

Problem-Based Learning Supported by Artificial Intelligence: An Empirical Study of Its Effects on Problem-Solving Skills and Student Learning Outcomes in Two Indonesian Higher Education Institutions

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ABSTRACT

The integration of artificial intelligence into higher education has created new opportunities to enhance problem-based learning, particularly in developing-country contexts where empirical evidence remains limited. This study aimed to examine the effects of AI-supported Problem-Based Learning on students' problem-solving skills and learning outcomes in two Indonesian higher education institutions. A quasi-experimental non-equivalent control group design was employed involving 120 undergraduate students from Al Khairiyah University and Serang Raya University. Data were collected using validated tests and questionnaires and analyzed through independent-samples t-tests and two-way ANOVA. The findings showed that students in the PBL-AI group achieved significantly higher gains in problem-solving skills and learning outcomes than those in conventional learning. These results support the pedagogical value of AI-enhanced PBL for improving higher education learning quality.

INTRODUCTION

The rapid integration of Artificial Intelligence into higher education has transformed the way students access information, receive feedback, and construct knowledge. At the global level, Artificial Intelligence is increasingly used to support adaptive learning, automated assessment, learning analytics, and personalized feedback, which are considered important for improving learning quality in complex academic environments (Wang et al., 2024). In Indonesia, the digital transformation of education has also become an urgent agenda, particularly as universities are encouraged to improve access, equity, and learning quality through technology-supported innovation. UNESCO reported that Indonesia has begun strengthening public digital learning initiatives to support educational equity and quality, indicating the growing relevance of technology integration in national education systems (UNESCO, 2024). Therefore, examining the pedagogical use of Artificial Intelligence in higher education is important not only as a global innovation agenda but also as a contextual response to the needs of Indonesian universities.

Problem-Based Learning is one of the pedagogical models that is theoretically aligned with the demands of twenty-first-century higher education because it emphasizes active inquiry, authentic problem analysis, collaboration, and reflective decision-making. Previous meta-analytic evidence shows that Problem-Based Learning has a positive effect on students' critical thinking and problem-solving abilities in higher education contexts (Liu & Pásztor, 2022). Anggraeni et al. (2023) also found that Problem-Based Learning research consistently demonstrates its relevance for developing higher-order thinking skills, particularly when students are required to interpret complex problems and construct evidence-based solutions. However, conventional implementation of Problem-Based Learning often faces limitations related to delayed feedback, unequal scaffolding, and the difficulty of monitoring individual student progress in large or heterogeneous classes. These limitations indicate the need for a technology-supported instructional design that can strengthen the effectiveness of Problem-Based Learning without reducing the central role of lecturers as learning facilitators.

Artificial Intelligence-supported learning platforms offer potential solutions to several limitations of conventional Problem-Based Learning by providing adaptive feedback, individualized scaffolding, and data-informed monitoring of student progress. A systematic review by Memarian and Doleck (2024) shows that Artificial Intelligence can support assessment for learning through feedback mechanisms that help students identify learning gaps and improve performance. Similarly, Zhu et al. (2023) found that the use of ChatGPT in undergraduate collaborative learning may support efficiency, knowledge gap reduction, and learning engagement, although its benefits depend on how the technology is pedagogically designed. These findings suggest that Artificial Intelligence should not be treated merely as an additional digital tool, but as a pedagogical support system that must be integrated with clear learning objectives and structured instructional strategies. In the context of Problem-Based Learning, Artificial Intelligence may function as an adaptive scaffold that

helps students understand problems, evaluate alternatives, and improve learning outcomes through timely formative support.

Despite the growing literature on Artificial Intelligence in education, several research gaps remain unresolved. First, many studies on Artificial Intelligence-supported learning are still concentrated in technologically advanced countries or single-institution contexts, limiting the generalizability of findings to developing-country higher education settings (Wang et al., 2024). Second, previous research often discusses the benefits of Artificial Intelligence broadly, but gives limited methodological detail about how adaptive feedback, scaffolding quality, and instructor monitoring are operationalized in classroom interventions. Third, empirical studies that compare the effectiveness of Artificial Intelligence-supported Problem-Based Learning across more than one institution remain limited, even though institutional differences may influence learning readiness, technology access, and student engagement. Fourth, ethical issues such as data privacy, transparency, consent, and responsible use of Artificial Intelligence remain important concerns, as UNESCO (2023) emphasizes that educational Artificial Intelligence must be implemented with clear safeguards for learners.

