*Pedagog. Rev., 5(2), 223-232, June, 2026*

**Pedagogy Review**

ISSN: 3025-6771 | Journal's DOI: 10.61436/pedrev

Homepage: https://imrecsjournal.com/journals/index.php/pedrev

# Problem-Based Learning in Algebra: Fostering Critical Thinking Skills Among Middle School Students

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**ARTICLE INFO**

***Article History:***

Received: 29 April 2026

Accepted: 01 June 2026

Published: 30 June 2026

***Keywords:***

Problem-based learning;

Critical thinking skills;

Algebra;

Middle school students.

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**ABSTRACT**

This study examines the effectiveness of Problem-Based Learning (PBL) in improving Grade 8 students' critical thinking skills in algebraic problem solving. A quasi-experimental design was employed with 53 students, divided equally between an experimental group receiving PBL instruction and a control group receiving conventional instruction. Students' critical thinking abilities were measured with pre- and post-tests, and the data were analyzed with independent-samples t-tests, paired-samples t-tests, normalized gain (N-gain), and effect size. The results revealed that both groups had comparable initial abilities, as indicated by the non-significant difference in pre-test scores. However, after the intervention, the experimental group achieved a significantly higher mean score compared to the control group ($p < 0.001$). Within-group analysis showed that both groups improved significantly, but the magnitude of improvement was substantially greater in the PBL group. This is further supported by the N-gain results, which showed that the experimental group reached the moderate-to-high category, while the control group remained in the moderate category. The calculated effect size ($d = 1.26$) indicates a strong practical impact of PBL on students' critical thinking skills. Additionally, gender-based analysis showed no significant differences, suggesting that PBL is equally effective for both male and female students. These findings indicate that Problem-Based Learning (PBL) creates a more effective environment for enhancing students' critical thinking skills through structured problem-solving activities, collaborative discussions, and reflective reasoning processes. The study emphasizes the significance of student-centered learning approaches in mathematics education and recommends integrating PBL into classroom instruction to promote higher-order thinking skills and deeper conceptual understanding among students.

***To cite this article:***

Ovan et al. (2026). Problem-based learning in algebra: Fostering critical thinking skills among middle school students. *Pedagogy Review*, *5*(2), 223-232. doi: https://doi.org/10.61436/pedrev/v5i2.pp223-232



## INTRODUCTION

In the context of 21st-century education, the development of critical thinking has become a central objective of mathematics instruction worldwide. Rapid advancements in science, technology, and information systems demand that students not only acquire knowledge but also develop the ability to analyze, evaluate, and synthesize information in solving complex and unfamiliar problems. Within mathematics education, critical thinking is particularly essential, as the discipline inherently requires logical reasoning, abstraction, and the construction of coherent arguments. Scholars consistently emphasize that learning mathematics is not just about performing procedures, but about thinking mathematically, involving exploration, justification, and reflection (Schoenfeld, 2016).

Despite its recognized importance, a substantial body of research indicates that students' critical thinking skills in mathematics remain relatively underdeveloped, especially in secondary education contexts. One of the primary contributing factors is the persistence of teacher-centered instructional practices that emphasize procedural fluency over conceptual understanding (Hiebert & Grouws, 2007). In such environments, students are often positioned as passive recipients of knowledge, relying heavily on memorization and routine procedures rather than engaging in meaningful reasoning processes. Consequently, they struggle to apply mathematical concepts in unfamiliar or real-world situations, limiting their capacity for higher-order thinking.

The issue becomes particularly evident in algebra, a foundational pillar of secondary mathematics education. Algebra is not only a gateway to advanced mathematical topics but also a critical medium for developing abstract reasoning and generalization skills (Sa'adah et al., 2023; Hidayah et al., 2023). It requires students to interpret symbolic representations, identify patterns, formulate generalizations, and model real-world phenomena mathematically (Kieran, 2007). However, empirical evidence consistently shows that students encounter significant difficulties in algebraic problem solving. These challenges include translating contextual problems into algebraic expressions, manipulating symbols meaningfully, and constructing logical solution strategies (Stacey & MacGregor, 2000). Such difficulties are closely linked to students' limited critical-thinking abilities, suggesting that improving algebra learning outcomes requires instructional approaches that explicitly foster reasoning and analytical thinking.

From a theoretical perspective, critical thinking in mathematics encompasses a range of cognitive processes, including interpretation, analysis, evaluation, inference, and reflection. These processes are essential for meaningful problem-solving, as they enable students to examine assumptions, justify their reasoning, and draw valid conclusions. However, recent studies indicate that students' mathematical critical thinking skills remain low, particularly due to instructional practices that prioritize procedural competence over deep conceptual engagement (Aritonang et al., 2024). As a result, there is a pressing need for pedagogical approaches that actively involve students in constructing knowledge through inquiry and problem-solving.

