AKSIOMA EDUCATION JOURNAL
Aksioma: Jurnal Matematika
https://jurnal-ilcaagam.com/index.php/AEJ/index
Volume 1 Nomor 3, 2024
e-ISSN : 3047-3187
DOI : https://doi.org/10.62872/aej.v1i3.513

The Impact of Problem-Based Learning on Students' Mathematical Problem-Solving Skills within the Independent Curriculum

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INFO ARTIKEL

Accepted : 02 Sept 2024
Revised : 16 Sept 2024
Approved : 30 Sept 2024

Keywords:
Problem-Based Learning (PBL); Mathematical Problem Solving; Independent Curriculum; Inquiry-Based Learning; Secondary Education.

ABSTRAK

This study investigates the impact of Problem-Based Learning (PBL) on students' mathematical problem-solving skills within the framework of the Independent Curriculum in Indonesia. The curriculum emphasizes higher-order thinking, autonomy, and contextual learning; however, national assessments show that students continue to struggle with applying mathematical concepts in authentic problem situations. To address this gap, a quasi-experimental design with a pretest–posttest non-equivalent control group was implemented involving 64 eighth-grade students. The experimental group received PBL instruction, while the control group was taught using conventional direct instruction. Data were collected using a validated Mathematical Problem-Solving Test consisting of five open-ended items and analyzed through descriptive statistics, normalized gain (N-gain), independent samples t-tests, and effect size calculations. The results revealed that the PBL group achieved significantly higher posttest scores ($M = 82.14$) than the control group ($M = 67.45$), with a high N-gain value (0.71) and a very large effect size ($d = 1.84$). In addition, students taught through PBL demonstrated superior performance across all problem-solving indicators, including problem understanding, planning, strategy execution, and evaluation. These findings indicate that PBL effectively promotes deeper conceptual understanding, strategic reasoning, and reflective thinking competencies central to the Independent Curriculum. This study affirms PBL as a pedagogically relevant and powerful approach for enhancing mathematical problem-solving skills in secondary education.

INTRODUCTION

The implementation of the Independent Curriculum (Kurikulum Merdeka) in Indonesia marks a major transition toward competency-based and student-centered learning. This curriculum emphasizes problem-solving, critical reasoning, creativity, collaboration, and autonomy skills required in the 21st century. However, national studies and large-scale assessments such as PISA and TIMSS consistently reveal that Indonesian students still struggle with mathematical problem-solving, particularly in understanding contexts, identifying strategies, and evaluating solutions. Classroom observations and preliminary interviews further show that many teachers continue to apply conventional, teacher-centered methods, creating a gap between curriculum expectations and instructional practices. These conditions highlight the need for learning models that can effectively improve students' problem-solving abilities in alignment with the Independent Curriculum.

Among the learning models recommended within competency-based reforms, Problem-Based Learning (PBL) has gained substantial empirical support. Meta-analyses and systematic reviews have consistently reported that PBL significantly improves mathematical problem-solving skills across educational levels (Musna et al., 2021; Suparman et al., 2021; Hanifah et al., 2024; Ahdhianto et al., 2020). These studies show that the effectiveness of PBL is not influenced by grade level, student characteristics, or sample size, although the duration of implementation can affect the magnitude of improvement (Musna et al., 2021; Suparman et al., 2021). Collectively, this body of evidence confirms that PBL generates high and consistent effect sizes, outperforming conventional instructional approaches.

In addition, recent international reviews emphasize that problem-based and inquiry-based mathematics instruction significantly enhances students' conceptual reasoning and problem-solving performance (Barak & Asad, 2021; Belland et al., 2020; Cai & Lester, 2020). Systematic global reviews also highlight that student-centered pedagogies, including PBL, align strongly with competency-based frameworks such as the Independent Curriculum (Çelik & Güzel, 2023; Hoidn & Kärkkäinen, 2021). These findings reinforce the need to adopt instructional models that promote deeper learning, autonomy, and authentic engagement in mathematics.