Based on these gaps, this study aims to examine the effects of Artificial Intelligence-supported Problem-Based Learning on students' problem-solving skills and learning outcomes in two Indonesian higher education institutions. Specifically, the study analyzes whether students who experience Artificial Intelligence-supported Problem-Based Learning achieve greater improvement in problem-solving skills than students who receive conventional instruction. The study also examines whether Artificial Intelligence-supported Problem-Based Learning significantly improves academic learning outcomes and how students perceive the clarity, relevance, and usefulness of the intervention. In addition, this study compares the effectiveness of the intervention between Al Khairiyah University and Serang Raya University to determine whether institutional context influences the results. By using a quasi-experimental non-equivalent control group design, this research seeks to provide empirical evidence regarding the relationship between Artificial Intelligence-supported instructional design, problem-solving competence, and student academic achievement.

This study contributes theoretically by extending the literature on constructivist learning, adaptive learning, and Artificial Intelligence in education through an empirical examination of Artificial Intelligence-supported Problem-Based Learning in a multi-institutional Indonesian context. The study strengthens the argument that technology-enhanced learning should be understood not only from a technological perspective but also from a pedagogical perspective that emphasizes scaffolding, feedback, and active problem construction. Practically, the findings are expected to inform lecturers, curriculum designers, and higher education leaders in designing Artificial Intelligence-supported learning models that are ethical, adaptive, and aligned with students' learning needs. The study also provides implications for instructor professional development, particularly in helping lecturers use Artificial Intelligence dashboards and automated feedback without neglecting human

judgment and academic supervision. Therefore, this research is expected to support the development of more responsive, evidence-based, and contextually relevant higher education learning practices in Indonesia.

LITERATURE REVIEW

Problem-Based Learning as a Constructivist Learning Approach

Problem-Based Learning is grounded in constructivist learning theory, which positions students as active knowledge constructors through engagement with authentic and ill-structured problems. This approach encourages students to identify problems, analyze information, develop strategies, implement solutions, and evaluate outcomes, making it relevant for higher education contexts that require analytical and decision-making skills. Recent evidence shows that problem-centered learning can strengthen student persistence, academic performance, and engagement because students apply knowledge in meaningful contexts (Davis & Burkholder, 2024). Problem-Based Learning is also closely related to metacognitive competence because students must monitor their reasoning, evaluate assumptions, and revise ineffective strategies. Bubnic et al. (2024) found that metacognitive awareness and behavior are important predictors of problem-solving success, supporting the use of structured rubrics to assess problem identification, analysis, strategy formulation, implementation, and evaluation.

Artificial Intelligence in Higher Education

Artificial Intelligence in higher education refers to computational systems that support learning through personalization, prediction, feedback, assessment, and data-informed decision-making. Crompton and Burke (2023) reported that research on Artificial Intelligence in higher education increased rapidly between 2021 and 2022, indicating growing institutional interest in intelligent technologies for teaching and learning. Artificial Intelligence can assist lecturers through learning analytics, automated feedback, adaptive recommendations, and early identification of students who need support. Kabudi et al. (2021) explain that Artificial Intelligence-enabled adaptive learning systems respond to individual learner needs by analyzing behavior and recommending suitable learning pathways. Similarly, Gligorea et al. (2023) show that Artificial Intelligence-supported adaptive learning can improve engagement, retention, and performance by personalizing learning experiences.

Integration of Problem-Based Learning and Artificial Intelligence

The integration of Problem-Based Learning and Artificial Intelligence creates a coherent instructional model that combines authentic inquiry with adaptive technological support. Problem-Based Learning provides the pedagogical structure through collaboration, reflection, and problem solving, while Artificial Intelligence strengthens the process through personalized feedback, scaffolding, and progress monitoring. Ouyang and Jiao (2021) argue that Artificial Intelligence-supported learning allows students to collaborate with intelligent systems while maintaining active learning agency. In this model, Artificial Intelligence does not replace student reasoning but supports students in navigating complex problem-solving processes. Kasneci et al. (2023) emphasize that intelligent systems can support educational interaction and

personalized learning, but they must be implemented with awareness of limitations, risks, and the need for lecturer supervision.

Problem-Solving Skills and Learning Outcomes

Problem-solving skills are high-level cognitive abilities involving problem identification, information analysis, strategy selection, solution implementation, and evaluation. These skills are essential in higher education because students are expected to apply academic knowledge to complex professional and social situations. Problem-solving is also strongly connected to learning outcomes because students who can analyze and solve problems tend to develop deeper conceptual understanding. Davis and Burkholder (2024) show that real-world problem-solving classes can support higher persistence and stronger academic performance than conventional instructional formats. In Artificial Intelligence-supported Problem-Based Learning, feedback and scaffolding may help students revise reasoning, regulate thinking, and construct solutions more independently, while Bubnic et al. (2024) confirm that metacognitive behavior contributes meaningfully to student performance.