One instructional approach that has gained considerable attention in addressing these challenges is Problem-Based Learning (PBL). Rooted in constructivist learning theory, PBL positions students as active participants in the learning process, in which knowledge is constructed through engagement with authentic, meaningful problems. Rather than receiving information passively, students work collaboratively to investigate problems, formulate hypotheses, test solutions, and reflect on their learning experiences (Lestari et al., 2020; Ahmad et al., 2023; Purnomo et al.,2024).

According to Hmelo-Silver (2004), PBL promotes deeper understanding by encouraging learners to integrate prior knowledge with new information through exploration and inquiry. Similarly, Savery (2006) highlights that PBL supports the development of critical thinking by requiring students to analyze complex problems, generate and evaluate alternative solutions, and justify their reasoning systematically.

A growing body of empirical research supports the effectiveness of PBL in enhancing students' critical thinking and problem-solving abilities. A meta-analysis conducted by Dochy et al. (2003) revealed that PBL has a significant positive impact on students' skill development, particularly in problem solving and the application of knowledge. In the context of mathematics education, English and Gainsburg (2016) argue that problem-based approaches provide meaningful opportunities for students to develop reasoning and analytical thinking skills. More recent studies further confirm these findings. For instance, Zetriuslita et al. (2023) found that PBL enhances both critical thinking and mathematical problem-solving abilities by engaging students in real-world contexts that require active inquiry.

The effectiveness of PBL has strengthened mathematics learning across various domains, with students participating in PBL-based learning achieving higher critical-thinking performance than their peers in traditional classrooms (Maharani & Laelasari, 2017). Meta-analytic evidence also indicates that PBL has a consistently positive effect on mathematical critical thinking. However, the magnitude of this effect may vary with instructional duration, implementation quality, and classroom context (Nugraha & Suparman, 2021). Furthermore, research by Izzaroh et al. (2025) highlights that PBL facilitates the development of critical thinking across different mathematical topics by providing structured opportunities for reasoning, discussion, and reflection.

Despite these promising findings, there remains a notable gap in the literature. Much of the existing research on PBL has focused on general mathematics achievement or isolated aspects of thinking skills, without providing a detailed examination of how critical thinking develops within specific mathematical domains such as algebra (Abrenica, 2025; Sánchez-García & Reyes-de-Cózar, 2025; Meiliati et al., 2026). Moreover, previous studies often emphasize learning outcomes rather than the underlying learning processes and cognitive mechanisms that cultivate critical thinking. In particular, there is limited research that investigates how PBL facilitates the development of critical thinking in algebraic problem solving at the middle school level, where students are transitioning from concrete to abstract mathematical thinking.

Addressing this gap is crucial, as understanding the processes through which students develop critical thinking can inform more effective instructional practices. Classroom-based empirical studies are needed to provide rich, contextualized insights into how PBL can be implemented to support students' cognitive development in algebra. Such studies can contribute not only to theoretical advancements in mathematics education but also to practical guidance for teachers seeking to design meaningful and engaging learning experiences (Yuliana & Firmansah, 2018; Maulidia et al.,2019).

Accordingly, this study is directed toward exploring how Problem-Based Learning supports the development of students' critical thinking skills in algebraic problem solving, the extent to which this instructional approach enhances critical thinking compared to conventional instruction, and how students' engagement throughout the learning process contributes to the development of their mathematical reasoning, analytical, and reflective abilities. Furthermore, this study also considers the possibility of gender-related differences in the development of critical thinking skills within a problem-based learning environment. By providing in-depth empirical evidence, this research is expected to contribute to the growing body of literature on PBL and critical thinking, while offering practical insights for improving the quality of mathematics teaching and learning in the 21st century.

## ■ METHOD

### Research Design and Procedures

This study employed a quasi-experimental design with a non-equivalent control group to investigate the effect of Problem-Based Learning (PBL) on students' critical thinking skills in algebraic problem solving. The design was selected to maintain the natural structure of classroom learning while enabling a rigorous comparison between instructional approaches. A pre-test–post-test design was incorporated to capture students' learning progression and control for initial differences between groups, thereby strengthening the study's internal validity.