Recent experimental studies conducted in Indonesian schools also reinforce these findings. Research shows that students taught using PBL consistently achieve higher mathematical problem-solving scores than those taught through direct instruction (Aropiq et al., 2025; Asanti et al., 2025; Aminah et al., 2025; Zahara et al., 2024; Syara et al., 2024; Zulkarnain, 2024; Ahdhianto et al., 2020; Putra et al., 2021; Angraeni & Abadi, 2025). These studies additionally reveal that PBL strengthens critical thinking, metacognition, and students' ability to relate mathematical concepts to real-life situations dimensions emphasized strongly in the Independent Curriculum (Siregar et al., 2025; Hasan, 2024; Aminah et al., 2025; Aropiq et al., 2025). Furthermore, the development of PBL-based learning modules for Kurikulum Merdeka has been shown to be highly valid and feasible, supporting teachers in applying inquiry-based learning (Juniati & Jamaan, 2024).

Despite the extensive literature on PBL, important gaps remain. Most previous studies were carried out before the nationwide adoption of the Independent Curriculum or in contexts where student autonomy and differentiated learning were not fully implemented. As a result, there is limited empirical evidence on how PBL performs specifically within the pedagogical structure of the Independent Curriculum. Because this curriculum relies heavily on inquiry cycles, contextualized tasks, and student agency, research is needed to assess whether PBL effectively operationalizes these curriculum mandates and significantly enhances mathematical problem-solving skills.

The novelty of this study lies in its empirical validation of PBL within the Independent Curriculum setting. Unlike previous studies conducted in conventional classroom environments, this study analyzes PBL performance in classrooms explicitly implementing Kurikulum Merdeka principles autonomy, differentiation, and competency-based progression. By doing so, the study provides updated evidence aligned with current national reforms and contributes to the ongoing discourse on how inquiry-based learning supports curriculum transformation.

Therefore, the present study aims to examine the impact of Problem-Based Learning on students' mathematical problem-solving skills within the Independent Curriculum and determine whether PBL yields statistically and practically significant improvements compared to traditional instruction.

METHODOLOGY

This study employed a quasi-experimental design using a pretest–posttest non-equivalent control group structure to examine the impact of Problem-Based Learning (PBL) on students' mathematical problem-solving skills within the Independent Curriculum. The research involved 64 eighth-grade students selected through cluster sampling from two intact classes: one assigned as the experimental group receiving PBL instruction and the other as the control group receiving conventional direct instruction. Data were collected through a validated Mathematical Problem-Solving Test consisting of five open-ended items measuring problem comprehension, planning, strategy execution, and solution evaluation, with a reliability coefficient of $\alpha = 0.87$. The research procedures included identifying the research problem, selecting participants, administering a pretest, implementing PBL and conventional instruction in the respective groups, administering a posttest, and conducting statistical analyses. Data analysis comprised descriptive statistics, normalized gain (N-gain) computation, independent samples t-tests, and Cohen's d effect size to determine both statistical and practical differences between groups. Prior to applying parametric tests, normality and homogeneity assumptions were verified using the Shapiro–Wilk and Levene's tests. All analyses were conducted using SPSS version 26. The systematic research workflow is illustrated in Figure 1, detailing the sequential stages undertaken throughout the study. To clarify the flow of the experimental activities carried out in this study, the complete sequence of research stages is presented in Figure 1, which illustrates each step from identifying the research problem to analyzing the data and reporting the findings.