Student Perceptions of Artificial Intelligence-Supported Learning

Student perception is an important dimension in evaluating Artificial Intelligence-supported learning because successful technology integration depends on user acceptance, clarity, relevance, usefulness, and trust. Students are more likely to benefit from Artificial Intelligence-supported learning when they understand how feedback is generated, how recommendations should be interpreted, and how the technology supports learning objectives. Santos et al. (2023) argue that Artificial Intelligence can transform higher education teaching and learning, but its success depends on institutional readiness, lecturer competence, and student experience. Kasneci et al. (2023) also note that students and lecturers need sufficient Artificial Intelligence literacy to understand both the benefits and limitations of intelligent tools. Therefore, evaluating students' perceptions of feedback clarity, scaffolding relevance, usefulness, and satisfaction is necessary to determine whether Artificial Intelligence-supported Problem-Based Learning functions as a meaningful learning support system.

Ethical Considerations in Artificial Intelligence-Supported Problem-Based Learning

The use of Artificial Intelligence in education raises ethical issues related to data privacy, transparency, fairness, accountability, and learner agency. These issues are important because Artificial Intelligence systems often collect and process student data to generate feedback, recommendations, and performance predictions. Porayska-Pomsta et al. (2024) emphasize that Artificial Intelligence in education must be examined from ethical, social, pedagogical, and technical perspectives. Panagopoulou et al. (2023) also explain that Artificial Intelligence applications in education create opportunities for academic support but raise concerns about privacy, authorship, accountability, and responsible use. Therefore, Artificial Intelligence-supported Problem-Based Learning requires informed consent, transparent system use, secure data handling, clear boundaries between Artificial Intelligence support and students' own work, and lecturer oversight to preserve human decision-making.

Research Gap and Conceptual Position of the Study

Although previous studies have examined Problem-Based Learning, Artificial Intelligence-supported learning, adaptive learning, and student engagement, several gaps remain. First, many studies discuss Artificial Intelligence-supported learning in general terms without explaining how Artificial Intelligence supports each stage of problem solving. Second, empirical research integrating Problem-Based Learning and Artificial Intelligence in multi-institutional higher education contexts remains limited, especially in developing-country settings. Third, previous studies often focus on achievement outcomes but give less attention to the combined measurement of problem-solving skills, academic learning outcomes, and student perceptions. Based on these gaps, this study positions Artificial Intelligence-supported Problem-Based Learning as a lecturer-supervised instructional model that integrates constructivist problem solving, adaptive feedback, individualized scaffolding, learning analytics, student perception, and ethical implementation to examine its effects on problem-solving skills and learning outcomes in two Indonesian higher education institutions.

METHODOLOGY

Research Type, Approach, and Design

This study employed a quantitative approach with a quasi-experimental non-equivalent control group design using pre-test and post-test measurements. This design was selected because the study aimed to examine the effect of Artificial Intelligence-supported Problem-Based Learning on students' problem-solving skills and learning outcomes in authentic classroom settings where individual random assignment was not feasible. The experimental group received Artificial Intelligence-supported Problem-Based Learning, while the control group received conventional lecture-based instruction. The independent variable was the type of instruction, whereas the dependent variables were students' problem-solving skills and learning outcomes. Institution was treated as a moderator variable to examine whether the effectiveness of the intervention differed between Al Khairiyah University and Serang Raya University, while prior technology experience was considered as a covariate in supplementary analysis. Quasi-experimental design is appropriate for educational intervention research because it enables comparison between treatment and control groups while maintaining ecological validity in real learning contexts (Capili, 2024).

Population, Sample, and Sampling Technique

The population of this study consisted of undergraduate students enrolled in selected courses at Al Khairiyah University and Serang Raya University in Banten Province, Indonesia. The sample comprised 120 undergraduate students, consisting of 60 students from Al Khairiyah University and 60 students from Serang Raya University. At each institution, 30 students were assigned to the experimental group and 30 students to the control group. The study used purposive sampling, a non-probability sampling technique, because participants were selected based on specific criteria relevant to the intervention. The inclusion criteria were active enrollment in the target course, semester 3 or 4 status, comparable academic profiles based on prior Grade Point Average and pre-test

scores, no prior formal exposure to Artificial Intelligence-supported Problem-Based Learning platforms, and willingness to provide written informed consent. The exclusion criteria included withdrawal from the course or absence from more than 20% of the instructional sessions.

Table 1.1 Baseline characteristics of the research sample

Characteristic	UNV Experimental (n=30)	UNV Control (n=30)	UNS Experimental (n=30)	UNS Control (n=30)
Age, years (M ± SD)	20.3 ± 1.2	20.1 ± 1.3	20.5 ± 1.1	20.4 ± 1.2
TKPM Pre- test (M ± SD)	52.1 ± 11.4	51.8 ± 10.9	50.9 ± 11.6	51.2 ± 11.1
Prior GPA (M ± SD)	2.89 ± 0.48	2.91 ± 0.45	2.85 ± 0.52	2.87 ± 0.50
Female (%)	53%	50%	57%	53%

Table 1.1 shows that the four research groups had relatively comparable baseline characteristics before the intervention. The mean age ranged from 20.1 to 20.5 years, indicating that participants came from similar academic cohorts. The pre-test scores on the Problem-Solving Ability Test were also relatively similar, ranging from 50.9 to 52.1, while prior Grade Point Average ranged from 2.85 to 2.91. Independent-samples t-tests and one-way Analysis of Variance confirmed that there were no significant between-group differences in pre-test problem-solving scores or prior Grade Point Average. These results indicate adequate baseline equivalence before the intervention was implemented.

