning: Evaluating an Innovative Model for Water Engineering Education in Indonesia

Integración de los Estándares Profesionales en el Aprendizaje Basado en Proyectos: Evaluación de un Modelo Innovador para la Educación en Ingeniería del Agua en Indonesia

Melda Fajra[1,2], Ambiyar[3], Sukardi[4], Danyl Mallisza[5]

[1]Universitas Negeri Padang, Doctoral Program of Technical Vocational and Education. Padang, Indonesia.
[2]Universitas Ekasakti, Civil Engineering Study Program. Padang, Indonesia.
[3]Universitas Negeri Padang, Department of Mechanical Engineering. Padang, Indonesia.
[4]Universitas Negeri Padang, Department of Electrical Engineering. Padang, Indonesia.
[5]Universitas Ekasakti, Diploma in Information Management. Padang, Indonesia.

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Corresponding author: Melda Fajra

ABSTRACT

Engineering education increasingly demands instructional approaches that connect academic knowledge with the professional competencies required in contemporary engineering practice. Responding to this need, the present study aimed to evaluate the effectiveness of a Profession-Oriented Project-Based Learning (PO-PBL) model that integrates professional engineering standards into the Water Infrastructure Design course at Universitas Ekasakti, Padang, Indonesia. The PO-PBL model embeds technical, ethical, and managerial competencies throughout the project cycle to strengthen students' conceptual mastery and professional readiness. Using a quasi-experimental nonequivalent control group design, the study involved 65 undergraduate students divided into an experimental class (n = 32) and a control class (n = 33). Data were collected through 40-item pretests and posttests, a 20-item Likert-scale survey on engagement and professional perception, and a rubric-based evaluation of project performance. Statistical analyses, including paired t-tests, independent t-tests, and analysis of covariance, indicated that students in the experimental class achieved higher posttest scores, greater learning gains, and stronger project outcomes than those in the control class. Survey responses also revealed higher levels of motivation, collaboration, and perceived professional relevance among students exposed to the PO-PBL model. These results suggest that integrating professional standards into project-based learning enhances the authenticity and purposefulness of instructional activities, thereby improving both cognitive achievement and professional competence. Overall, the PO-PBL model offers a practical and scalable framework for aligning engineering education with national professional expectations and supporting the development of industry-ready water engineering graduates in Indonesia.

Keywords: Profession-Oriented Project-Based Learning; Professional Standards; Water Engineering Education; Cognitive Achievement; Effectiveness.

RESUMEN

La educación en ingeniería exige cada vez más enfoques de enseñanza que conecten el conocimiento académico con las competencias profesionales requeridas en la práctica contemporánea de la ingeniería. En respuesta a esta necesidad, el presente estudio tuvo como objetivo evaluar la efectividad de un modelo de

Aprendizaje Basado en Proyectos Orientado a la Profesión (PO-PBL) que integra estándares profesionales de ingeniería en el curso de Diseño de Infraestructura Hidráulica en la Universidad Ekasakti, Padang, Indonesia. El modelo PO-PBL incorpora competencias técnicas, éticas y de gestión a lo largo del ciclo del proyecto para fortalecer el dominio conceptual y la preparación profesional de los estudiantes. Mediante un diseño cuasiexperimental con grupos no equivalentes, el estudio involucró a 65 estudiantes de pregrado divididos en una clase experimental (n = 32) y una clase de control (n = 33). Los datos se recopilaron mediante pretest y postest de 40 ítems, una encuesta tipo Likert de 20 ítems sobre compromiso y percepción profesional, y una evaluación del desempeño del proyecto basada en rúbricas. Los análisis estadísticos, incluidos t de muestras relacionadas, t independientes y análisis de covarianza, indicaron que los estudiantes de la clase experimental obtuvieron puntuaciones postest más altas, mayores ganancias de aprendizaje y mejores resultados de proyecto que los del grupo de control. Las respuestas a la encuesta también revelaron mayores niveles de motivación, colaboración y percepción de relevancia profesional entre los estudiantes expuestos al modelo PO-PBL. Estos resultados sugieren que integrar estándares profesionales en el aprendizaje basado en proyectos mejora la autenticidad y el propósito de las actividades de instrucción, mejorando así tanto el logro cognitivo como la competencia profesional. En conjunto, el modelo PO-PBL ofrece un marco práctico y escalable para alinear la educación en ingeniería con las expectativas profesionales nacionales y apoyar la formación de graduados en ingeniería hidráulica preparados para la industria en Indonesia.