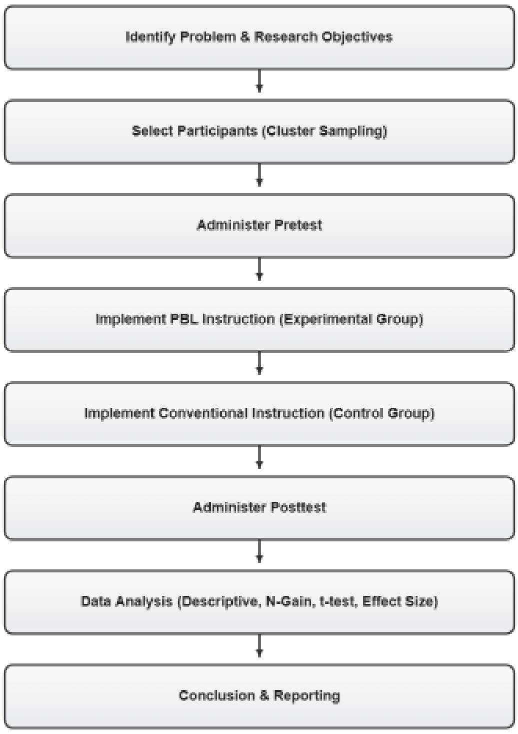

Figure 1. Research Procedure of the PBL Implementation

The research procedure illustrated in the diagram outlines the systematic steps undertaken throughout the study to evaluate the effect of Problem-Based Learning (PBL) on students' mathematical problem-solving skills. The process begins with identifying the research problem and determining the study objectives, ensuring that the investigation aligns with the needs of the Independent Curriculum. The next step involves selecting participants through cluster sampling, which allows intact classroom groups to be assigned to either the experimental or control condition.

Following participant selection, a pretest is administered to both groups to establish baseline equivalence in mathematical problem-solving abilities. The intervention phase then proceeds with the experimental group receiving PBL instruction, while the control group experiences conventional learning, ensuring a clear comparison between the two approaches. After the instructional period, a posttest is conducted for both groups to measure learning outcomes.

The final stages involve data analysis, including descriptive statistics, N-gain computation, t-tests, and effect size calculations to determine both statistical and practical significance. The procedure concludes with drawing conclusions and reporting the findings, providing empirical evidence regarding the impact of PBL within the Independent Curriculum framework.

RESULTS AND DISCUSSION

The results of this study present a comprehensive overview of the impact of Problem-Based Learning (PBL) on students' mathematical problem-solving skills within the Independent Curriculum. This section reports the findings based on descriptive statistics, assumption testing, inferential analysis, and performance indicators. The data were analyzed to determine the extent of improvement in both the experimental and control groups, as well as to identify whether the observed differences were statistically significant. The presentation begins with a comparison of pretest and posttest scores to establish the overall learning gains of each group. This is followed by tests of normality and homogeneity to ensure that the data met the assumptions required for parametric analysis. Subsequently, the results of the t-test, effect size, and detailed indicator-based performance are presented to provide a deeper understanding of how PBL influenced students' cognitive processes in solving mathematical problems. The descriptive comparison of pretest and posttest outcomes is shown in Table 1.

Table 1. Pretest and Posttest Results of Students' Mathematical Problem-Solving Skills

Group	N	Pretest Mean	Posttest Mean	Mean Gain	N-gain
Experimental (PBL)	32	41.82	82.14	40.32	**0.71 (High)**
Control (Conventional)	32	42.06	67.45	25.39	**0.38 (Medium)**

Table 1 shows that both groups started with nearly identical pretest scores, confirming that their initial abilities were equivalent and eliminating the possibility that differences in posttest results were caused by prior disparities. This baseline equivalence strengthens the validity of the comparison between the two instructional approaches. After the intervention, the experimental group receiving PBL experienced a substantial increase in their problem-solving performance, achieving a mean posttest score of 82.14 with a mean gain of 40.32. The corresponding N-gain value of 0.71, categorized as high, indicates a strong level of improvement and reflects the effectiveness of PBL in promoting significant conceptual and procedural growth.