Data Collection Techniques and Research Instruments

Data were collected through tests, questionnaires, platform records, and documentation. The test instruments consisted of the Problem-Solving Ability Test and the Learning Outcome Examination, while the questionnaire instrument consisted of the Student Perception Questionnaire. The Problem-Solving Ability Test contained eight open-ended items assessing five dimensions of problem solving, namely problem identification, problem analysis, strategy development, solution implementation, and evaluation. The Learning Outcome Examination consisted of multiple-choice, short-answer, and case-based questions with a maximum score of 100. The Student Perception Questionnaire contained 25 Likert-scale items measuring prompt clarity, feedback relevance, scaffolding effectiveness, satisfaction, and intention to continue using the learning model. Content validity was assessed through expert judgment using the Content Validity Index, while reliability was assessed using Cronbach's alpha and Cohen's Kappa for open-ended scoring. The Problem-Solving Ability Test obtained Cronbach's alpha of .82 and Cohen's Kappa of .84, the Learning Outcome Examination obtained Cronbach's alpha of .79, and the Student Perception Questionnaire obtained Cronbach's alpha of .84, indicating acceptable reliability (Sürücü & Maslakçı, 2020; Jebb et al., 2021).

Artificial Intelligence-Supported Problem-Based Learning Intervention

The experimental group used an adaptive learning platform integrated with an Artificial Intelligence module based on a rule-based expert system and a natural language processing-driven feedback engine. The platform included three main features: an Adaptive Problem Engine, an Automated Feedback Module, and an Instructor Dashboard. The Adaptive Problem Engine adjusted problem difficulty based on students' performance, while the Automated Feedback Module provided formative feedback on each stage of problem solving. The Instructor Dashboard enabled lecturers to monitor individual and group progress and identify students requiring additional guidance. The Artificial Intelligence feedback followed a structured format consisting of diagnosis, targeted scaffolding, and guiding questions to encourage metacognitive reflection. The platform did not use generative Artificial Intelligence or large language models due to institutional data privacy considerations, and all feedback was based on instructor-curated response libraries. This design ensured that Artificial Intelligence functioned as a pedagogical support system while lecturers retained academic supervision and decision-making authority (Wang et al., 2023; United Nations Educational, Scientific and Cultural Organization, 2023).

Research Procedure

The research was conducted over 16 weeks through three phases: preparation, intervention, and evaluation. In weeks 1 and 2, instructors participated in platform orientation and certification, while students received platform navigation training and completed digital literacy assessment. Pre-tests were administered to measure baseline problem-solving skills and confirm group equivalence. During weeks 3 to 14, the experimental group worked in groups of four to five students on authentic and complex problems, submitted reasoning outputs through the platform, received automated formative feedback within 24 hours, and participated in weekly 90-minute lecturer facilitation sessions. Meanwhile, the control group received conventional face-to-face lecture-based instruction, textbook-based exercises, and instructor feedback during scheduled question-and-answer sessions. In weeks 15 and 16, students completed post-tests for problem-solving skills and learning outcomes, while the experimental group also completed the Student Perception Questionnaire. All data were then checked, coded, and prepared for statistical analysis.

Data Analysis Techniques

Quantitative data were analyzed using IBM Statistical Package for the Social Sciences version 26.0. Descriptive statistics were used to calculate mean, standard deviation, minimum score, maximum score, and score distribution. Assumption testing was conducted using the Shapiro-Wilk test for normality and Levene's test for homogeneity of variance. Paired-samples t-tests were used to analyze within-group pre-test and post-test differences, while independent-samples t-tests were used to compare the experimental and control groups. A two-way Analysis of Variance was conducted to examine the effects of instructional condition and institution, while Analysis of Covariance was used to control for residual baseline differences using pre-test scores as a covariate. Effect size was calculated using Cohen's d and partial eta squared to determine the

practical magnitude of the intervention effect. Open-ended questionnaire responses were analyzed using inductive thematic analysis through coding, theme development, theme review, and interpretation (Braun & Clarke, 2021; Kang, 2021).