Palabras Clave: Aprendizaje Basado en Proyectos Orientado a la Profesión; Estándares Profesionales; Educación en Ingeniería Hidráulica; Logro Cognitivo; Eficacia.

INTRODUCTION

Engineering education plays a central role in shaping professionals capable of addressing complex technological and environmental challenges.[1,2] In the field of water resources, the increasing pressure from climate change, urbanization, and sustainability demands requires engineers who possess not only technical competence but also professional judgment and ethical responsibility.[3,4] These competencies are no longer adequately developed through traditional lecture-based instruction, which often emphasizes theoretical mastery over practical problem solving.[5,6]

Globally, educational reform in engineering has shifted toward competency-based and experiential learning models that emphasize collaboration, innovation, and real-world application. Among these, Project-Based Learning (PBL) has emerged as a pedagogical approach that integrates knowledge acquisition with authentic project experiences.[7,8] PBL allows students to engage in design-oriented tasks, simulate professional practice, and cultivate transversal skills such as critical thinking, teamwork, and communication—skills highly valued by the engineering profession.[9,10,11]

However, while PBL has been widely adopted in engineering curricula, its implementation often remains detached from the explicit standards and expectations of professional engineering organizations.[12,13] This disconnection can limit its impact on students' readiness for professional certification or practice. In the water engineering domain, the incorporation of professional standards—such as those recommended by national or international engineering councils—can bridge this gap by aligning academic learning outcomes with industry and societal needs.[14,15]

In Indonesia, the professional formation of engineers is governed by the Insinyur Profession Act (Undang-Undang Keinsinyuran No. 11/2014) and operationalized through the Indonesian Engineers Association (PII), which establishes professional competency standards across engineering fields.[16,17] Despite this formal framework, engineering education programs often face challenges in integrating these standards into curricular activities. Courses such as Water Infrastructure Design tend to focus on technical design outputs without systematically embedding professional attributes, ethical reasoning, or sustainability-oriented decision making.[18,19]

Recent studies on engineering pedagogy in Indonesia have highlighted the need for contextualized instructional models that not only enhance cognitive learning but also foster professional identity and ethical awareness.[20,21] While PBL provides a strong foundation for experiential learning, its effectiveness depends on how well it is contextualized to reflect local professional practices.[22,23] A profession-oriented PBL model—one that explicitly incorporates professional competencies and engineering ethics—may thus offer a strategic framework for aligning university education with national professional standards.[24,25]

Furthermore, previous empirical findings in engineering education suggest that PBL's success varies according to contextual and disciplinary factors. For instance, studies in civil and environmental engineering have demonstrated improvements in problem-solving and collaboration skills, yet evidence regarding its effectiveness in developing professional competencies specific to water engineering remains limited.[26,27] This gap indicates the need for models that integrate disciplinary depth with professional breadth, ensuring that graduates can both design technically sound solutions and navigate the ethical, environmental, and regulatory dimensions of their profession.[28,29]

The integration of professional standards into PBL is expected to enhance students' engagement and sense of professional relevance.[30,31] When project tasks are explicitly linked to professional criteria—such as competency units, ethical codes, and sustainability standards—students can perceive a clearer connection between academic learning and real engineering practice.[32,33] Such alignment not only strengthens motivation but also facilitates smoother transition from university to professional environments.[34,35]

Against this backdrop, this study develops and evaluates an innovative Profession-Oriented Project-Based Learning (PO-PBL) model for the Water Infrastructure Design course. The model integrates the professional standards recommended by the Indonesian Engineers Association (PII) into each stage of the project cycle—from problem identification and planning to design, reflection, and presentation.[3,18] The model aims to operationalize professional values within the learning process, enabling students to internalize technical, ethical, and societal responsibilities as future engineers.

Therefore, the primary objective of this study is to evaluate the effectiveness of the profession-oriented PBL model in enhancing learning outcomes and professional competencies among water engineering students. By examining its impact on cognitive achievement, project performance, and perceived professional relevance, this research seeks to contribute to the growing body of knowledge on contextualized engineering pedagogy. Ultimately, the findings are expected to offer theoretical insights and practical implications for universities seeking to align engineering education with national and global professional standards.