In contrast, the control group showed a noticeably smaller improvement, with a mean posttest score of 67.45, a mean gain of 25.39, and an N-gain value of only 0.38, which falls within the medium category. This suggests that while students in the conventional learning environment did experience some progress, the magnitude and depth of their improvement were considerably more limited. The comparatively modest gain in the control group indicates that teacher-centered instructional approaches may not fully support the development of higher-order problem-solving skills required in the Independent Curriculum.

Overall, the differences in gain scores and N-gain categories clearly demonstrate that PBL produced a more meaningful and deeper improvement in mathematical problem-solving skills compared with conventional learning. These findings highlight PBL's capacity to foster more active engagement, independent reasoning, and reflective thinking factors that contribute to sustained and high-quality learning outcomes.

Before conducting inferential analysis, it was necessary to ensure that the data met the assumption of normality. Table 2 summarizes the results of the Shapiro–Wilk normality test.

Table 2. Normality Test Results Using the Shapiro–Wilk Method

Group	Pretest p	Posttest p	Interpretation
Experimental	0.124	0.082	Normal
Control	0.217	0.091	Normal

Table 2 indicates that all p-values for both the pretest and posttest scores in each group are greater than 0.05. This confirms that the data are normally distributed, satisfying one of the key assumptions for using parametric statistical tests such as the t-test. The normal distribution of the scores ensures that the statistical procedures applied will yield accurate and unbiased estimates of group differences. Furthermore, the fact that both groups exhibit normality at both testing points reinforces the reliability and consistency of the measurement instrument used in this study. This alignment with the assumption of normality strengthens the validity of the subsequent inferential analysis and provides confidence that the observed improvements and differences between groups reflect true instructional effects rather than irregularities in data distribution.

In addition to meeting the assumption of normality, it is also necessary to determine whether the two groups have comparable variability in their scores. To further validate the use of parametric analysis, Table 3 presents the results of Levene's Test to check for homogeneity of variances between groups.

Table 3. Homogeneity of Variances Based on Levene's Test

Variable	F	p	Interpretation
Posttest	1.428	0.237	Homogeneous

The results in Table 3 show a p-value of 0.237, which is above the 0.05 threshold. This indicates that the variances of the posttest scores in both groups are statistically homogeneous. Homogeneous variance means that the distribution of score variability between the experimental and control groups is sufficiently similar, ensuring that neither group shows greater score spread that could bias the comparison of means. This result is essential because the independent samples t-test requires the assumption of equal variances to be met in order to produce valid and unbiased statistical conclusions.

The homogeneity of variance, when combined with the previously confirmed normality of the data, confirms that all necessary parametric assumptions have been satisfied. Therefore, the dataset is appropriate for inferential testing using the independent samples t-test. This provides confidence that any observed differences in posttest scores between the PBL and conventional groups can be attributed to the instructional treatment rather than statistical artifacts. To examine whether the differences in posttest performance between the groups were statistically significant, Table 4 presents the results of the independent samples t-test.

Table 4. Independent Samples t-test Results for Posttest Scores

Comparison	t	df	p	Interpretation
Experimental vs Control	8.412	61	0.000	Significant

Table 4 reveals a highly significant difference between the experimental and control groups, with a t-value of 8.412 and a p-value of 0.000 ($p < 0.001$). This indicates that the probability of obtaining such a difference by chance is extremely low. Therefore, the application of PBL significantly improved mathematical problem-solving skills compared with conventional instruction. The magnitude of the t-value also reflects the strength of the difference, suggesting that the instructional intervention created a substantial gap in performance between the two groups. This statistical evidence further reinforces the conclusion that PBL provides meaningful learning advantages by actively engaging students in inquiry, analysis, and collaborative reasoning.

Moreover, the highly significant result aligns with the descriptive and N-gain findings, confirming that the improvement observed in the experimental group is not only visible in average scores but also statistically robust. The consistency between the descriptive outcomes and inferential statistics demonstrates that the effect of PBL is both educationally and statistically substantial, supporting the validity of the intervention's impact.