The learning intervention in the experimental group was designed to embody the principles of Problem-Based Learning, emphasizing active engagement, inquiry, and collaboration. Learning activities began with the presentation of contextual, meaningful algebra problems, encouraging students to explore and construct their understanding rather than simply apply formulas. Students collaborated to identify key elements of the problem, formulate possible solution strategies, and investigate mathematical relationships through guided inquiry. They then developed and presented their solutions, followed by a reflective discussion to evaluate the correctness of their answers and the reasoning processes involved. In contrast, the control group received conventional instruction characterized by teacher explanations, demonstrations of procedures, and individual practice exercises, with a primary focus on procedural fluency. Conventional instruction placed the teacher and textbook as the primary sources of information in the learning process. In the experimental class, the intervention was conducted over six weeks, with only one meeting per week, each meeting lasting 80 minutes (2 x 40 minutes), covering important algebraic topics such as systems of linear equations. For example, students were given a problem related to a system of linear equations in two variables. They then discussed, investigated in groups, presented their results, and drew conclusions. For example, "There are 40 cars and motorcycles in a parking lot. The total number of wheels on each vehicle is 124. Determine the number of cars and motorcycles". Using this example, the teacher can ask students to draw illustrations of vehicles, identify more than one solution, and explain the reasoning behind their answers.

Data collection was carried out in three stages. Initially, a pretest was administered to both groups to assess students' baseline critical-thinking abilities in algebra. This was followed by the implementation of the instructional treatments, during which the experimental group engaged in Problem-Based Learning, while the control group received conventional instruction. At the end of the intervention, a post-test was administered using the same instrument to evaluate changes in students' critical thinking skills. All assessments were conducted under standardized classroom conditions to ensure consistency and fairness.

Throughout the study, ethical considerations were carefully observed. Permission was obtained from the school, and students' participation was voluntary. All data were treated confidentially, and participants' identities were anonymized to protect their privacy. Overall, the methodology was designed to ensure coherence between the instructional approach, the learning context, and the measured outcomes, thereby providing a robust framework for examining how Problem-Based Learning can foster students' critical thinking skills in algebraic problem solving.

### Participants

The participants consisted of 8th-grade students from Bajiminasa Junior High School in Makassar City, where algebra is a central component of the mathematics curriculum. Two whole classes of approximately 53 students were purposively selected and given tests to assess similarity in academic background, previous mathematics achievement (test scores and semester report card scores), and similar exposure to the curriculum. One class was assigned as the experimental group and received instruction through Problem-Based Learning. In contrast, the other class served as the control group and was taught using conventional teacher-centered methods. This arrangement allowed the study to reflect authentic classroom conditions while maintaining comparability between groups.

### Instruments

To measure students' critical thinking skills, the researchers developed a four-item test consisting of open-ended questions related to real-life situations. Each test item was given a maximum score of 10 (range 0-10). These scoring guidelines are based on student responses to test questions. Researchers have established a scoring rubric in which students receive a score of 10 for correct answers, 5 for somewhat correct answers, and 0 for incorrect answers. This instrument was designed to capture various dimensions of critical thinking, as outlined in Facione's framework, including interpretation, analysis, evaluation, and inference. Students were not only required to obtain correct answers but also to justify their reasoning, construct algebraic models, and evaluate alternative solution strategies. Prior to implementation, the instrument underwent expert validation by mathematics education specialists to ensure content relevance and alignment with the targeted constructs, using a Likert scale of 0-4; the results were valid in both content and the targeted constructs. A pilot study was also conducted to examine the instrument's reliability, with results showing a Cronbach's alpha coefficient of 0.73, indicating acceptable internal consistency.

### Data Analysis

The collected data were analyzed using descriptive and inferential statistical methods. Before hypothesis testing, prerequisites were met to ensure that the data met the parametric statistical assumptions. Data normality was tested using the Kolmogorov-Smirnov and Shapiro–Wilk test, while homogeneity of variance between groups was tested using the Levene test. The test results showed that all data were normally distributed and homogeneous at the 0.05 significance level. Furthermore, the Independent Samples T-Test was used to compare post-test results between the experimental and control groups. In contrast, the Paired Samples T-Test was used to examine improvement within each group. To provide a more comprehensive measure of learning outcome improvement, normalized gain (N-gain) was calculated, and the magnitude of the effect of a particular treatment was calculated using Cohen's d. All statistical analyses were conducted at a significance level of 0.05.

## ■ RESULT AND DISCUSSION

The study involved 53 Grade 8 students, comprising 25 males and 28 females, divided into an experimental group (Problem-Based Learning) and a control group (conventional instruction). Prior to the intervention, a pre-test was conducted to ensure equivalence between the two groups in their initial critical-thinking ability in algebraic problem solving. The following presents the reported results of the statistical tests.

### Normality Test

The normality test is used to determine whether the research data is normally distributed. The results of the normality test are shown in Table 1 below. Table 1 presents the results of the normality tests conducted using the Kolmogorov–Smirnov and Shapiro–Wilk tests for the pretest and posttest scores in both the control and experimental groups. The normality test was performed to determine whether the data were normally distributed before conducting further parametric statistical analyses.

The results indicate that all significance values exceeded 0.05, suggesting that the data for both groups were normally distributed. Therefore, the assumption of normality was satisfied, and the data were considered appropriate for subsequent parametric analyses, including the independent samples t-test.