Ethical Considerations

This study followed ethical principles for research involving human participants. Ethical approval was obtained from the Research Ethics Board of Universitas Sultan Ageng Tirtayasa under reference number ETH/2025/042. All participants provided written informed consent before participating in the study, and they were informed about the study objectives, intervention procedures, data collection, confidentiality protection, voluntary participation, and the right to withdraw without academic penalty. Artificial Intelligence-related safeguards were also implemented, including lecturer oversight of automated feedback, institutional storage of student data, transparency regarding the role of Artificial Intelligence in the learning process, and restrictions on sharing student data with third-party commercial Artificial Intelligence vendors without explicit consent. These procedures were aligned with ethical guidance emphasizing data privacy, transparency, human agency, and responsible use of Artificial Intelligence in education (United Nations Educational, Scientific and Cultural Organization, 2023).

RESEARCH RESULT

Descriptive Statistics and Baseline Equivalence

The initial analysis was conducted to ensure that the experimental and control groups had comparable baseline conditions before the intervention was implemented. As presented in the methodology section, the four groups showed relatively similar characteristics in terms of age, pre-test problem-solving scores, prior Grade Point Average, and gender distribution. The mean pre-test scores of the Problem-Solving Ability Test ranged from 50.9 to 52.1, indicating that students from both institutions began the study with comparable problem-solving ability. Independent-samples t-tests and one-way Analysis of Variance confirmed that there were no significant baseline differences between the experimental and control groups at either institution in terms of pre-test problem-solving scores and prior Grade Point Average, with all significance values above .05. Assumption testing also showed that residuals were approximately normally distributed based on the Shapiro-Wilk test, with all p-values above .05, and that the variances were homogeneous based on Levene's test, with all p-values above .10. These results indicate that the data met the assumptions for parametric statistical analysis and that the groups were sufficiently equivalent before the intervention.

Effects of Artificial Intelligence-Supported Problem-Based Learning on Problem-Solving Skills

The first main finding concerns the effect of Artificial Intelligence-supported Problem-Based Learning on students' problem-solving skills. The results showed that all groups experienced statistically significant improvement from pre-test to post-test; however, the gains in the experimental groups were substantially higher than those in the control groups. At Al Khairiyah University, the experimental group increased from 52.1 to 78.5, with a gain of 26.4 points, while the control group increased from 51.8 to 61.3, with a gain of 9.5 points. At Serang Raya University, the experimental group increased from 50.9 to 76.2, with a gain of 25.3 points, while the control group increased from 51.2 to 60.8, with a gain of 9.6 points. These findings indicate that the students who received Artificial Intelligence-supported Problem-Based Learning demonstrated greater improvement in problem-solving skills than those who received conventional instruction.

Table 1.2 Pre-test and post-test problem-solving skill scores by group and institution

Institution	Group	Pre-test M (SD)	Post-test M (SD)	Gain	t-value	p-value	Cohen's d	95% Confidence Interval of Gain
Al Khairiyah University	Experimental	52.1 (11.4)	78.5 (8.9)	+26.4	15.23	< .001	2.48	[22.3, 30.5]
Al Khairiyah University	Control	51.8 (10.9)	61.3 (9.7)	+9.5	5.67	< .001	0.96	[6.1, 12.9]
Serang Raya University	Experimental	50.9 (11.6)	76.2 (9.3)	+25.3	14.18	< .001	2.36	[21.5, 29.1]
Serang Raya University	Control	51.2 (11.1)	60.8 (10.2)	+9.6	5.81	< .001	0.89	[6.3, 12.9]

Table 1.2 shows that the experimental groups at both institutions achieved larger gains than the control groups. The effect size for the experimental group at Al Khairiyah University was very large, with Cohen's $d = 2.48$, while the experimental group at Serang Raya University also showed a very large effect size, with Cohen's $d = 2.36$. In comparison, the control groups showed moderate to large improvements, but their gains were considerably smaller. Between-group analysis confirmed that the experimental group significantly outperformed the control group at Al Khairiyah University, $t(58) = 8.74$, $p < .001$, $d = 1.87$, 95% Confidence Interval [13.2, 21.1], and at Serang Raya University, $t(58) = 7.93$, $p < .001$, $d = 1.71$, 95% Confidence Interval [11.8, 19.8]. Across both institutions, the average gain of the experimental group was 25.85 points, which was approximately 2.7 times higher than the control group's average gain of 9.55 points.

Effects of Artificial Intelligence-Supported Problem-Based Learning on Learning Outcomes

The second main finding concerns student learning outcomes as measured by the Learning Outcome Examination. The results showed that the experimental groups achieved higher learning outcome gains than the control groups at both institutions. At Al Khairiyah University, the experimental group increased from 63.2 to 82.4, with a gain of 19.2 points, while the control group increased from 62.8 to 71.6, with a gain of 8.8 points. At Serang Raya University, the experimental group increased from 62.5 to 80.1, with a gain of 17.6 points, while the control group increased from 62.9 to 70.9, with a gain of 8.0 points. These results indicate that Artificial Intelligence-supported Problem-Based Learning was associated with higher academic achievement than conventional instruction.