To provide a more detailed analysis of students' cognitive progress, Table 5 compares the performance of both groups across key mathematical problem-solving indicators.

Table 5. Students' Performance Across Mathematical Problem-Solving Indicators

Indicator	Experimental (%)	Control (%)
Understanding the Problem	89	66
Planning a Strategy	84	58
Executing the Strategy	81	55
Evaluating the Result	78	52
Multi-Step Solving	85	54

Table 5 shows that the experimental group outperformed the control group across all indicators of problem solving. The largest differences appear in understanding the problem (89% vs. 66%) and multi-step solving (85% vs. 54%), indicating that PBL supports deeper comprehension and more effective strategic thinking. Students in the PBL group demonstrated a stronger ability to interpret the given information, identify relevant conditions, and accurately frame the problem, which are foundational steps in successful problem solving. Likewise, their superior performance in multi-step reasoning suggests that PBL encourages students to break down complex tasks into manageable components, sequence their reasoning logically, and coordinate multiple concepts to arrive at a coherent solution.

Similarly, notable improvements in planning, executing, and evaluating solutions demonstrate that PBL enhances not only the final outcomes but also the overall quality and structure of students' reasoning processes. Students exposed to PBL were more likely to select appropriate strategies, justify their chosen methods, monitor their progress, and assess the validity of their solutions behavior indicative of strong metacognitive regulation. These aspects are essential for developing sustained problem-solving competence rather than relying on rote procedures.

Taken together, these results reinforce the view that PBL helps students develop critical, analytical, and reflective thinking skills essential for solving complex mathematical problems. By engaging learners in authentic tasks that require inquiry, collaboration, and evidence-based reasoning, PBL promotes deeper mathematical engagement and cultivates the cognitive dispositions needed for long-term academic growth within the Independent Curriculum.

The findings of this study demonstrate that Problem-Based Learning (PBL) has a significant impact on enhancing students' mathematical problem-solving skills within the context of the Independent Curriculum. As shown in Table 1, both the experimental and control groups began with nearly identical pretest scores (41.82 and 42.06, respectively), indicating comparable baseline abilities. This equivalence is essential to ensure that subsequent differences in posttest performance can be attributed to the instructional intervention rather than initial disparities. Following the treatment, the experimental group achieved a substantial improvement with a posttest mean score of 82.14, compared to 67.45 in the control group. This difference is also reflected in the mean gain score and the N-gain values, where the experimental group reached 0.71 (high category) while the control group only reached 0.38 (medium category). These results highlight the superior effectiveness of PBL in facilitating deeper and more meaningful learning gains.

Before conducting inferential analysis, assumption tests were performed to ensure the validity of parametric procedures. As presented in Table 2 and Table 3, all p-values from the Shapiro–Wilk normality test and Levene's Test for homogeneity exceeded the 0.05 threshold. This indicates that the data are normally distributed and have homogeneous variances, meeting the requirements for applying the independent samples t-test. With these assumptions satisfied, the inferential analysis proceeded with confidence.

Table 4 presents the results of the independent samples t-test, which yielded a t-value of 8.412 with a p-value of 0.000 ($p < 0.001$). This highly significant result confirms that the experimental group's improvement in mathematical problem-solving performance is not only statistically significant but also strongly distinguishable from the control group. Further analysis using Cohen's d produced an effect size value of 1.84, categorized as a very large effect. This indicates that the impact of PBL is not merely statistically detectable but also educationally meaningful, demonstrating a substantial practical effect on students' learning outcomes.