METHOD

Type of Study, Period, and Location

This study employed a quasi-experimental design with a nonequivalent control group to evaluate the effectiveness of a Profession-Oriented Project-Based Learning (PO-PBL) model integrating professional engineering standards into water engineering education. This design was selected because it allows comparison of learning outcomes under natural classroom conditions while maintaining ecological and pedagogical authenticity. The intervention focused on embedding the standards of the Indonesian Engineers Association (PII) into each instructional phase, responding to the growing demand for engineering graduates who demonstrate not only technical mastery but also ethical, managerial, and sustainability-related competencies.

The research was conducted during the odd semester of the 2024/2025 academic year within the Water Infrastructure Design course of the Civil and Environmental Engineering Program at Universitas Ekasakti, Padang. This course was selected because it requires students to design water infrastructure systems with explicit attention to sustainability, ethics, and professional accountability, making it an appropriate context for applying the PO-PBL model.

Description of the Intervention (PO-PBL Model)

The PO-PBL model is the core innovation of this study. It integrates PII professional standards—technical, ethical, managerial, and sustainability competencies—into each learning and project phase. The model consists of five structured phases, each mapped to specific competency indicators.

Table 1. Integration of PII Professional Standards into PO-PBL Phases

PO-PBL Phase	Description of Learning Activities	Integrated PII Competency Indicators
1. Problem Diagnosis	Students analyze water infrastructure problems in a real case area.	Problem identification; ethical judgment; environmental considerations.
2. Design Formulation	Groups prepare conceptual and technical design plans.	Technical competence; design accountability; sustainability assessment.
3. Project Execution	Students develop technical drawings, hydraulic calculations, and design reports.	Technical accuracy; adherence to engineering codes; teamwork and communication.
4. Reflection	Students evaluate design decisions, constraints, and ethical dilemmas.	Professional ethics; risk awareness; professional responsibility.
5. Evaluation & Presentation	Students defend their designs before a panel.	Professional communication; compliance with engineering standards; managerial competence.

Authentic Project Used in the Intervention (Design Brief)

The intervention employed an authentic engineering project designed to reflect the study's objective of integrating professional standards into project-based learning in Indonesian water engineering education. Students worked on: "Design of a Sustainable and Professionally Compliant Water Distribution System for a Semi-Urban Community in Padang Pariaman."

The project required students to:

1. Analyze local water demand and supply conditions.
2. Design a clean water distribution network using hydraulic principles.
3. Produce technical drawings and system models following engineering conventions.
4. Consider environmental, social, and ethical aspects of the design.
5. Justify design decisions based on relevant PII professional standards.

This real-world design brief ensured that the PO-PBL model was implemented in an authentic engineering context, reinforcing the integration of technical and professional competencies central to the study's purpose.

Population, Sample, and Sampling Technique

The study involved all students enrolled in the Water Infrastructure Design course, from which two intact classes were purposively selected to support the evaluation of the profession-oriented project-based learning model. The experimental group consisted of 32 students who received PO-PBL instruction, while the control group comprised 33 students taught through conventional PBL. The sample size reflected natural class enrollment since no formal power analysis could be conducted, a limitation acknowledged within the study. The use of intact classes preserved ecological authenticity but also introduced potential threats to internal validity, which were minimized through comparable baseline scores, the same course instructor, and ANCOVA adjustments.

Students were eligible to participate if they were officially registered in the course, attended at least 80 % of sessions, and provided voluntary consent, with exclusions applied for withdrawal or excessive absenteeism. These criteria ensured that the comparison between the PO-PBL and conventional PBL groups remained academically fair and ethically compliant. All procedures were conducted in accordance with the ethical guidelines of Universitas Ekasakti, supporting the study's objective of evaluating an innovative, professionally aligned learning model for water engineering education in Indonesia.

Variables Analyzed

The independent variable in this study was the Profession-Oriented Project-Based Learning (PO-PBL) model, which integrates the professional standards of the Indonesian Engineers Association (PII) into the instructional process. The dependent variables consisted of three key learning outcomes. First, cognitive learning achievement was assessed through pretest and posttest scores to measure students' conceptual understanding and problem-solving abilities in water engineering. Second, project performance was evaluated using a standardized rubric aligned with professional engineering standards to assess technical accuracy, sustainability considerations, ethical awareness, and teamwork quality. Third, student engagement and professional perception were measured through a 20-item Likert-scale survey capturing motivation, collaboration, and students' perceived relevance of professional standards within the learning experience.