Table 1.3 Learning outcome scores by group and institution

Institution	Group	Pre-assessment Mean (Standard Deviation)	Post-assessment Mean (Standard Deviation)	Gain	p-value
UNV	Experimental	63.2 (9.1)	82.4 (7.5)	+19.2	< .001
UNV	Control	62.8 (8.8)	71.6 (9.2)	+8.8	< .001
UNS	Experimental	62.5 (9.4)	80.1 (8.2)	+17.6	< .001
UNS	Control	62.9 (9.0)	70.9 (9.7)	+8.0	< .001

Table 1.3 shows that all groups improved significantly, but the magnitude of improvement was higher in the experimental groups. The two-way Analysis of Variance on post-test learning outcome scores showed a significant main effect of instructional condition, $F(1, 116) = 42.15$, $p < .001$, partial eta squared = .267, indicating a large effect. The main effect of institution was not significant, $F(1, 116) = 1.87$, $p = .174$, partial eta squared = .016, and the interaction between instructional condition and institution was also not significant, $F(1, 116) = 0.42$, $p = .519$, partial eta squared = .004. The experimental group achieved an average gain of 18.4 points, while the control group achieved an average gain of 8.4 points, with Cohen's $d = 1.34$ and 95% Confidence Interval [7.8, 12.2]. The proportion of students achieving scores of 80 or higher increased from 28% to 78% in the experimental group, whereas the control group increased from 25% to 35%.

Cross-Institutional Comparison of Intervention Effectiveness

The cross-institutional analysis was conducted to determine whether the effectiveness of Artificial Intelligence-supported Problem-Based Learning differed between Al Khairiyah University and Serang Raya University. The two-way Analysis of Variance on post-test Problem-Solving Ability Test scores showed no significant main effect of institution, $F(1, 116) = 1.23$, $p = .268$, partial eta squared = .011. The interaction between instructional condition and institution was also not significant, $F(1, 116) = 0.87$, $p = .353$, partial eta squared = .007. However, the main effect of instructional condition was significant, $F(1, 116) = 83.42$, $p < .001$, partial eta squared = .418. These results indicate that the intervention produced consistent benefits across both institutions and that

institutional context did not significantly moderate the effect of Artificial Intelligence-supported Problem-Based Learning on problem-solving skills.

Table 1.4 Summary of cross-institutional two-way Analysis of Variance results

Outcome Variable	Effect	F-value	p-value	Partial Eta Squared	Interpretation
Problem-solving skills	Instructional condition	83.42	< .001	.418	Significant large effect
Problem-solving skills	Institution	1.23	.268	.011	Not significant
Problem-solving skills	Condition × Institution	0.87	.353	.007	Not significant
Learning outcomes	Instructional condition	42.15	< .001	.267	Significant large effect
Learning outcomes	Institution	1.87	.174	.016	Not significant
Learning outcomes	Condition × Institution	0.42	.519	.004	Not significant

Table 1.4 summarizes the cross-institutional findings. The results show that instructional condition was the only statistically significant factor for both problem-solving skills and learning outcomes. Institution did not significantly influence the results, and there was no significant interaction between institution and instructional condition. This means that the effectiveness of Artificial Intelligence-supported Problem-Based Learning was relatively stable across the two institutions. These findings answer the fourth research question by showing that there was no significant cross-institutional difference in the effectiveness of the intervention.

Student Perceptions of Artificial Intelligence-Supported Problem-Based Learning

Student perception data were collected from 60 students in the experimental group using the Student Perception Questionnaire. The results showed positive responses across all five measured dimensions, with mean scores above 4.00 on a five-point Likert scale. The highest mean score was found in feedback relevance, with a mean of 4.48, followed by overall satisfaction with a mean of 4.42. Intention to continue using the model obtained a mean of 4.35, Artificial Intelligence prompt clarity obtained a mean of 4.32, and scaffolding effectiveness obtained a mean of 4.21. These results indicate that students generally perceived the Artificial Intelligence-supported Problem-Based Learning intervention as clear, relevant, useful, and satisfying.

Table 1.5 Student perception scores on the Student Perception Questionnaire

Dimension	Mean (Standard Deviation)	Score Range
AI prompt clarity	4.32 (0.78)	2–5
Feedback relevance	4.48 (0.65)	3–5
Scaffolding effectiveness	4.21 (0.82)	2–5
Overall satisfaction	4.42 (0.71)	3–5
Intention to continue	4.35 (0.74)	2–5

Table 1.5 shows that students' perceptions of the intervention were consistently positive. Feedback relevance received the highest score, indicating that students considered the formative feedback provided by the platform to be useful for improving their reasoning and learning process. Overall satisfaction and intention to continue also received high scores, suggesting that students accepted the learning model positively. The slightly lower mean score for scaffolding effectiveness indicates that some students may have required additional guidance in interpreting or applying the scaffolding provided by the system. Overall, these results answer the third research question by showing that students perceived Artificial Intelligence-supported Problem-Based Learning as clear, relevant, and beneficial.

