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Enhancing Elementary Students' Mathematical Problem-Solving Skills Through AI-Assisted Problem-Based Learning

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Abstract

The purpose of this study was to investigate the effectiveness of the use of AI assisted PBL on enhancing elementary school students' mathematical problem-solving skills. Inspired by the persisting issues in developing skills of elementary school students in Indonesian, this study investigated whether AI-supported PBL might be more a promising method of instruction than traditional teaching method. Quasi-experimental with non-equivalent control group design was applied with 5th graders (N = 60). The experimental group was taught using AI-assisted PBL, and the control group was taught by traditional method. An established test based on Polya's heuristic devised was used to collect data. Descriptive statistics, independent samples t-test, and N-Gain analysis were used to analyze the data. The results showed a significant difference ($p < 0.05$) in the two groups with respect to all indicators (comprehending the problem, formulating a plan, executing the plan and evaluating the solution); for the experimental group (M = 78.40; SD = 7.20) exceeded the control groups (M = 68.10; SD = 8.50). In addition, the treatment group exhibited a high N-Gain score (M= 0.78). The findings suggest that using AI-assisted PBL is an effective way to promote elementary students' mathematical problem-solving ability, which indicates the role of integrating modern technology with creative pedagogical pattern in math teaching.

INTRODUCTION

The application of technology with regard to the Artificial Intelligence (AI) in the field of education has become a significant issue, particularly in an at tempt to refine student problem solving ability in mathematics (Hosseini et al., 2023). Observations of the current situation in the subject also reveal that even at primary school, only a very small fraction of students is able to solve mathematical problems, even simple ones, and especially word problems or problems that require more than a single step in their solution (Myers et al., 2022). This is reflected in the below average student levels in minimum competency testing and PISA, particularly in the problem-solving domain (Delafia Maghfiroh & Wahyuningsih, 2024). One certain effect is that the students do not have ability on transforming the realistic problems into the mathematical ones and selecting suitable solution methods. This is also aggravated by the absence of technology, and in particular AI, in lower elementary mathematics learning, despite its strong potential in personalising learning and giving adaptive feedback (Pramuditya et al., 2022).

Problem-Based Learning (PBL) is a sound educational strategy in theory to develop learners'problem solving abilities (Alreshidi & Alreshidi, 2023; Supriatna et al., 2024). In PBL, students will have active learning experiences where they plan problems, explore solutions, and evaluate their work (Supriatna et al., 2024; Wang, 2022), Consistent with constructivist theory, PBL is predicated on the notion that students learn through doing and talking. The incorporation of AI in PBL could provide opportunities for personalized, adaptive learning in enhancing mathematical problem-solving. The objective of this integration is to link theoretical learning with applied learning in mathematics teaching (Barus et al., 2025; Schunk, 2012).

Mathematical Problem-Solving Ability involves more than just procedural understanding; it encompasses complex cognitive processes like comprehension, strategizing, execution, and verification (Polya, 2014). Affective elements such as being confident or being persistent are as well important (Krulik & Rudnick, 1987). PBL is another effective strategy that is learner-centred, where problems form the stimulus for learning and fits well in building this capability. AI can make this process easier and much faster for us to build and understand (Rachmadtullah et al., 2024).

There is evidence that PBL is more effective than the traditional teacher-centred approach for teaching mathematical problem solving (Ajeng Julia et al., 2025; Saputra, 2022). In addition, research shows that AI supported PBL helps motivate involvement, provides personalized-feedback and promotes complex thinking(Azman & Tümkaya, 2025; Canonigo, 2024; S. Hwang, 2022). However, studies investigating the effect of AI-integrated PBL on math problem-solving for students at the elementary level are still scarce (Chau et al., 2025; Yusuf, 2025).

A disparity also exists between the theory and the practice on the effect on maths problem-solving ability of AI-based PBL for elementary school students. Even if PBL and AI are of theoretically high potential, there are several obstacles remaining in the practical use. An issue identified among these inconsistencies is the underuse of AI in facilitating the PBL process. According to some researches, AI is used as a traditional learning tool more than it is an element of the PBL (Ahdhianto et al., 2020; Davis, 2024).