Instruments, Techniques, and Procedures

The research was implemented across eight instructional sessions over eight weeks within the Water Infrastructure Design course at Universitas Ekasakti, Padang. The research was conducted over eight instructional sessions spanning eight weeks. During Week 1, both groups completed the pretest to establish baseline knowledge. Weeks 2–7 were dedicated to implementing either the PO-PBL model (experimental group) or conventional PBL (control group), during which students engaged in project work, collaborative discussions, and design development. In Week 8, the posttest, engagement survey, and rubric-based project evaluation were administered to assess cognitive gains, professional perceptions, and design performance. All data were collected in both printed and digital formats to ensure completeness and accuracy throughout the study.

The experimental group (n = 32) followed the PO-PBL model, which integrated the PII professional standards across five key phases: problem diagnosis, design formulation, project execution, reflection, and evaluation. The control group (n = 33) participated in conventional PBL activities focusing only on academic project completion without explicit professional standard integration. This structure enabled a meaningful comparison between the pedagogical impacts of profession-oriented and conventional PBL methodologies.[36,37]

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Table 2. Research Design			
Group	**Pre-Test**	**Treatment (X)**	**Post-Test**
Experiment	O_1	X	O_2
Control	O_3	-	O_4
Source: Sugiyono (2016)[37]			

Explanation:
O_1 & O_3: Pretest observation for the experimental and control group.
X: The treatment or intervention given to the experimental group
O_2 & O_4: Posttest observation for the experimental and control group.

The study employed three main instruments to measure learning outcomes comprehensively. First, the Cognitive Achievement Test consisted of 40 items—30 multiple-choice questions and 10 short-answer items—designed to assess students' conceptual understanding and analytical skills in water infrastructure design. Sample items included: "Which factor most influences head loss in a 150 mm PVC pipeline transporting clean water?" (MCQ) and "Explain two sustainability considerations in designing a rural water distribution network." (short answer). Second, the Engagement and Professional Perception Survey, comprising 20 Likert-scale items (1–5), measured students' motivation, collaboration, ethical awareness, and perceived relevance of engineering standards; sample items included: "I feel more aware of ethical responsibilities in engineering design" and "The project improved my confidence in applying engineering standards." Third, students' design outputs were evaluated using a Project Performance Rubric aligned with professional engineering standards, assessing technical accuracy, ethical reasoning, sustainability integration, teamwork, and compliance with PII standards.

Table 3. Project Performance Rubric		
Criterion	**Description**	**Scale (1-5)**
Technical Soundness	Accuracy of calculations, hydraulic design, and drawings	1 = poor → 5 = excellent
Ethical Consideration	Identification of ethical issues and responsible decision-making	1-5
Sustainability Integration	Environmental and social considerations reflected in design	1-5
Teamwork & Communication	Coordination, documentation, and clarity of presentation	1-5
Professional Compliance	Alignment with PII standards, codes, and professional principles	1-5

Data Analysis Process

Quantitative data analysis was performed using SPSS software to ensure statistical precision. Descriptive statistics were calculated to summarize overall learning trends, while Shapiro–Wilk and Levene's tests were applied to verify data normality and homogeneity. To determine the intervention's impact, paired sample t-tests were conducted to examine pretest-posttest improvements within each group, and independent sample t-tests were used to compare posttest outcomes between the experimental and control groups. Additionally, ANCOVA was employed to control for potential pretest differences and isolate the effect of the PO-PBL intervention.

Effect sizes were calculated using Cohen's d to assess the magnitude of the treatment effect, providing a deeper understanding of the practical significance of the model. Qualitative reflections collected from students and instructors were analyzed thematically to enrich the quantitative findings with contextual insights into engagement, collaboration, and perceived professional growth. Through this comprehensive analytical framework, the study produced robust empirical evidence on the effectiveness of integrating professional standards into project-based learning for water engineering education at Universitas Ekasakti, Padang, Indonesia.

Ethical Considerations

All research procedures followed the ethical guidelines of the Research Ethics Committee of Universitas Ekasakti, Padang. Participants were informed verbally and in writing about the study's purpose, procedures, potential benefits, and their rights, including the freedom to withdraw without academic consequences. Informed consent was obtained prior to data collection, and confidentiality was safeguarded through anonymous coding and secure, password-protected data storage accessible only to the research team. No personally identifiable information appeared in any report or publication. These measures ensured that the implementation of the PO-PBL model was conducted with full transparency, voluntariness, and academic integrity, consistent with national and international standards for ethical research in education.