Regression Analysis of Predictors of Problem-Solving Performance

Multiple regression analysis was conducted to identify predictors of post-test problem-solving performance. The model included learning condition, pre-test Problem-Solving Ability Test score, prior technology experience, and frequency of group participation as predictors. The regression model was statistically significant, $F(4, 115) = 51.38$, $p < .001$, and explained 64% of the variance in post-test problem-solving scores, with $R^2 = .64$. Learning condition was the strongest predictor, with standardized beta = .52 and $p < .001$. Other significant predictors included pre-test score, frequency of group participation, and prior technology experience.

Table 1.6 Multiple regression analysis predicting post-test problem-solving scores

Predictor	Standardized Beta	p-value	Interpretation
Learning condition	.52	< .001	Significant positive predictor
Pre-test problem-solving score	-.31	< .001	Significant negative predictor
Frequency of group participation	.24	.003	Significant positive predictor

Prior technology experience	.18	.021	Significant positive predictor
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Table 1.6 shows that participation in the Artificial Intelligence-supported Problem-Based Learning condition was the strongest predictor of post-test problem-solving performance. The positive coefficient for learning condition indicates that students in the experimental group tended to achieve higher post-test scores than students in the control group. The positive coefficient for group participation indicates that more frequent involvement in group activities was associated with higher problem-solving performance. Prior technology experience also had a positive effect, suggesting that students who were more familiar with digital tools may have benefited more from the platform. The negative coefficient for pre-test score indicates that students with lower initial problem-solving scores demonstrated greater relative improvement by the end of the intervention.

DISCUSSION

Interpretation of the Main Findings

The findings of this study show that Artificial Intelligence-supported Problem-Based Learning significantly improved students' problem-solving skills and learning outcomes in two Indonesian higher education institutions. The experimental group achieved a much higher mean gain in problem-solving skills than the conventional learning group, indicating that the intervention was more effective in supporting students' cognitive development. This result confirms that learning models based on authentic problems are highly relevant for strengthening students' capacity to analyze, formulate strategies, and implement solutions in higher education contexts. A recent meta-analysis by Atmaja et al. (2024) found that Problem-Based Learning had a strong positive effect on students' problem-solving skills in higher education, which supports the present finding that problem-centered instruction can produce meaningful learning improvement. However, the stronger gains in the present study suggest that the addition of Artificial Intelligence-supported feedback and scaffolding may further increase the effectiveness of conventional Problem-Based Learning.

The improvement in learning outcomes also indicates that Artificial Intelligence-supported Problem-Based Learning does not only affect students' problem-solving processes but also contributes to measurable academic achievement. Students in the experimental group achieved higher post-assessment scores and a larger proportion of them reached scores of 80 or above compared with the control group. This finding suggests that adaptive feedback, structured problem-solving activities, and lecturer-supervised monitoring may help students connect conceptual knowledge with practical application. Laak and Aru (2024) argue that Artificial Intelligence-supported personalized learning can improve learning performance when it is aligned with broader educational goals, including cognitive engagement and competency development. Therefore, the present findings indicate that Artificial Intelligence becomes pedagogically

meaningful when it is integrated into a structured learning model rather than used as an isolated technological tool.

Theoretical Contributions

This study contributes to the development of learning theory by showing that Artificial Intelligence-supported Problem-Based Learning can operationalize constructivist principles in a technology-supported environment. The findings demonstrate that authentic problem solving, adaptive scaffolding, formative feedback, and lecturer monitoring can work together to strengthen students' problem-solving skills and learning outcomes. The study also extends the theory of personalized learning by showing that personalization is more effective when it is connected to collaborative and problem-centered pedagogy. Laak and Aru (2024) emphasize that the future of personalized learning should not be limited to individualized digital pathways, but should also include collaboration and broader competency development. The present study supports this argument by showing that Artificial Intelligence-supported feedback was most effective when combined with group-based Problem-Based Learning and lecturer supervision.

The regression results also provide theoretical insight into the role of learner characteristics. Learning condition was the strongest predictor of post-test problem-solving performance, but prior technology experience and group participation also contributed significantly. This means that the effectiveness of Artificial Intelligence-supported learning depends not only on the platform itself but also on students' digital readiness and active engagement in collaborative learning. The negative coefficient for pre-test scores suggests that students with lower initial ability experienced greater relative improvement, indicating that adaptive scaffolding may help reduce learning gaps. This finding is important because it implies that Artificial Intelligence-supported instruction can support educational equity when it is designed to assist students who need additional guidance.