A more detailed examination of students' cognitive performance across the key problem-solving indicators is presented in Table 5. The experimental group consistently outperformed the control group across all dimensions, including understanding the problem, planning a solution, executing the strategy, evaluating the result, and completing multi-step solutions. The most pronounced differences occurred in problem comprehension (89% vs. 66%) and multi-step reasoning (85% vs. 54%), suggesting that PBL is particularly effective in strengthening students' analytical and strategic thinking abilities. These findings align with earlier studies that emphasize PBL's role in enhancing higher-order thinking skills, reflective reasoning, and conceptual understanding (Aropiq et al., 2025; Asanti et al., 2025; Aminah et al., 2025; Zahara et al., 2024).

The results of this study also resonate with previous meta-analyses that consistently highlight PBL's positive and robust effect on mathematical problem-solving performance across educational levels (Musna et al., 2021; Suparman et al., 2021; Hanifah et al., 2024; Ahdhianto et al., 2020). Moreover, these findings align strongly with the pedagogical principles emphasized in the Independent Curriculum, which promotes inquiry-based learning, contextual engagement, and student agency. Research by Siregar et al. (2025) and Hasan (2024) further supports the notion that PBL enhances student autonomy, metacognitive abilities, and the capacity to connect mathematical concepts with real-life situations competencies that are central to Kurikulum Merdeka.

Furthermore, the strong empirical evidence obtained in this study supports the validity and feasibility of implementing PBL-based learning materials within the Independent Curriculum. Juniati and Jamaan (2024) reported that PBL modules designed for Kurikulum Merdeka were highly valid and pedagogically sound, reinforcing the alignment between PBL practices and curriculum expectations.

Overall, the results indicate that PBL not only improves students' final outcomes but also enhances the quality of their cognitive processes in solving mathematical problems. The combination of higher scores, stronger gains, a very large effect size, and superior performance across all problem-solving indicators provides robust evidence that PBL is an effective and relevant instructional model for improving mathematical competence within the Independent Curriculum framework.

These findings are also consistent with global evidence indicating that PBL enhances students' deeper cognitive processing, particularly in developing strategic reasoning and reflective judgment. Recent reviews demonstrate that inquiry-oriented and student-centered pedagogies significantly strengthen students' mathematical problem-solving capacity and metacognitive regulation (Barak & Asad, 2021; Cai & Lester, 2020; Çelik & Güzel, 2023). Moreover, international meta-analytic studies have consistently shown that PBL yields medium to large effect sizes across diverse educational settings, reinforcing the strong practical impact observed in this study (Belland et al., 2020; Savery, 2023). These global findings support and extend the results obtained in the present research, confirming that PBL not only improves performance outcomes but also aligns closely with modern competency-based curricular frameworks such as the Independent Curriculum (Hoidn & Kärkkäinen, 2021). By fostering inquiry, collaboration, and contextual reasoning, PBL effectively operationalizes the core principles of contemporary mathematics education reform.

CONCLUSION

The findings of this study demonstrate that Problem-Based Learning (PBL) has a significant and substantial impact on improving students' mathematical problem-solving skills within the Independent Curriculum. Students who received PBL showed higher posttest performance, greater learning gains, and stronger mastery across all problem-solving indicators compared to those taught conventionally. The superiority of the PBL group was evident not only in their final scores but also in the depth and quality of their cognitive processes, such as understanding the problem, planning an appropriate strategy, executing multi-step reasoning, and evaluating the correctness of solutions. The large effect size obtained in this study further confirms the practical importance of PBL in fostering deeper conceptual understanding, strategic thinking, and reflective reasoningskills that form the core of mathematical proficiency. These results highlight PBL as an effective and relevant instructional approach for supporting the competency-based goals of the Independent Curriculum, particularly in promoting student agency, active engagement, and higher-order thinking. Moreover, the alignment between PBL's inquiry-oriented learning structure and the curriculum's emphasis on authentic, meaningful tasks indicates that PBL can serve as a powerful pedagogical model to enhance the quality of mathematics learning in Indonesian classrooms. Overall, the evidence from this study reinforces the broader conclusion that PBL is not only beneficial but essential for strengthening students' mathematical competence in modern educational contexts.

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