**Table 1.** Normality test

| | **Kolmogorov-Smirnova** | | | **Shapiro-Wilk** | | |
|---|---|---|---|---|---|---|
| | **Statistic** | **df** | **Sig.** | **Statistic** | **df** | **Sig.** |
| Pretest_Control | .118 | 25 | .200* | .939 | 25 | .142 |
| Posttest_Control | .156 | 25 | .117 | .970 | 25 | .640 |
| Pretest_Experiment | .140 | 28 | .173 | .961 | 28 | .375 |
| Posttest_Experiment | .127 | 28 | .200* | .938 | 28 | .097 |

## Homogeneity Test

The Levene test is used to determine whether the variances between groups are homogeneous (i.e., equal). The Levene test results are shown in Table 2. Table 2 presents the results of Levene's test for homogeneity of variances among the groups. The test was conducted based on the mean, median, adjusted median, and trimmed mean.

**Table 2.** Homogeneity test

| | Levene Statistic | df1 | df2 | Sig. |
|---|---|---|---|---|
| Based on Mean | 2.047 | 3 | 102 | .112 |
| Based on Median | 1.683 | 3 | 102 | .175 |
| Based on Median and with adjusted df | 1.683 | 3 | 78.030 | .177 |
| Based on the trimmed mean | 1.970 | 3 | 102 | .123 |

The results showed that the significance values for all testing methods were greater than 0.05: 0.112 (based on the mean), 0.175 (based on the median), 0.177 (based on the median with adjusted degrees of freedom), and 0.123 (based on the trimmed mean). These findings indicate that the variances between the experimental and control groups were homogeneous. Therefore, the assumption of homogeneity of variance was satisfied, indicating that the data were appropriate for subsequent parametric statistical analyses, including the independent samples t-test.

## Descriptive Statistics of Pre-test and Post-test Scores

Descriptive statistical analysis was conducted to compare students' critical-thinking performance before and after the intervention, and the results are presented in Table 3. Table 3 presents the descriptive statistics of students' critical thinking scores before and after the intervention. The results indicate that both groups started with relatively similar pre-test mean scores, suggesting comparable initial abilities. However, after the intervention, the experimental group demonstrated a substantially higher post-test mean compared to the control group. This finding suggests that students exposed to Problem-Based Learning experienced greater improvement in critical thinking skills than those who received conventional instruction. For greater clarity, this is also evident in the scatter plot shown in Figure 1.

The box plot shows the distribution of students' learning result scores in the control and experimental classes before and after treatment. Both classes experienced an increase from pretest to posttest scores. However, the experimental class shows a much greater improvement, with the highest median score in the Posttest_Experiment group. Meanwhile, the control class only shows a slight increase. One outlier is also visible in the Posttest_Control group, indicating a student with a notably lower score than the others. Overall, the plot suggests that the experimental treatment had a positive effect on students' learning outcomes.

## Independent Samples t-test Results (Pretest) and Posttest

Before examining the effect of the intervention, it was necessary to verify that both groups had comparable initial abilities; therefore, an independent-samples t-test was performed on the pre-test scores. The analysis indicates no statistically significant difference between the experimental and control groups ($t(51) = 0.34$, $p = 0.751$). This result confirms that both groups had equivalent initial critical-thinking abilities before the intervention, thereby supporting the study's internal validity. After the intervention was implemented, an independent-samples t-test was conducted to compare post-test scores between the experimental and control groups. The findings reveal a statistically significant difference between the experimental and control groups ($t(51) = 5.34$, $p < 0.001$). The higher mean score achieved by the experimental group indicates that Problem-Based Learning had a significant positive effect on students' critical thinking skills in algebraic problem solving.

## Paired Samples t-test Results

In addition to comparing differences between groups, it is important to analyze improvement within each group, therefore, a paired-samples t-test was performed, as shown in Table 4. Table 4 summarizes the paired samples t-test results for each group. Both groups showed statistically significant

**Table 3.** Descriptive statistics of pretest and posttest scores

| Group | N | Pre-test Mean | Pre-test SD | Post-test Mean | Post-test SD |
|---|---|---|---|---|---|
| Experimental | 28 | 52.13 | 8.45 | 78.56 | 7.92 |
| Control | 25 | 51.47 | 8.72 | 68.21 | 8.35 |

**Table 4.** Paired samples t-test results (within groups)

| Group | Comparison | t | df | p | Interpretation |
|---|---|---|---|---|---|
| Experimental | Pre-test vs Post-test | 14.62 | 27 | < .001 | Significant improvement |
| Control | Pre-test vs Post-test | 9.11 | 24 | < .001 | Significant improvement |

improvements from pre-test to post-test. However, the experimental group exhibited a much higher t-value compared to the control group, indicating a stronger improvement in critical thinking skills. This suggests that while conventional instruction may contribute to learning gains, Problem-Based Learning leads to more substantial cognitive development.

