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The Effect of the Problem-Based Learning (PBL) Model on Students' Critical Thinking Skills

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ABSTRACT

Critical thinking skills are essential competencies in twenty-first-century education, yet conventional instruction often provides limited opportunities for students to develop higher-order thinking. Problem-Based Learning (PBL) offers a student-centered approach that engages learners in contextual problem-solving activities. This study aimed to examine the effect of PBL on the critical thinking skills of Grade X students at SMA Negeri 1 Sedayu. A quasi-experimental pretest-posttest control group design was employed involving 56 students, with 30 students in the experimental class and 26 in the control class. Data were collected using a validated and reliable critical thinking test and analyzed using paired and independent sample t-tests. The experimental class showed a 52.63% increase in critical thinking scores, compared with 17.22% in the control class. The posttest difference between the two groups was statistically significant ($p < .001$), with a large effect size. These findings indicate that PBL is more effective than conventional instruction in improving students' critical thinking skills. The study suggests that PBL can be integrated into mathematics instruction to promote analytical reasoning, active problem-solving, and evidence-based decision-making.

Keywords: Problem-Based Learning; Critical Thinking Skills; Mathematics Education; Statistics Learning; Quasi-Experimental Study.

INTRODUCTION

Rapid technological development and increasingly complex social and professional environments require education to develop competencies that extend beyond mastery of subject matter. Students are expected to communicate, collaborate, solve unfamiliar problems, and make decisions based on evidence. Among these competencies, critical thinking is particularly important because it enables students to respond rationally and adaptively to complex situations rather than merely reproduce information or memorized procedures. Critical thinking is therefore regarded as an essential educational outcome for preparing students to participate effectively in academic, professional, and everyday contexts (Facione, 1990; Purba et al., 2026).

Critical thinking refers to purposeful and reasoned thinking used to determine what should be believed or what action should be taken (Ennis, 1993). It involves interpreting information, identifying relevant evidence, analysing relationships, evaluating arguments, drawing logical inferences, and explaining conclusions based on defensible reasons (Facione, 1990). In mathematics learning, these abilities are reflected when students can understand the focus of a problem, select relevant information, justify the strategies used, examine alternative solutions, and review the reasonableness of their conclusions. These processes are consistent with the **focus, reason, inference, situation, clarity, and overview** components of the FRISCO framework that underlie the critical thinking indicators employed in this study (Ennis, 1993).

Critical thinking is particularly relevant to statistics learning because statistical problems require more than the mechanical application of formulas. Students must interpret data, examine patterns and distributions, compare different representations, and formulate conclusions that are consistent with the available evidence. The GAISE II framework emphasizes that statistics education should engage students in a problem-solving process involving the formulation of statistical questions, consideration of data, analysis of data representations, and interpretation of results (Bargagliotti et al., 2020). Consequently, learning topics such as frequency distributions, histograms, and measures of central tendency provides an appropriate context for developing students' analytical reasoning and evidence-based decision-making skills.

Despite its importance, several studies have indicated that students' critical thinking skills remain insufficiently developed. Putri et al. (2024) reported that students continue to experience difficulties in analysing information, evaluating possible solutions, and constructing conclusions in science-related learning. Similar difficulties commonly arise in mathematics when students encounter contextual or nonroutine problems that require explanations rather than direct procedural calculations. These conditions suggest that students need learning experiences that allow them to investigate problems, discuss alternative strategies, justify their ideas, and reflect on the solutions they produce.

A similar situation was identified through preliminary observations of mathematics learning at SMA Negeri 1 Sedayu. Students generally completed exercises by following examples and procedures previously demonstrated by the teacher. However, when they were presented with contextual problems requiring the identification of relevant information, selection of an appropriate strategy, and explanation of the reasoning behind an answer, several students had difficulty completing the tasks independently. They also tended to wait for direct guidance from the teacher before attempting alternative solutions. These preliminary findings indicate the need for an instructional approach that provides students with more opportunities to engage actively in mathematical reasoning and problem-solving.

One factor contributing to this problem may be the continued dominance of teacher-centred instruction. Lectures, demonstrations, and routine exercises can help students acquire fundamental concepts and procedural knowledge, but their exclusive use may provide limited opportunities for students to investigate complex problems, evaluate different strategies, and communicate mathematical reasoning. Students may consequently become proficient in reproducing procedures without sufficiently understanding when, why, or how those procedures should be applied. A more studentcentred instructional environment is therefore needed to encourage active inquiry, collaboration, justification, and reflection.