One of the alternative solutions can be designed and executed in an integrated and contextual AI-based PBL model at an elementary school level. This model should take into account background of students, infrastructure and teacher capacities. There is also the need to create interactive and user-friendly AI-driven teaching materials. Furthermore, it is also important to train teachers in terms of the actual application of AI-supported PBL.

The focus of this research is the imperative to narrow the gap between expected and actual gains in 3 rd - 5 th grade students problem-solving performance in mathematics. The results are expected to support the development of new and effective learning models and offer suggestions to support educators, curriculum developers, and policy makers in their crucial endeavor towards improving the quality of mathematics education in Indonesia. Developing these problem-solving skills will support students in being prepared for life in the 21st century and will give them valuable tools for successful futures.

METHODS

As experimental research, this research used nonequivalent control group design, which is one type of quasi-experimental design to determine the effect of AI-assisted Problem-Based Learning (PBL) to students' mathematical problem solving. The subjects of this research were 60 students of the fifth grade at SDIT Baitul Jannah, Bandar Lampung. They had quite homogeneous age (10-11 years) and social-economic characteristics.

Participants were randomised to receiving AI-integrated PBL (experimental group) or traditional lecture (control group). Ethical considerations, such as obtaining informed consent from the school management, parents and students, as well as ensuring anonymity, confidentiality and accessibility, have been taken care of. The study was approved by the ethics board/committee.

Data were gathered with a mathematics problem-solving test designed according to Polya's model—consisting of four steps in problem solving, namely, understand the problem, devise a plan, carry out the plan, and look back. Items were constructed to measure each of these dimensions (Purba et al., 2021; Rosiyanti et al., 2021). The instrument was concurrently validated for first face and content and then form and style by experts. Content validity of the test items in relation to the curriculum objectives was ensured, and clarity, readability and age appropriateness were evaluated by experts of the instrument. Revisions were made as needed. A pilot study of the similar sample not included in the study was conducted. Internal consistency or reliability using Cronbach's Alpha was 0.87, indicating that the instrument was reliable and presented good internal consistency.

The data were analyzed through SPSS version 25. Normality and homogeneity of variance were verified before hypothesis testing. After the assumptions of parametric test were verified, an independent samples t-test was conducted to compare the two groups regarding mathematical problem-solving performance. In addition, n-gain analysis was appied to investigate the effectiveness of the use of AI assisted PBL on enhancing elementary school students' mathematical problem-solving skills.

RESULTS

This section presents the results of the implementation of the AI-assisted Problem-Based Learning (PBL) model in the experimental group and the traditional method in the control group. The data were obtained from pre-test and post-test scores related to the students' mathematical problem-solving abilities.

1. Descriptive Statistics of Mathematical Problem-Solving Ability

Descriptive statistics were used to examine the performance of students in both groups. As shown in Table 1, the means, standard deviations, and variances of the final test scores were analyzed.

Table 1. Descriptive Statistics of Mathematical Problem-Solving Skills

Group	N	Mean	Standard Deviation (SD)	Variance
Experiment	30	78.40	7.20	51.84
Control	30	68.10	8.50	72.25

Source: Results of research data analysis

The results showed that the average score of students in the AI-supported PBL group (M = 78.40, SD = 7.20) was higher than that of the control group (M = 68.10, SD = 8.50). This suggested that the intervention had a positive effect on students' mathematical problem-solving abilities.

To provide a more detailed analysis, the results were further examined based on Polya's four-phase problem-solving model: understanding the problem, devising a plan, implementing the plan, and evaluating the solution. The mean scores of these indicators in both groups are presented in Figure 1.