RESULT

Data Analysis and Findings

The data analysis in this study demonstrates significant improvements in student outcomes following the implementation of the Profession-Oriented Project-Based Learning (PO-PBL) model, which integrates professional standards into water engineering education. Both quantitative and qualitative data were collected, with pretest and posttest assessments serving as the primary instruments to measure students' cognitive achievement, project performance, and professional engagement. Descriptive statistics were used to compare the pretest and posttest results between the experimental group, which participated in the PO-PBL learning model incorporating professional engineering standards, and the control group, which followed the conventional project-based learning approach. The experimental group showed notable improvements in conceptual understanding of water infrastructure design, problem-solving accuracy, teamwork performance, and adherence to professional standards in project execution. In contrast, the control group, which experienced traditional PBL instruction, demonstrated only moderate progress in these areas.

The comparison between the two groups underscores the effectiveness of integrating professional standards into project-based learning to strengthen both technical and professional competencies among engineering students. Analysis of the pretest and posttest data revealed that the experimental group achieved higher gains in learning outcomes, particularly in their ability to apply theoretical knowledge to practical design problems and in demonstrating professional responsibility throughout the project process. These findings suggest that embedding professional competencies within PBL not only enhances students' cognitive mastery but also promotes higher engagement, ethical awareness, and confidence in solving real engineering challenges. The overall results provide compelling evidence that the PO-PBL model, as implemented in the Water Infrastructure Design course at Universitas Ekasakti, offers a more effective pedagogical approach for cultivating professionally competent and industry-ready water engineers compared to conventional instructional methods.

Table 4. Results of the Descriptive Analysis Results for Pre-Test and Post-Test

Group	**Mean Pre-Test Score**	**Mean Post-Test Score**
Experiment	67,03	87,78
Control	67,97	81,76

The descriptive analysis presented in table 4 shows clear differences between the experimental group, which implemented the Profession-Oriented Project-Based Learning (PO-PBL) model, and the control group, which used conventional project-based learning. Before the intervention, both groups had nearly identical pre-test means—67,03 for the experimental group and 67,97 for the control group—indicating comparable initial ability levels. After the intervention, the experimental group's post-test mean increased sharply to 87,78, while the control group's mean reached only 81,76. This difference demonstrates that integrating professional standards into project-based learning substantially improves students' conceptual mastery and practical competence. Overall, the results confirm that the PO-PBL model effectively enhances professional readiness and learning performance in water engineering education. Furthermore, a normality test was conducted to determine the suitability of the data for inferential analysis, specifically to assess the extent to which the data followed a normal distribution. The Shapiro-Wilk test was utilized to analyze the distribution of the data.

Table 5. Results of the Shapiro-Wilk Test

Group	**Pre-Test (p-value)**	**Post-Test (p-value)**
Experiment	0,551	0,158
Control	0,257	0,093

The results show that the data in both groups, for both pre-test and post-test, were normally distributed ($p > 0,05$). Levene's Test was used to examine the homogeneity of variances between the experiment and control groups.

Table 6. Results of Levene's Test		
Variable	**F**	**Sig. (p-value)**
Post-Test	0,196	0,660

The analysis indicates that the variances of the experiment group to the control group were similar (p > 0,05) suggesting that the groups could be compared parametrically. To establish the researching hypothesis the two condition Independent Sample T-Test was used to compare the post test results between the experimental and control groups.

Table 7. Results of T-Test				
Test Type	**Variable**	**t**	**Sig. (p-value)**	**Interpretation**
Independent Sample T-Test	Post-Test scores of Experimental Group vs Control Group	-5,321	0,000	The experimental group achieved a higher mean post-test score than the control group

The results of the independent sample t-test in table 7 show a significant difference in post-test scores between the experimental and control groups (t = -5,321; p = 0,000), confirming the effectiveness of the Profession-Oriented Project-Based Learning (PO-PBL) model in water engineering education. Students taught using the PO-PBL model, which integrated professional standards into each project phase, achieved higher learning outcomes than those in the conventional PBL class. These results demonstrate that embedding professional competencies within project-based learning enhances students' conceptual mastery, practical skills, and professional readiness The gain scores (Post-Test – Pre-Test) were calculated for both groups to evaluate the improvement from pre- to post-test. The experimental group showed a larger gain compared to the control group.