Problem-Based Learning (PBL) offers an instructional approach that is consistent with these needs. PBL organizes learning around complex and meaningful problems that become the starting point for acquiring and applying knowledge. Students identify what they already know, determine what information is needed, conduct investigations, discuss possible explanations, and propose solutions, while the teacher facilitates rather than dominates the learning process (Hmelo-Silver, 2004; Savery, 2006). Through this process, students assume greater responsibility for their learning and are encouraged to connect conceptual knowledge with contextual problem situations.

The learning processes embedded in PBL are theoretically related to the development of critical thinking. Problem analysis encourages students to identify the focus and conditions of a task; independent inquiry requires them to collect and evaluate relevant information; group discussion requires them to explain reasons and respond to different viewpoints; and solution evaluation encourages them to draw inferences and review the consistency of their conclusions. PBL also involves the activation of prior knowledge, collaborative elaboration, self-directed learning, and synthesis of newly acquired information (Yew & Goh, 2016). Therefore, PBL may provide a learning environment in which critical thinking is practised throughout the learning process rather than assessed only at the end of instruction.

Previous empirical studies have generally supported the positive relationship between PBL and critical thinking. Hutagalung et al. (2023) found that students taught through PBL demonstrated stronger critical thinking skills than students who participated in conventional instruction. In mathematics education, Cahyani and Setyaningsih (2024) reported that PBL facilitated students' critical thinking when solving contextual mathematical problems, while Sihaloho and Saragih (2024) documented improvement in students' mathematical critical thinking following PBL implementation. Broader reviews have also concluded that PBL generally produces positive effects on students' critical thinking and mathematical literacy, although the magnitude of its effectiveness may vary according to educational level, subject matter, intervention duration, assessment instruments, and implementation quality (Damayanti et al., 2025; Rahima DB et al., 2025).

Nevertheless, existing evidence does not eliminate the need for further investigation in specific instructional contexts. Previous studies have been conducted across different subjects, educational levels, and learning materials, while research focusing specifically on Grade X statistics topics remains relatively limited. Statistics presents distinctive reasoning demands because students must interpret data displays, compare measures of central tendency, and formulate conclusions from contextual information rather than merely obtain numerical answers. Moreover, evidence is still needed regarding whether a relatively short PBL intervention can generate a meaningful improvement in students' critical thinking skills compared with conventional learning in an authentic senior high school classroom.

Accordingly, this study aims to determine the effect of the Problem-Based Learning model on the critical thinking skills of Grade X students at SMA Negeri 1 Sedayu in learning statistics. The study compares changes in the critical thinking skills of students participating in PBL with those receiving conventional instruction. Its findings are expected to provide empirical evidence concerning the effectiveness of PBL in statistics education and practical guidance for designing mathematics learning that is more active, contextual, collaborative, and oriented toward reasoned problem-solving.

METHOD

This study employed a quasi-experimental design with a pretest-posttest control group design to examine the effect of the Problem-Based Learning (PBL) model on students' critical thinking skills (Creswell & Creswell, 2018). The study involved two classes: an experimental class taught using the PBL model and a control class taught using a conventional learning model. Both classes were given a pretest before the treatment and a posttest after the treatment.

The population of this study consisted of all tenth-grade students of SMA Negeri 1 Sedayu, comprising nine classes with a total of 324 students. The samples were selected using purposive sampling based on the consideration that the two classes had relatively similar academic abilities and on the recommendation of the mathematics teacher. Class X-2, consisting of 30 students, was selected as the experimental class, while class X-3, consisting of 26 students, was selected as the control class.

The study was conducted in four meetings. The first meeting was used to administer the pretest, while the second and third meetings were used to implement the learning treatment. The fourth meeting was used to administer the posttest. Two meetings were conducted for 2 × 45 minutes, while the other two meetings were conducted for 3 × 45 minutes. The learning materials used in the treatment were statistics, specifically frequency distribution and histogram in the second meeting, and mean, median, and mode in the third meeting.