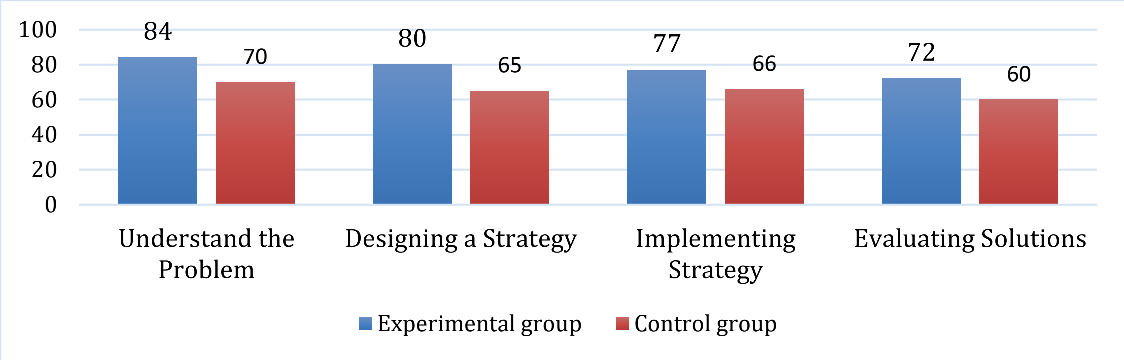

Figure 1. Comparison of Problem-Solving Indicator Achievement between Experimental and Control Groups

Source: Results of research data analysis

Figure 1 showed that the experimental group outperformed the control group across all four indicators: (1) Understanding the Problem: Experimental group = 84; Control group = 70; (2) Designing a Strategy: Experimental group = 80; Control group = 65; (3) Implementing the Strategy: Experimental group = 77; Control group = 66; (4) Evaluating the Solution: Experimental group = 72; Control group = 60. These results indicated that the AI-based PBL model improved students' performance throughout the entire problem-solving process, particularly in the initial phase of understanding the problem.

2. Assumption Testing for Hypothesis Testing

Before conducting hypothesis testing, assumption checks were performed to confirm the suitability of parametric analysis.

Table 2. Shapiro-Wilk Normality Test

Group	Statistic	df	Sig. (p)
Experiment	0.958	30	0.123
Control	0.940	30	0.087

Source: Results of research data analysis

The Shapiro-Wilk test results indicated that the data in both groups are normally distributed ($p > 0.05$).

Table 3. Levene's Test of Homogeneity

Test	F	df_1	df_2	Sig. (p)
Varians	1.188	1	58	0.276

Source: Results of research data analysis

The results of Levene's Test confirmed that the assumption of homogeneity of variances was met ($p = 0.276$, $p > 0.05$). Hence, the data were appropriate for independent samples t-test.

3. Independent Samples t-Test Results

An independent samples t-test was conducted to determine whether the difference in mathematical problem-solving abilities between the two groups was statistically significant. The results are presented in Table 4.

Table 4. Independent Samples t-Test

Group	Mean	SD	t	df	Sig. (2-tailed)
Experiment and Control	78.40	7.20	5.21	58	0.000

Source: Results of research data analysis

The results in Table 4 showed that the p-value was 0.000 ($p < 0.05$), indicating a statistically significant difference between the experimental and control groups. This finding confirmed the hypothesis that AI-assisted PBL was more effective than traditional teaching in improving students' problem-solving abilities.

4. N-Gain Test Results

To measure the improvement in learning, an N-Gain test was conducted by comparing the pre-test and post-test scores in the experimental group. The average normalized gain was 0.78, which was categorized as a high gain. This indicated that the intervention effectively enhanced students' understanding and learning outcomes in mathematical problem-solving. The high N-Gain value served as further evidence of the effectiveness of the AI-assisted PBL model in improving students' abilities.

DISCUSSION

In this study, the integration of PBL with AI in the domain of elementary school mathematics has been found to have a large positive effect. Published data show that the experimental group, with PBL accompanied by AI, obtained an average value of 78.40, and the control group with classical methods, only 68.10. This is a noticeable distinction in mathematical problem-solving capacity of learners among the categories of two groups that clearly support the utility of interactive learning methods that involve technology use in the teaching-learning process as enkindled evidence (Nugraha & Lestari, 2023). These results are consistent with the notion that more dynamic and constructive teaching can be associated with superior academic performance, particularly in complex domains like mathematics (Nst et al., 2023).