**Normalized Gain (N-gain) Analysis**

Beyond statistical significance, it is important to examine the magnitude of students' learning gains; therefore, the normalized gain (N-gain) analysis was conducted. The experimental group achieved a higher N-gain score (0.55), categorized as moderate to high, compared to the control group (0.34), categorized as moderate. This result indicates that Problem-Based Learning is more effective in promoting meaningful learning gains than conventional instruction. Furthermore, using the pooled standard deviation, Cohen's d indicated a large effect size (d = 1.26), indicating that the difference between the experimental and control groups is not only statistically significant but also practically meaningful. This finding highlights the strong impact of Problem-Based Learning on students' critical thinking development.

**Gender-Based Analysis in the Experimental Group**

In addition to overall performance, it is important to examine whether gender differences affect learning outcomes; therefore, a gender-based analysis was conducted within the experimental group, as shown in Table 5.

Table 5 presents an analysis of students' performance by gender within the experimental group. Both male and female students showed substantial improvement from pre-test to post-test. Although female students achieved slightly higher post-test scores, the difference between genders was not statistically significant ($p > 0.05$). This suggests that Problem-Based Learning is equally effective for both male and female students.

The findings of this study provide strong empirical evidence that Problem-Based Learning (PBL) significantly enhances students' critical thinking skills in algebraic problem solving. The absence of a statistically significant difference in the pre-test results confirms that both the experimental and control groups had comparable baseline abilities, thereby strengthening the study's internal validity. More importantly, the post-test results revealed a statistically significant difference ($t(53) = 5.34$, $p < 0.001$), accompanied by a large effect size ($d = 1.26$), indicating that the impact of PBL is not only statistically significant but also practically meaningful in educational contexts.

These findings are consistent with a substantial body of international research highlighting the effectiveness of PBL in promoting higher-order thinking skills. For instance, Hmelo-Silver (2004) emphasizes that PBL facilitates deep learning through inquiry, collaboration, and self-directed knowledge construction. Similarly, Dochy et al. (2003) demonstrate that PBL is particularly effective

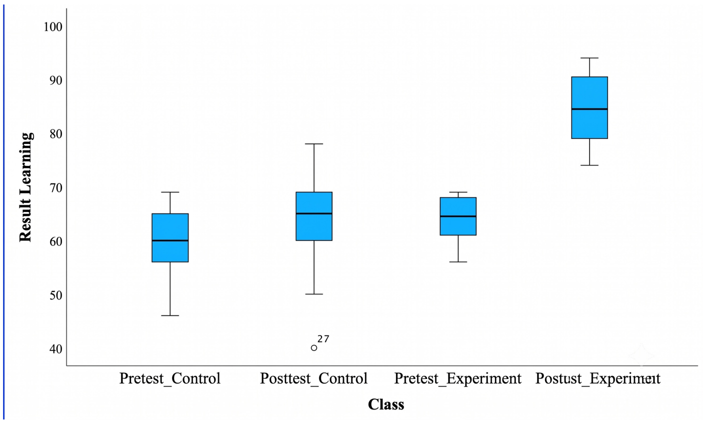


**Figure 1.** The movement of individual scores ranges from pre-test to post-test

**Table 5.** Gender-based analysis in the experimental group

| Gender | N | Pre-test Mean | Post-test Mean | Improvement | p | Interpretation |
|---|---|---|---|---|---|---|
| Male | 25 | 51.80 | 77.90 | +26.10 | > 0.05 | Not significant |
| Female | 28 | 52.40 | 79.10 | +26.70 | > 0.05 | Not significant |

in improving students' ability to apply knowledge and solve complex problems compared to conventional instruction. More recent perspectives, such as those of Loyens et al. (2015), further suggest that PBL enhances self-regulated learning, which plays a critical role in the development of critical thinking skills.

The significant improvement observed within the experimental group (t = 14.62) compared to the control group (t = 9.11) reinforces the added value of PBL beyond traditional instruction. While both groups demonstrated statistically significant improvement, the magnitude of change was substantially greater in the experimental group. This finding aligns with Savery (2006), who argues that PBL fosters active knowledge construction through structured problem-solving processes. In contrast, conventional teaching approaches tend to emphasize procedural knowledge, which may limit opportunities for students to engage in deeper reasoning. This view is supported by Hiebert and Grouws (2007), who highlight that instruction focused primarily on procedures often leads to superficial understanding with limited transferability.

The normalized gain results further strengthen the argument for PBL's effectiveness. The experimental group achieved a moderate-to-high N-gain (0.55), compared to a moderate gain (0.34) in the control group. This suggests that PBL not only improves learning outcomes but also enhances the efficiency of learning relative to students' initial abilities. From a theoretical perspective, this can be explained through constructivist learning principles, particularly Vygotsky's (1978) work, which emphasizes the role of social interaction and guided learning in cognitive development. These elements are inherently embedded in PBL environments, where students collaborate, discuss, and reflect on their problem-solving processes.