In the experimental class, the PBL model was implemented based on five main stages: orienting students to problems, organizing students for learning, guiding individual and group investigations, developing and presenting work, and analyzing and evaluating the problem-solving process. At the problem-orientation stage, the teacher introduced contextual statistical problems related to frequency distribution, histograms, mean, median, and mode. Students were asked to identify the known information, determine the problem being asked, and relate the problem to the statistical concepts being studied. At the organizing stage, students were divided into small groups and given student worksheets to guide their discussion. During the investigation stage, students worked collaboratively to collect information, analyze data, solve problems, and formulate conclusions. At the presentation stage, representatives of each group presented their discussion results, while other students responded through questions and comments. Finally, the teacher and students evaluated the problem-solving process, clarified important concepts, and drew conclusions from the lesson. Meanwhile, the control class was taught using a conventional learning model, in which the teacher explained the material, provided examples, and assigned exercises to students.

The research instrument was a critical thinking skills test consisting of three essay questions. Each question contained several sub-items: the first question consisted of three sub-items, the second of two sub-items, and the third of four sub-items. Each sub-item was scored using a rubric ranging from 1 to 5. The maximum scores for the first, second, and third questions were 15, 10, and 20, respectively, resulting in a total raw score of 45. For ease of interpretation and statistical reporting, the raw scores were converted to a 0–100 scale using the following formula: converted score = (obtained raw score/45) × 100. The test was developed based on six indicators of critical thinking skills, namely focus, inference, clarity, reason, situation, and overview, and was aligned with the statistical topics of frequency distributions, histograms, and measures of central tendency.

Before being used in the main study, the instrument was validated by three mathematics teachers who had relevant competence and teaching experience. The expert validation assessed the content, construction, and language aspects of the instrument using Aiken's V coefficient (Aiken, 1985). The results showed that the overall Aiken's V value was 0.86, indicating that the instrument was valid and appropriate for use. Empirical item validity was also tested using the product moment correlation, and all pretest and posttest items were declared valid because their correlation coefficients were higher than the r-table value. The reliability test showed that the pretest instrument had a reliability coefficient of 0.684, while the posttest instrument had a reliability coefficient of 0.696. These results indicate that both instruments were reliable and suitable for measuring students' critical thinking skills.

Data were analyzed using descriptive and inferential statistics with IBM SPSS Statistics 25. Descriptive statistics were used to describe students' pretest and posttest scores, including mean, median, mode, standard deviation, minimum score, and maximum score. Before hypothesis testing, normality and homogeneity tests were conducted to ensure that the data met the assumptions for parametric analysis. The Shapiro-Wilk test was used to examine data normality, while Levene's test was used to examine homogeneity of variance. After the assumptions were met, paired sample t-tests were used to examine the differences between pretest and posttest scores within each class, while an independent sample t-test was used to examine the difference in critical thinking skills between the experimental and control classes after the treatment. In addition, effect size analysis using Cohen's d and eta squared was conducted to determine the magnitude and practical significance of the effect of the PBL model on students' critical thinking skills (Lakens, 2013).

RESULT

The results of this study were obtained from the pretest and posttest scores of students' critical thinking skills in the experimental and control classes. The experimental class consisted of 30 students who received instruction using the Problem-Based Learning (PBL) model, while the control class consisted of 26 students who received conventional instruction. Data analysis was conducted using IBM SPSS Statistics 25 and included descriptive statistics, assumption tests, paired sample t-tests, an independent sample t-test, and effect size analysis. All scores reported in the following tables are converted scores on a 0–100 scale.

Descriptive Statistics of Students' Critical Thinking Skills

Descriptive statistics were used to examine the distribution of pretest and posttest scores in both classes. The results are presented in Table 1.

Table 1. Descriptive Statistics of Students' Critical Thinking Skills

Group and Test	N	Mean	Median	Mode	SD	Minimum	Maximum
Experimental class pretest	30	51.30	51.00	47	4.12	41	57
Experimental class posttest	30	78.30	80.00	89	8.91	61	91
Control class pretest	26	49.12	50.00	50	6.49	33	59
Control class posttest	26	57.58	59.50	63	7.18	40	69

Note. All test scores were converted from raw scores with a maximum of 45 to a 0–100 scale.

As shown in Table 1, the experimental class obtained a mean pretest score of 51.30, which increased to 78.30 in the posttest. This represents an increase of 27.00 points. Meanwhile, the mean score of the control class increased from 49.12 in the pretest to 57.58 in the posttest, representing an increase of 8.46 points. These descriptive results indicate that the increase in critical thinking scores was greater in the experimental class than in the control class.