The research evidence almost unanimously suggests that AI can increase students motivation to learn, improve the interactivity of learning and help teacher in that process, designing and modifying mathematical tasks (Qawaqneh et al., 2023; Walkington, 2025). Moreover AI-based PBL assists students in learning and acquiring the abilities of critical thinking and problem-solving, which are essential in tackling 21st-century problems (Kim et al., 2025; Ssali et al., 2025). In this regard, these research results support the assumption that active problembased learning enhanced by advanced technologies, such as AI, contributes remarkably to the learning outcomes of mathematics in both cognitive and affective dimensions (G. J. Hwang & Tu, 2021; Opesemowo & Adewuyi, 2024; Qiu et al., 2022).

The result of this study supports Piaget's argument that learners learn best when they are active and construct their own understanding based on experience. In such an environment, AI acts as not just an aid but an interactive instrument, helping learners to grasp concepts through meaningful problems and feedback. Prior studies have also emphasized the importance of PBL in promoting student's active seeking of solutions and participation in the learning process (Negara et al., 2023; Rajagukguk & Hazrati, 2021). This is in line with constructivist teaching methodologies, in which learning occurs in a manner that stimulates students' interest and comprehension by real-world problematical situations.

Secondly, within Anderson's theory of cognitive learning, attention should also be paid to students' sense making with respect to new material and the subsequent refashioning of their cognitive structures. Anderson stressed that learning theory should reflect learners' capacity to adjust to new knowledge. In the current case, AI served as an active agent and provided feedback to students in a timely and focused manner, enabling them to adjust their own thinking about mathematical concepts in a timely manner (Rahmat et al., 2023). This corresponds to other research findings which infer AI technology to be beneficial in the classroom setting and that there is a notable effect of students' mathematical concept comprehension (Jaya & Kelana, 2022).

Furthermore, Bandura's social cognitive learning theory sheds more light on the role of social interaction in learning. While the dimension of observational learning was not directly considered by this study, AIs ability to provide the learning environment with the lively problem-solving landscape, in which students can develop self-efficacy, was demonstrated. When students have constant and individual feedback, it increases their motivation to learn (Rajagukguk & Hazrati, 2021).

The use of AI in mathematics learning is consistent with the differentiation learning theory and Vygotsky's theory of scaffolding in which technology acts as a "tool" that enhances students' zones of proximal development (G. J. Hwang & Tu, 2021). According to Vygotsky's Zone of Proximal Development (ZPD) AI is an intelligent scaffold that adapts at each student's level of difficulty. This method offers opportunities for learners to develop and learn within their ZPD with appropriate help (Wardani et al., 2024). In general, the results of this study support the notion that integrating PBL techniques with AI can improve not only the students' problem-solving performance in mathematics, but also the manner in which they perceive the process itself. This enhancement is reflected in each of Polya's problem-solving criteria, justifying students' advancement to a systematic view of it and the progression in cognitive development (Negara et al., 2023).

In line with various previous studies, this study provides evidence supporting the success of PBL in improving learning outcomes (Yusri, 2018). More importantly, it addresses a gap in the existing literature, in which most previous studies focused on either PBL or AI in isolation without examining the synergistic interaction between the two (Choridah, 2013). The results of this study indicate the importance of integration in mathematics teaching and require contextual adaptation based on the characteristics of Indonesian students locally. This research is especially interesting because Indonesia is one of the lowest ranked countries in international tests of mathematical literacy, e.g., the Programme for International Student Assessment (PISA). The case in this study was SDIT Baitul Jannah in Lampung, which provides useful information for local educational implementation (Kencanawaty et al., 2020).