Table 8. Gain Score Analysis			
Group	**Mean Pre-Test Score**	**Mean Post-Test Score**	**Gain Score (Post - Pre)**
Experiment	67,03	87,78	20,75
Control	67,97	81,76	13,79

The gain score analysis shows that the experimental group, which received instruction using the Profession-Oriented Project-Based Learning (PO-PBL) model, achieved a higher improvement (20,75) than the control group (13,79). This indicates that integrating professional standards into project-based learning produced a greater enhancement in student learning outcomes in the Water Infrastructure Design course at Universitas Ekasakti. An ANCOVA was conducted to adjust for pre-test differences. After controlling for pre-test scores, the post-test differences remained significant, confirming the effectiveness of the intervention.

Table 9. ANCOVA Result			
Source	**F**	**Sig. (p-value)**	**Interpretation**
Post-Test (covariate)	0,196	0,660	Initial differences controlled
Group (Experimental vs. Control)	28,316	0,000	Significant group effect on post-test

The ANCOVA results indicate that the pre-test covariate did not have a significant effect on post-test scores (F = 0,196; p = 0,660), confirming that initial group differences were statistically controlled. In contrast, the group variable showed a highly significant effect on the post-test results (F = 28,316; p = 0,000), demonstrating that the Profession-Oriented Project-Based Learning (PO-PBL) model significantly improved learning outcomes compared to conventional PBL. These findings validate the effectiveness of integrating professional standards into project-based learning in enhancing students' competence and achievement in the Water Infrastructure Design course at Universitas Ekasakti.

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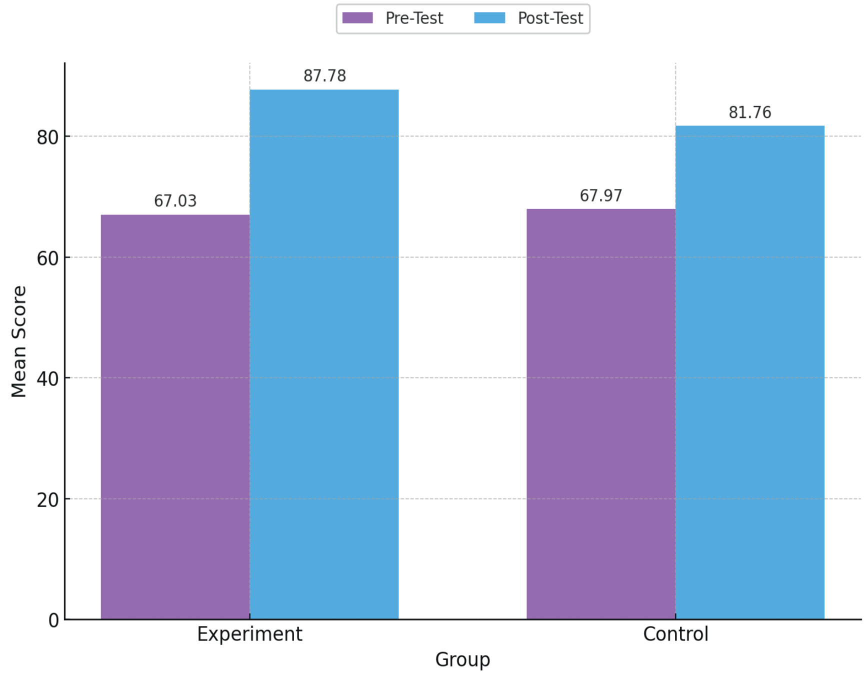