Assumption Testing

Before conducting parametric hypothesis testing, the normality and homogeneity assumptions were examined. The Shapiro-Wilk test was used to assess the normality of the pretest and posttest scores.

Table 2. Results of the Normality Test

Data	Significance	Interpretation
Experimental class pretest	.081	Normally distributed
Experimental class posttest	.082	Normally distributed
Control class pretest	.087	Normally distributed
Control class posttest	.052	Normally distributed

All significance values were greater than .05, indicating that the pretest and posttest data in both classes were normally distributed.

The homogeneity of variance was subsequently examined using Levene's test.

Table 3. Results of the Homogeneity Test

Data	Significance	Interpretation
Pretest scores	.114	Homogeneous
Posttest scores	.130	Homogeneous

The significance values for the pretest and posttest scores were greater than .05. Therefore, the variances of the experimental and control classes were homogeneous. These results confirmed that the assumptions required for parametric testing were satisfied.

Changes in Critical Thinking Skills Within Each Class

Paired sample *t*-tests were conducted to determine whether there were significant differences between the pretest and posttest scores within the experimental and control classes.

Table 4. *Results of the Paired Sample t-Tests*

Group	Mean Difference	*t*	*df*	*p*	Cohen's *d*	Eta Squared (η^2)
Experimental class	27.00	-18.781	29	< .001	3.429	.924
Control class	8.46	-5.260	25	< .001	1.068	.543

The experimental class demonstrated a statistically significant difference between the pretest and posttest scores, $t(29) = -18.781$, $p < .001$. The effect size was very large, as indicated by Cohen's $d = 3.429$ and $\eta^2 = .924$. This result shows that the students in the experimental class experienced a substantial improvement after participating in PBL-based instruction.

The control class also demonstrated a statistically significant difference between the pretest and posttest scores, $t(25) = -5.260$, $p < .001$. Its effect size was also classified as large, with Cohen's $d = 1.068$ and $\eta^2 = .543$. However, the magnitude of improvement in the control class was considerably lower than that observed in the experimental class.

Comparison Between the Experimental and Control Classes

An independent sample *t*-test was conducted to compare the posttest critical thinking scores of students in the experimental and control classes.

Table 5. Results of the Independent Sample *t*-Test

Comparison	Experimental Mean	Control Mean	*t*	*df*	*p*	Cohen's *d*	Eta Squared (η^2)
Posttest scores	78.30	57.58	9.485	54	< .001	2.540	.625

The independent sample *t*-test revealed a statistically significant difference between the posttest scores of the experimental and control classes, $t(54) = 9.485$, $p < .001$. The experimental class obtained a substantially higher mean score than the control class. The effect size was also very large, with Cohen's $d = 2.540$ and $\eta^2 = .625$. These findings indicate that the difference between the two classes was not only statistically significant but also educationally meaningful.

Comparison of Score Improvement

The percentage increase in each class was calculated by comparing the difference between the pretest and posttest mean scores with the respective pretest mean.

Table 6. Comparison of Mean Scores and Percentage Improvement

Class	Pretest Mean	Posttest Mean	Mean Increase	Percentage Increase
Experimental	51.30	78.30	27.00	52.63%
Control	49.12	57.58	8.46	17.22%

The experimental class demonstrated a 52.63% increase in the mean critical thinking score, whereas the control class showed a 17.22% increase. Thus, the percentage improvement in the experimental class was approximately three times greater than that in the control class.