According to the research results on the fusion of PBL and AI in elementary mathematics education, several implications for educational policy and teaching practices can be drawn as follows:

1. Enhanced Learning Performance and Interaction Quality: Studies have also shown that combining PBL and with an AI support component has a positive effect on conceptual knowledge, confidence, and engagement during mathematics learning (Canonigo, 2024; Ramos & Condotta, 2024). Students in the experimental conditions, who underwent these intervention programs, obtained superior problem-solving skills scores compared to control groups (S. Hwang, 2022; Nugraha & Lestari, 2023). This implies that using AI tools such as ChatGPT, GeoGebra, and interactive simulations might enrich a more personalized and meaningful b-learning experience, with students being more active during the learning process.
2. Responsive and Meaningful Curriculums Development: These results echo the significance of reshaping the elementary school curriculum, so that it comprises problem-solving technologies and highlights the development of critical thinking and cooperation skills (Bayaga, 2024; Canonigo, 2024). AI-enhanced models of learning like the one we've shown in the primaryAI program and game-based initiatives show promise as a way of making learning more deep and connected to the real world (Glazewski et al., 2022; Ottenbreit-Leftwich et al., 2022). Thus, the orientation of the curriculum should be aimed at fostering it from an early age.
3. Continuous Professional Development for Teachers: Teachers should be empowered with continuous professional development to promote the effective usage of AI and PBL. Studies underline the need to provide teachers with technical training, scaffolding, and capacity building to design

individualized pedagogical experiences when integrating AI in the classroom (Canonigo, 2024; Glazewski et al., 2022; Ottenbreit-Leftwich et al., 2022). The teacher's work is still at the centre of guidance for learning and curriculum design in cooperation will make the material more relevant to student needs.

4. Equitable Access and Closing the Education Gap: AI can greatly reduce educational access gaps by enabling more personalized, adaptable and affordable learning support (Canonigo, 2024). Adaptive learning platforms and intelligent tutoring systems facilitate learning experiences based on the individual needs of students coming from different starting points (Khazanchi et al., 2025). However, this still requires attention to challenges such as unequal access to technology, the risk of dependency, and infrastructure readiness (Henny Sutrisman et al., 2024).
5. Balancing Technological Innovation with Sound Pedagogy: Although AI brings various opportunities, its implementation in education must be carried out with careful planning and maintain pedagogical principles as the main foundation. Innovation should not sacrifice the quality of human interaction in education (Canonigo, 2024; Nguyen et al., 2023; Ramos & Condotta, 2024) Therefore, education policies must encourage the wise integration of technology to create an inclusive and meaningful learning environment for all students.

The implications of this research indicate that the implementation of AI-based PBL has significant potential to improve the quality of mathematics learning in elementary schools. However, its successful implementation depends heavily on adaptive curriculum design, teacher support, and policy commitment to ensuring equitable access. Strategic measures by national and regional educations policies will have to be planned in a timely manner to facilitate a systematic and sustainable embedding of PBL and AI into all elementary education units.

This study acknowledges several limitations. These and other confounders may be introduced with use of a quasi-experimental, nonequivalent-control group design. Yet, the small sample size (a single school with 60 students) may not be representative of Indonesia's student allocation elsewhere. Vagueness of the intervention period makes us skeptical of the long-term effect of this approach. In addition, the mathematical problem-solving measures were expert-validated but potentially do not assess the full range of problem solving processes. The cognitive learning effect of AI-assisted PBL is mainly investigated in this study, and the effect on non-cognitive aspects (e.g., motivation, collaboration skills) is another research issue that needs to be addressed for a full understanding of AI-assisted PBL in the educational context in further research.

CONCLUSION

The Problem-Based Learning (PBL) method combined with Artificial Intelligence (AI) was effective enough to improve students' mathematical problem solving abilities at the elementary school level. This enhancement can clearly be observed in the lift in all problem solving measures, indicating that AI promote understanding at a finer level of concepts and the structured evolution of the student's cognitive capabilities. The results support perceptive and cognitive learning theories that are based on the significance of active student participation and adaptative feedback in learning.

This study makes a significant contribution to the development of interactive and adaptive learning models in the digital age. The combination PBL and AI not only contributes to the improvement of mathematical problem solving but also addresses problems in the education area, especially to tackle the current poor mathematics literacy in Indonesia. The use of AI in learning also has the ability to deliver a more personalised, fairer education system, which in turn leads to a better standard of education for all.

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