Despite these positive findings, a critical perspective is necessary. Not all international studies report uniformly strong effects of PBL. For example, Kirschner et al. (2006) and Leary et al. (2013) argue that minimally guided instructional approaches may lead to cognitive overload, particularly for novice learners. Schmidt et al. (2019) and Dolmans et al. (2016) argue that while traditional teaching methods are effective at supporting procedural learning, they are less effective at promoting critical thinking than student-centered approaches such as PBL. Therefore, the advantage of PBL lies in its ability to complement and enhance traditional instruction rather than replace it entirely. This suggests that the effectiveness of PBL is highly dependent on the quality of its implementation, including the level of teacher scaffolding. In the present study, the strong outcomes may be attributed to the structured design of the PBL phases, which ensured that students received adequate guidance throughout the learning process.

Furthermore, the finding that both groups showed statistically significant improvement raises an important consideration. While PBL proved to be more effective, conventional instruction also contributed to learning gains. This supports Mayer (2004), who suggests that guided instruction remains essential and that the most effective learning environments often combine structured guidance with active learning strategies. Therefore, rather than positioning PBL as a replacement for traditional instruction, it may be more appropriate to view it as a complementary approach that enhances existing teaching practices (Arbo & Ching, 2022; Yuhana & Fajari, 2025).

Another important finding is the absence of significant gender differences in PBL effectiveness. Both male and female students benefited equally from the intervention, indicating that PBL provides an inclusive learning environment (Anasagasti et al., 2023; Mumu et al., 2025). This aligns with broader international research emphasizing that student-centered and collaborative learning environments tend to reduce disparities in participation and achievement, thereby promoting equity in education.

Compared with previous international studies, this research contributes by providing a comprehensive evaluation of PBL effectiveness using multiple analytical indicators, including statistical significance, normalized gain, and effect size. While many studies rely primarily on significance testing, the inclusion of effect size (d = 1.26) in this study provides a clearer understanding of the practical implications of the findings. This strengthens the conclusion that PBL has a substantial and meaningful impact on students' critical thinking skills in algebraic contexts.

Overall, the findings of this study reinforce the global consensus that Problem-Based Learning is a powerful pedagogical approach for fostering critical thinking skills in mathematics education. At the same time, the study highlights the importance of careful implementation, including structured guidance, meaningful problem design, and effective teacher facilitation. Future research should explore the long-term impact of PBL, its integration with other instructional approaches, and the role of contextual factors in influencing its effectiveness.

## ■ CONCLUSION

This study demonstrates, in a specific and empirically grounded manner, that implementing Problem-Based Learning (PBL) for algebraic problem solving at the Grade 8 level produces a substantial, measurable improvement in students' critical thinking skills. The findings show that although the experimental and control groups began with comparable initial abilities, as confirmed by the non-significant pre-test difference, the six-week PBL intervention resulted in markedly higher post-test performance in the experimental group ($M = 78.56$) than in the control group ($M = 68.21$). This difference was statistically significant and supported by a large effect size ($d = 1.26$), indicating a strong and meaningful instructional impact. The improvement was most evident in students' ability to analyze algebraic problems systematically, identify relevant mathematical relationships, and independently formulate logical solution strategies. Students also demonstrated stronger reasoning in interpreting problem situations, evaluating alternative procedures, and justifying their answers using appropriate mathematical arguments. These findings suggest that PBL not only enhanced students' overall achievement but also strengthened higher-order thinking competencies essential for algebraic problem solving.

More specifically, the within-group analysis reveals that while both instructional approaches contributed to learning gains, the magnitude of improvement in the PBL group ($t = 14.62$) was substantially greater than that of the control group ($t = 9.11$). This pattern is further reinforced by the normalized gain results, with the experimental group achieving a moderate-to-high N-gain (0.55) compared to a moderate gain (0.34) in the control group. These results indicate that PBL not only improves students' outcomes but also enhances the effectiveness of learning to their initial performance, suggesting deeper conceptual engagement rather than surface-level acquisition.

Importantly, the gender-based analysis indicates that both male and female students experienced comparable levels of improvement, with no statistically significant differences between them. This finding confirms that the effectiveness of PBL in this study is consistent across gender, highlighting its potential as an equitable instructional approach in algebra learning contexts. Taken together, these results suggest that the effectiveness of PBL in this study is closely linked to its structured implementation, which required students to actively analyze problems, discuss solution strategies, and reflect on their reasoning processes. This structured engagement appears to be a key factor in fostering critical thinking, as evidenced by the substantial gains observed.