Figure 1. Pre-Test and Post-Test Scores Bar Chart

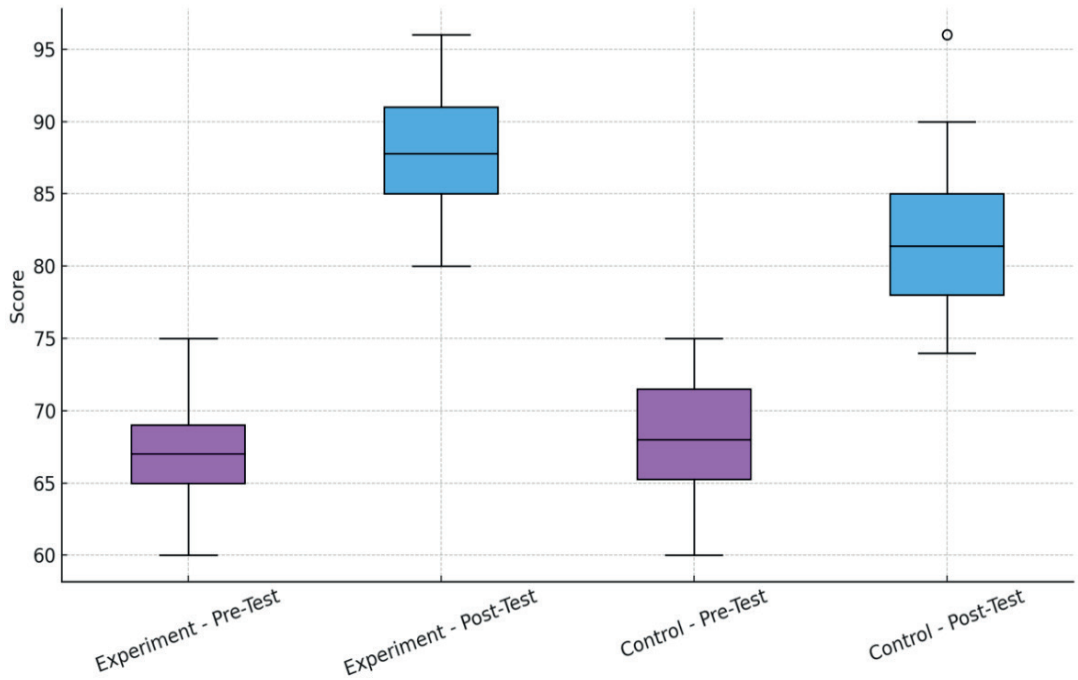

Figure 2. Box Plot Pre-Test and Post-Test Scores

Figure 2 illustrates the differences in score distributions between the experimental and control groups before and after the intervention. The experimental group showed a substantial increase in post-test scores, with a higher median and narrower score range, indicating consistent improvement following the implementation of the Profession-Oriented Project-Based Learning (PO-PBL) model. In contrast, the control group also experienced a moderate improvement from pre-test to post-test, but with a lower median and wider score variability. Overall, the boxplot clearly demonstrates that integrating professional standards into project-based learning led to greater and more uniform gains in student performance compared to the conventional approach.

DISCUSSION

The findings of this study suggest that integrating professional standards into project-based learning can meaningfully enhance student learning outcomes in water engineering education. The experimental group achieved considerably higher cognitive gains—20,75 points compared with 13,79 points in the control group—indicating that embedding PII-based competencies within the instructional process supported deeper conceptual understanding. This result aligns with the theoretical foundation of Project-Based Learning, which emphasizes the role of authentic, problem-centered experiences in strengthening the link between theory and practice.[8,24] The stronger improvement in the PO-PBL group suggests that professional contextualization helped students make more meaningful cognitive connections.

The increased authenticity embedded in the PO-PBL model appears to have contributed significantly to these gains. By requiring students to integrate sustainability, ethics, accountability, and engineering codes into their design work, the learning environment reflected real-world engineering responsibilities. This perspective is consistent with Situated Learning Theory, which posits that knowledge becomes more meaningful when constructed in contexts resembling actual professional practice. Similar to findings reported by Ejichukwu et al. and Bosch et al.,[12,27] the contextualization present in this study appears to have fostered stronger problem-solving and higher-order reasoning.

Beyond cognitive achievement, the PO-PBL model enhanced broader dimensions of professional competence, as reflected in the higher rubric scores attained by the experimental group. Students demonstrated stronger technical soundness, ethical reasoning, sustainability integration, teamwork, and professional compliance—competencies essential for engineering practice. These results extend earlier studies, such as those by Bell et al. and Guerra,[4,14] by showing that when professional expectations are made explicit within PBL, students exhibit richer professional behaviors than when assessed solely through tests. The rubric-based evaluation adds nuanced evidence of competence development that would not be captured through cognitive assessments alone.

Student engagement outcomes further reinforce the effectiveness of the model. Learners participating in PO-PBL reported greater motivation and more active involvement during all stages of the project—diagnosis, design formulation, execution, reflection, and evaluation. This higher engagement echoes earlier empirical findings [20,23] indicating that PBL approaches rooted in local contexts and real-world tasks can enhance student participation and learning retention. The alignment between instructional activities and professional expectations may have strengthened students' sense of purpose and ownership throughout the learning process.