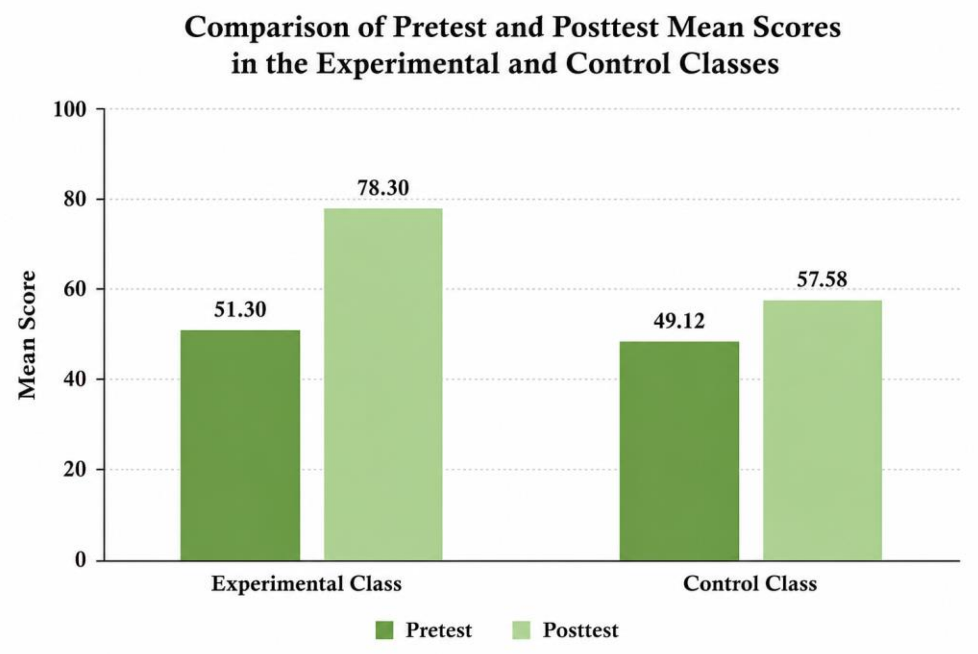

Figure 1. Comparison of Pretest and Posttest Mean Scores in the Experimental and Control Classes

Figure 1 visually demonstrates that the experimental and control classes had relatively similar mean scores before the intervention. After the intervention, however, the posttest mean of the experimental class increased more substantially than that of the control class. Overall, the descriptive statistics, hypothesis tests, and effect size estimates consistently indicate that students taught using the PBL model achieved greater improvement in critical thinking skills than students taught using conventional instruction.

DISCUSSION

The findings of this study demonstrate that the Problem-Based Learning (PBL) model was more effective than conventional instruction in improving the critical thinking skills of tenth-grade students at SMA Negeri 1 Sedayu. The mean score of the experimental class increased from 51.30 on the pretest to 78.30 on the posttest, representing an improvement of 52.63%. In contrast, the control class showed a smaller increase, from 49.12 to 57.58, or 17.22%. Furthermore, the independent-samples *t*-test revealed a statistically significant difference between the posttest scores of the two classes ($t(54) = 9.485$, $p < .001$), accompanied by a very large effect size (Cohen's $d = 2.540$; $\eta^2 = .625$). These findings indicate that the implementation of PBL produced not only statistically significant improvements but also substantial educational benefits in enhancing students' critical thinking skills.

The superiority of PBL can be explained by the learning processes embedded within the model. Rather than receiving information passively, students actively engaged in identifying contextual statistical problems, analysing relevant information, discussing alternative strategies, evaluating evidence, and communicating logical conclusions. Such learning experiences directly correspond to the critical thinking indicators assessed in this study, namely focus, inference, clarity, reason, situation, and overview. Consequently, the observed improvement is likely attributable to the close alignment between the learning activities and the competencies measured by the assessment instrument. This finding supports the argument of Sari et al. (2023), who emphasized that PBL enhances critical thinking by engaging students in collaborative problem analysis and authentic solution development. Similarly, Cahyani and Setyaningsih (2024) reported that students became more capable of analysing contextual mathematical problems after participating in PBL-based learning, while Sihaloho and Saragih (2024) found that contextual problem-solving activities effectively stimulated students' analytical reasoning and reflective thinking.

The difference between the experimental and control classes can also be explained by the contrasting instructional approaches employed during the intervention. Conventional instruction primarily emphasized teacher explanations, worked examples, and procedural exercises, allowing students to understand concepts through direct guidance. Although this approach resulted in a statistically significant improvement in the control class, as reflected by Cohen's $d = 1.068$ and $\eta^2 = .543$, the magnitude of improvement remained substantially lower than that achieved through PBL. This suggests that while conventional instruction may facilitate conceptual understanding, it provides fewer opportunities for students to analyse unfamiliar situations, evaluate alternative solutions, and construct arguments independently. In contrast, PBL encourages deeper cognitive engagement by positioning students as active participants responsible for investigating problems, justifying decisions, and reflecting on the effectiveness of their solutions.