In conclusion, this study provides concrete, context-specific evidence that PBL is significantly more effective than conventional instruction at improving critical thinking skills in algebraic problem solving among middle school students. The strength of this conclusion lies in the consistency of the findings across multiple statistical indicators, including significance testing, normalized gain, and effect size. These results underscore the importance of adopting instructional approaches that actively involve students in meaningful problem-solving and provide clear support for integrating PBL into mathematics classrooms with similar characteristics.

## ■ DECLARATION ON THE USE OF GENERATIVE AI IN THE WRITING PROCESS

The authors hereby declare that artificial intelligence (AI) tools were used during the preparation of this manuscript to support, but not replace, human intellectual contributions. Specifically, SPSS was used to organize the quantitative data during the analysis phase. Additionally, Grammarly and QuillBot were used for grammar checking to improve the manuscript's clarity and language quality. Google Translate was used to assist in translating the initial draft into better academic English.

## ■ REFERENCES

Abrenica, E. C. (2025). Problem-Based Learning: A Strategic Intervention in Enhancing Critical and Analytical Thinking Skills of Middle School

Students in Mathematics. *International Journal of Research and Innovation in Social Science, 9*(9), 575–580. https://doi.org/10.47772/IJRISS.2025.90900050

Ahmad, A., Akhsani, L., & Mohamed, Z. (2023). The profile of students' mathematical representation competence, self-confidence, and habits of mind through problem-based learning models. Infinity Journal, 12(2), 323–338. https://doi.org/10.22460/infinity.v12i2.p323-338

Anasagasti, J., Berciano, A., & Izagirre, A. (2023). A comparison of the effects of different methodologies on the statistics learning profiles of prospective primary education teachers from a gender perspective. Journal on Mathematics Education, 14(4), 741–756. https://doi.org/10.22342/jme.v14i4.pp741-756

Arbo, J. B., & Ching, D. A. (2022). Problem-based learning approach in developing mathematical skills. International Journal of Science, Technology, Engineering and Mathematics, 2(1), 26–47. https://doi.org/10.53378/352873

Aritonang, P. S. B., Hutajulu, M., & Purwasih, R. (2024). Analysis of mathematical critical thinking skills using problem-based learning models. Journal of Innovative Mathematics Learning. https://doi.org/10.22460/jiml.v7i2.19658

Dochy, F., Segers, M., Van den Bossche, P., & Gijbels, D. (2003). Effects of problem-based learning: A meta-analysis. Learning and Instruction, 13(5), 533–568. https://doi.org/10.1016/S0959-4752(02)00025-7

Dolmans, D. H. J. M., Loyens, S. M. M., Marcq, H., & Gijbels, D. (2016). Deep and surface learning in problem-based learning: A review. Advances in Health Sciences Education, 21(5), 1087–1112. https://doi.org/10.1007/s10459-015-9645-6

English, L. D., & Gainsburg, J. (2016). Problem solving in a 21st-century mathematics curriculum. ZDM Mathematics Education, 48(6), 675–688.

Hake, R., R. (1999). *Analyzing Change/Gain Scores*. AREA-D American Education Research Association's Division. D, Measurement and Research Methodology.

Hidayah, I. N., Irawati, S., Agung, M., Sa'dijah, C., Subanji, & Sudirman. (2023). Creative conjecture: Abductive reasoning to generate some ideas in algebra. *Mathematics Teaching-Research Journal, 15*(1), 108–126.

Hiebert, J., & Grouws, D. A. (2007). The effects of classroom mathematics teaching on students' learning. In F. K. Lester Jr. (Ed.), Second handbook of research on mathematics teaching and learning (pp. 102–121). Information Age Publishing.

Hmelo-Silver, C. E. (2004). Problem-based learning: What and how do students learn? Educational Psychology Review, 16(3), 235–266. https://doi.org/10.1023/B:EDPR.0000034022.16470.f3

Izzaroh, I., Prajitno, S. H., Hadi, S., & Prayitno, L. L. (2025). Implications of Problem-Based Learning on students' critical thinking ability. Journal of Education, Language, and Mathematics Research (JELMaR), 6(1). https://doi.org/10.37303/jelmar.v6i1.3827

Kieran, C. (2007). Learning and teaching algebra. In F. K. Lester Jr. (Ed.), Second handbook of research on mathematics teaching and learning (pp. 124–153). Information Age Publishing.