The collective results across cognitive gain, project performance, and engagement provide insight into the mechanism through which professional standards strengthen PBL effectiveness. Rather than merely adding additional content, the standards appear to clarify purpose, strengthen professional identity, and increase authenticity, thereby encouraging students to approach tasks in ways that mirror professional engineering practice. This interpretation is supported by studies emphasizing the value of structured competency frameworks in fostering professional growth. This aligns with findings by Adi et al. and Chrismondari et al.,[30,31] who found that integrating collaborative and real-world elements within PBL enhances learning performance in vocational and technical education. When students understand the ethical, technical, and managerial implications of their design decisions, they engage more intentionally and demonstrate more consistent professional behaviors.

Statistical analyses further support these interpretations. The ANCOVA results confirmed that differences between groups remained significant after controlling for pre-test scores, indicating that the gains were attributable to the intervention rather than initial academic disparities. Similar findings have been reported in the work of Usmeldi & Amini and Fitriningtias & Churiyah,[6,11] which emphasize that structured competency-based instructional models produce consistent improvements across technical disciplines. The present study extends these insights to the context of water engineering education in Indonesia, demonstrating the value of anchoring PBL in professional standards.

These outcomes also correspond to broader educational priorities related to Industry 4.0 and Society 5.0, where engineering graduates are expected not only to demonstrate technical proficiency but also to uphold sustainability, ethics, collaboration, and adaptability.[2,15] By systematically embedding these competencies into the PO-PBL model, this study addresses concerns raised in earlier research regarding the gap between academic learning and workplace readiness in technical and vocational education.[22,28] The model therefore offers a practical instructional approach for aligning university-level engineering courses with real-world professional expectations.

Overall, this study extends the literature by providing empirical evidence that the Profession-Oriented Project-Based Learning model is an effective pedagogical innovation for water engineering education in Indonesia. It bridges the gap between theory and professional application, reinforcing the arguments of Patnawar[1] and García-Segura et al.[13] that integrating professional frameworks within PBL supports both cognitive and affective learning outcomes. Consequently, the PO-PBL model represents a sustainable educational approach capable of producing graduates who are not only technically proficient but also professionally responsible and adaptable to the evolving challenges of engineering practice.

Implications

However, several limitations must be acknowledged to contextualize these interpretations. This study involved a relatively small sample drawn from a single institution and relied on intact classes, which may introduce pre-existing differences despite statistical controls. Moreover, the evaluation occurred over one academic term, limiting conclusions regarding long-term professional development or transfer to workplace performance. Recognizing these constraints strengthens the credibility of the findings and highlights areas for future inquiry.

Limitations and Future Research

This study indicates that embedding professional standards within a project-based learning framework can enhance both cognitive and professional competencies in water engineering education. By clarifying purpose, increasing authenticity, and strengthening students' professional identity, the PO-PBL model offers a promising approach for aligning classroom learning with the expectations of engineering practice in Indonesia. Further research in diverse institutions and disciplines, including longitudinal studies, would help assess the model's broader applicability and long-term impact.

CONCLUSION

The study concludes that integrating professional engineering standards into a project-based learning framework provides a coherent and effective approach for strengthening both academic understanding and professional formation in water engineering education. By embedding ethical, technical, and managerial competencies into each stage of the learning process, the Profession-Oriented Project-Based Learning (PO-PBL) model enhances the relevance of coursework, encourages purposeful engagement, and supports the development of professional judgment and collaborative skills aligned with real engineering practice. These findings indicate that the model offers a practical pathway for bridging the gap between classroom instruction and the expectations of the engineering profession in Indonesia, suggesting its potential for broader application across engineering programs seeking to cultivate industry-ready graduates.

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AUTHORSHIP CONTRIBUTION
Conceptualization: Melda Fajra.
Data curation: Ambiyar.
Formal analysis: Sukardi.
Research: Melda Fajra.
Methodology: Ambiyar.
Project management: Sukardi.
Resources: Melda Fajra.
Software: Danyl Mallisza.
Supervision: Sukardi.
Validation: Ambiyar.
Display: Danyl Mallisza.
Drafting - original draft: Danyl Mallisza.
Writing - proofreading and editing: Melda Fajra.