The findings of this study are consistent with a growing body of literature demonstrating the effectiveness of PBL in developing higher-order thinking skills. Minarti et al. (2023) found that PBL significantly improved students' critical thinking skills, while Hutagalung et al. (2023) similarly reported positive improvements following the implementation of problem-based instruction. More recently, Damayanti et al. (2025), through a systematic literature review, concluded that PBL consistently contributes to the development of critical thinking because it encourages students to identify problems, formulate hypotheses, analyse information, and construct evidence-based solutions. Likewise, Purba et al. (2026) argued that critical thinking enables students to examine problems from multiple perspectives, develop logical arguments, and generate more effective solutions. Collectively, these findings reinforce the growing empirical evidence that PBL is an effective instructional model for cultivating critical thinking across different educational contexts.

Beyond confirming previous studies, the present research also contributes additional empirical evidence within the context of senior high school statistics learning. The intervention focused specifically on frequency distributions, histograms, and measures of central tendency, demonstrating that PBL effectively supports critical thinking even in mathematical topics that are often taught procedurally. The comparable pretest means of the experimental (51.30) and control (49.12) classes indicate that both groups started from relatively similar levels of critical thinking. Following the intervention, however, the substantially greater improvement observed in the experimental class suggests that contextual problem-solving activities promoted deeper reasoning processes beyond procedural computation. Students were encouraged to interpret statistical information, justify the selection of appropriate statistical measures, compare alternative solutions, and defend their conclusions using logical arguments, thereby fostering analytical and reflective thinking.

The findings also have important implications for classroom practice. Mathematics teachers should consider integrating contextual problems that encourage students to investigate authentic situations rather than merely applying memorised procedures. The success of PBL depends not only on presenting meaningful problems but also on teachers' ability to facilitate productive discussions, provide appropriate scaffolding, and encourage students to justify and evaluate their reasoning throughout the learning process. These findings are supported by Rahima et al. (2025), who concluded that PBL enhances mathematical literacy by strengthening students' reasoning, problem-solving abilities, and capacity to apply mathematical concepts in real-life situations. Therefore, successful implementation of PBL requires careful lesson planning, well-designed contextual tasks, and effective classroom facilitation.

The implementation of PBL is also consistent with the educational demands of the twenty-first century, which emphasize critical thinking, creativity, collaboration, communication, and adaptive problem-solving. As highlighted by Subro and Fawaid (2025) and Arifin and Mu'id (2024), contemporary mathematics education should provide learning experiences that enable students to analyse information critically, solve complex problems, and communicate evidence-based conclusions. The findings of this study provide further empirical support for integrating PBL into mathematics instruction as a strategy for developing these essential competencies.

Despite these positive findings, several limitations should be acknowledged. First, the study involved only 56 students from two classes in one senior high school, limiting the generalisability of the findings to broader educational settings. Second, the intervention was conducted over a relatively short period and focused only on selected statistics topics; consequently, the results mainly reflect the immediate impact of PBL rather than its long-term effectiveness. Third, participants were selected using purposive sampling rather than random assignment, meaning that uncontrolled differences between groups may still have influenced the results. Moreover, variables such as learning motivation, prior mathematical ability, group interaction quality, and implementation fidelity were not directly measured and may also have contributed to students' learning outcomes.

Future research should therefore involve larger and more diverse samples, implement PBL over a longer instructional period, and investigate its effectiveness across various mathematical topics and educational levels. Researchers are also encouraged to employ more rigorous statistical procedures, such as ANCOVA, to control for students' initial ability and to incorporate additional variables—including learning motivation, collaborative engagement, and classroom interaction—to obtain a more comprehensive understanding of the mechanisms through which PBL enhances students' critical thinking skills.

CONCLUSION

Based on the analysis conducted, it can be concluded that the implementation of the Problem Based Learning model has an effect on improving the critical thinking skill of class X students at SMA Negeri 1 Sedayu. This result is supported by the results of the paired sample t-test with a significance value of 0.000 < 0.05, which indicates thatH_0 rejected and accepted. Thus, the PBL learning model is proven to influence students' critical thinking skill. In addition, the results of the independent sample t-test show a sig value (2-tailed) of 0.000 < 0.05, these results indicate that the experimental class using the PBL learning model is more influential than the control class using conventional learning. The results of the average comparison test also confirm that the application of PBL is effective in improving students' critical thinking skill compared to conventional learning methods.H_1

Based on these findings, it is recommended that teachers consider implementing the PBL model as the main teaching strategy, especially in subjects that require high-level analytical thinking. Schools are also encouraged to provide professional training for teachers in designing high-quality contextual problems and facilitating productive class discussions. Additionally, future research with larger samples, longer durations, and more rigorous designs is needed to strengthen and expand the conclusions of this study.

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