Practical Implications

The findings have practical implications for curriculum developers, lecturers, and institutional leaders. For curriculum developers, Artificial Intelligence-supported Problem-Based Learning can be used as an instructional model for courses that require analytical thinking, applied reasoning, and problem-solving competence. The results suggest that Artificial Intelligence should be embedded into learning activities through structured feedback, adaptive scaffolding, and clear problem-solving stages. For lecturers, the findings imply that their role should shift from information delivery to learning facilitation, feedback interpretation, and monitoring of student progress. Lecturer professional development is therefore necessary to strengthen competencies in Problem-Based Learning facilitation, Artificial Intelligence literacy, dashboard use, and data-informed instructional decision-making.

For institutional leaders, the study highlights the importance of phased and responsible implementation. McDonald et al. (2024) found that many universities have developed guidance for generative Artificial Intelligence use, but institutional guidance often places additional burdens on lecturers when pedagogical expectations are not clearly supported. This suggests that higher

education institutions should not only provide access to Artificial Intelligence tools, but also develop clear policies, ethical guidelines, technical support, and training mechanisms. In the Indonesian higher education context, a phased implementation can begin with courses where problem solving is a core learning outcome, such as education, engineering, health sciences, business, and information technology. This approach may reduce implementation risks while allowing institutions to evaluate readiness, student response, and learning impact gradually.

Limitations and Recommendations for Future Research

Several limitations should be acknowledged. First, the intervention lasted 12 weeks, so the study cannot determine whether the gains in problem-solving skills and learning outcomes would be sustained over a longer period. Future research should conduct longitudinal follow-up to examine retention of learning gains and transfer of problem-solving skills to new contexts. Second, although baseline equivalence was confirmed, the non-equivalent control group design cannot fully eliminate possible selection effects. Future studies should consider randomized controlled trials or larger cluster-based designs to strengthen causal inference.

Third, the study was conducted only in two institutions in Banten Province, which limits geographical generalizability. Future research should involve universities from different regions in Indonesia and include institutions with varied technological infrastructure, student demographics, and disciplinary backgrounds. Fourth, this study used a template-based Artificial Intelligence feedback system rather than a generative Artificial Intelligence system, so the findings may not directly apply to learning environments using large language models. Future studies should compare rule-based Artificial Intelligence, generative Artificial Intelligence, and hybrid Artificial Intelligence models to determine their relative effectiveness, risks, and ethical implications. Fifth, the study did not include cost-benefit analysis, so future research should examine implementation costs, lecturer workload, infrastructure requirements, and long-term institutional sustainability.

CONCLUSIONS AND RECOMMENDATIONS

This study concludes that Problem-Based Learning supported by Artificial Intelligence has a significant positive effect on students' problem-solving skills and learning outcomes in Indonesian higher education. Students who participated in the PBL-AI intervention achieved substantially higher gains than those who received conventional instruction, both in problem-solving ability and academic learning outcomes. The consistency of results across Al Khairiyah University and Serang Raya University indicates that the intervention can be applied effectively in different institutional contexts when supported by structured instructional design, validated instruments, lecturer supervision, and adequate technological preparation. Student responses also showed positive perceptions of AI prompt clarity, feedback relevance, scaffolding effectiveness, satisfaction, and intention to continue using the model. These findings confirm that AI-enhanced PBL can serve as a pedagogically meaningful approach for

improving higher education learning quality, particularly when AI is used as a supportive tool rather than a replacement for human instruction.

Based on these findings, higher education institutions are recommended to integrate AI-supported PBL gradually into courses that emphasize problem-solving, analytical thinking, and applied knowledge. Lecturers should receive professional development in PBL facilitation, AI literacy, data-informed teaching, and ethical management of AI-supported learning environments. Curriculum developers should design AI-supported learning activities that include authentic problems, adaptive feedback, structured scaffolding, collaborative learning, and reflective evaluation. Institutional leaders should also ensure that AI implementation follows ethical principles, including informed consent, transparency, data privacy protection, and human oversight. Therefore, the adoption of PBL-AI should be treated not only as a technological innovation but also as a pedagogical and ethical transformation in higher education.

ADVANCED RESEARCH

Future research should extend the scope of this study by conducting longitudinal investigations to examine whether the effects of PBL-AI on problem-solving skills and learning outcomes are sustained beyond the 12-week intervention period. Further studies are also recommended to use randomized controlled trial designs where individual random assignment is feasible, involve broader institutional and regional samples, and replicate the model across different disciplines such as engineering, health sciences, business, teacher education, and information technology. In addition, future research should compare rule-based AI, generative AI, and hybrid AI platforms as scaffolding tools in Problem-Based Learning environments. Cost-effectiveness analysis is also needed to evaluate infrastructure requirements, lecturer workload, implementation costs, and long-term institutional sustainability. These directions will strengthen empirical evidence on the scalability, ethical feasibility, and practical value of AI-supported Problem-Based Learning in higher education.

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