Kirschner, P. A., Sweller, J., & Clark, R. E. (2006). Why minimal guidance during instruction does not work: An analysis of the failure of constructivist, discovery, problem-based, experiential, and inquiry-based teaching. Educational Psychologist, 41(2), 75–86. https://doi.org/10.1207/s15326985ep4102_1

Leary, H., Walker, A., Shelton, B. E., & Fitt, M. H. (2013). Exploring the relationships between problem-based learning and self-regulated learning. Interdisciplinary Journal of Problem-Based Learning, 7(1), 1–15. https://doi.org/10.7771/1541-5015.1334

Lestari, I., Kesumawati, N., & Ningsih, Y. L. (2020). Mathematical representation of grade 7 students in set theory topics through problem-based learning. Infinity Journal, 9(1), 103–110. https://doi.org/10.22460/infinity.v9i1.p103-110

Loyens, S. M. M., Jones, S. H., Mikkers, J., & Van Gog, T. (2015). Problem-based learning as a facilitator of conceptual change. Educational Psychology Review, 27(4), 665–681. https://doi.org/10.1016/j.learninstruc.2015.03.002

Maharani, A., & Laelasari. (2017). Experimentation of SPICES learning strategies with the method of problem based learning (PBL) to build motivation and the ability to think logically for vocational school students. Infinity Journal, 6(2), 149–156. https://doi.org/10.22460/infinity.v6i2.p149-156

Maulidia, F., Johar, R., & Andariah. (2019). A case study of students' creativity in solving mathematical problems through problem based learning. Infinity Journal, 8(1), 1–10. https://doi.org/10.22460/infinity.v8i1.p1-10

Mayer, R. E. (2004). Should there be a three-strikes rule against pure discovery learning? The case for guided methods of instruction. American Psychologist, 59(1), 14–19. https://doi.org/10.1037/0003-066X.59.1.14

Meiliati, R., Djodding, I. M., Aswin, A., Salido, A., Husain, D. S., Tahir, T., & Hidayati, U. (2025). Exploration problem-based learning in mathematics learning in higher education: A bibliometric review. Social Sciences & Humanities Open, 13, 102345. https://doi.org/10.1016/j.ssaho.2025.102345

Mumu, J., Prahmana, R. C. I., Tanujaya, B., & Sampouw, F. (2025). In-service teachers' perceptions of problems in mathematics instruction when using a problem-based learning model. *Journal on Mathematics Education, 16*(3), 1463–1482. https://doi.org/10.22342/jme.v16i4.pp1463-1482

Nugraha, T., & Suparman. (2021). Mathematical critical thinking skills through PBL: A meta-analysis. https://doi.org/10.24042/ajpm.v12i2.9645

Purnomo, Y. W., Nabillah, R., Aziz, T. A., & Widodo, S. A. (2024). Fostering mathematical connections and habits of mind: A problem-based learning module for elementary education. Infinity Journal, 13(2), 333–348. https://doi.org/10.22460/infinity.v13i2.p333-348

Sa'adah, N., Faizah, S., Sa'dijah, C., Khabibah, S., & Kurniati, D. (2023). Students' mathematical thinking process in algebraic verification based on crystalline concept. *Mathematics Teaching Research Journal, 15*(1), 90–107.

Sánchez-García, R., & Reyes-de-Cózar, S. (2025). Enhancing project-based learning: A framework for optimizing structural design and implementation-A systematic review with a sustainable focus. Sustainability, 17(11), 4978. https://doi.org/10.3390/su17114978

Savery, J. R. (2006). Overview of problem-based learning: Definitions and distinctions. Interdisciplinary Journal of Problem-Based Learning, 1(1), 9–20. https://doi.org/10.7771/1541-5015.1002

Schmidt, H. G., Rotgans, J. I., & Yew, E. H. J. (2019). The process of problem-based learning: What works and why. Medical Education, 53(5), 1–12. https://doi.org/10.1111/j.1365-2923.2011.04035.x

Schoenfeld, A. H. (2016). Learning to think mathematically. Journal of Education, 196(2), 1–38. https://doi.org/10.1177/002205741619600202

Stacey, K., & MacGregor, M. (2000). Learning the algebraic method of solving problems. Journal of Mathematical Behavior, 18(2), 149–167. https://doi.org/10.1016/S0732-3123(99)00026-7

Vygotsky, L. S. (1978). Mind in society: The development of higher psychological processes. Harvard University Press.

Yuhana, Y., & Fajari, L. E. W. (2025). Cross-disciplinary effects of problem-based learning on problem-solving skills in mathematics and beyond: A comprehensive meta-analysis and bibliometric. *Eurasia Journal of Mathematics, Science and Technology Education*, *21*(11), em2732. https://doi.org/10.29333/ejmste/17345

Yuliana, Y., & Firmansah, F. (2018). The effectiveness of problem-based learning with social media assistance to improve students' understanding toward statistics. Infinity Journal, 7(2), 97–108. https://doi.org/10.22460/infinity.v7i2.p97-108

Zetriuslita, Z., Ariawan, R., Suripah, S., & Hidayat, R. (2023). Using Problem-Based Learning to promote critical thinking and problem-solving skills. *Journal of Progressive Education*, 13(2). https://doi.org/10.23960/jpp.v13.i2.202311