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Implementation of Problem-Based Learning to Improve Mathematical Critical Thinking Ability of High School Students

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ABSTRACT

Problem-based learning (PBL) is widely acknowledged as an effective approach for enhancing students' critical thinking abilities, particularly in mathematics education. This study aims to evaluate the impact of PBL on the mathematical critical thinking skills of high school students. A quasi-experimental method was employed using a pre-test and post-test control group design, instead of the originally stated post-test only design, to reflect the availability of both pretest and posttest data. The participants consisted of two randomly selected Grade XI classes: one assigned as the experimental group receiving PBL instruction, and the other as the control group receiving conventional teaching methods. The findings revealed a significant difference between the two groups. The experimental group achieved a higher average post-test score, with notable improvements observed in the indicators of interpretation and inference. Statistical analysis confirmed that the implementation of PBL had a meaningful and positive effect on students' mathematical critical thinking. These findings suggest that PBL can serve as a more effective alternative instructional strategy to foster students' critical thinking in mathematics. Therefore, teachers are encouraged to integrate and adapt PBL in their teaching to promote student engagement and independence in problem-solving. Future studies are suggested to explore additional factors that may affect the success of PBL in enhancing critical thinking skills.

***Keywords**: Problem Based Learning, Critical Thinking, Mathematics, High School Education.*

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INTRODUCTION

In the context of 21st-century education, higher-order thinking skills particularly critical thinking are essential competencies that every student must possess. The Merdeka Curriculum serves as a breakthrough in the Indonesian education system by granting greater flexibility to schools and educators in designing learning strategies that are more adaptive to students' needs (Hasibuan, 2019). In mathematics education, critical thinking is especially important, as this subject not only involves computation but also emphasizes analysis, problem-solving, and logic-based decision-making (Sulistiani, 2017). However, various studies indicate that the level of students' mathematical critical thinking in Indonesia remains relatively low (Sari, 2015). This presents a significant challenge for the education sector in preparing future generations who are capable of adapting to and solving complex problems in the modern world (Inayati, 2022).

Mathematics is a discipline that is closely connected to everyday life and is a fundamental component of the education curriculum (Fazriah et al., 2021). Mathematical concepts are not only theoretical but are also applicable in solving real-world problems (Saputri et al., 2019). To solve problems effectively, students must be able to relate mathematical ideas to practical situations, making the learning experience more meaningful. Zulkarnain et al. (2020) emphasized that mathematics plays a critical role in shaping logical, critical, and diligent thinking, as well as in enhancing students' ability to make responsible decisions. One of the key skills fostered through mathematics learning is critical thinking, which serves as a foundation for students to navigate intellectual challenges in various areas of life.

According to Alvino, critical thinking is a core aspect of higher-order thinking that involves analysis, synthesis, and evaluative judgment (Minarni et al., 2018). From another perspective, critical thinking is seen as a systematic and goal-oriented cognitive process, utilized in various intellectual tasks such as problem-solving, decision-making, argument evaluation, identifying assumptions, and conducting scientific inquiry. This skill not only enhances conceptual understanding but also contributes to developing a rational and objective mindset when dealing with complex situations.

Mathematical critical thinking skills serve as a crucial foundation for individuals to engage in systematic thinking, logically analyze interrelated concepts, and formulate sound and justifiable conclusions. According to Minarni et al. (2018), solving mathematical problems requires more than computational ability—it demands logical reasoning to develop defensible solutions. In essence, critical thinking in mathematics encompasses one's capability to analyze, assess, and reflect on problems using reasoned judgment as a basis for decision-making. This not only strengthens conceptual understanding but also cultivates a rational and well-structured approach to tackling academic and real-life challenges.

Enhancing students' critical thinking is essential for equipping them with the adaptability and resilience needed to address both personal and societal issues. Nonetheless, field evidence indicates that students' mathematical critical thinking abilities remain underdeveloped and in need of significant improvement (Herdiman et al., 2018). A contributing factor to this issue is the dominance of teacher-centered learning approaches, which offer limited opportunities for students to explore ideas independently or construct their own understanding. Consequently, many students resort to rote memorization rather than grasping underlying concepts, as they are rarely encouraged to engage in critical reasoning. Widayanti and Nur'aini (2020) assert that mathematics instruction should begin with real-life problem contexts that are relevant to students, allowing them to internalize mathematical concepts through active participation.

Research conducted by Herdiman et al. (2018) confirmed that students' critical thinking skills in mathematics are generally low. Empirical data showed that a significant proportion of students struggle to provide logical justifications and formulate accurate conclusions when solving mathematical problems. One major contributing factor is their difficulty in identifying the appropriate initial formulas and organizing coherent steps for problem-solving. These findings underscore the urgent need for targeted instructional strategies to cultivate stronger critical thinking abilities, enabling students to adopt logical and effective approaches to mathematical challenges.

Similarly, Hafni et al. (2022) reported that diagnostic assessment results revealed a widespread deficiency in students' mathematical critical thinking. The data indicated low achievement across essential indicators such as interpretation, analysis, evaluation, and drawing systematic conclusions. When presented with problems designed to assess these competencies, many students gave incomplete or incorrect responses, reflecting a lack of structured reasoning.

Given these research findings, it is essential to incorporate the development of critical thinking into mathematics education from an early stage. Making this a habitual part of learning can support students in generating creative ideas, constructing sound arguments, and reaching logical, evidence-based conclusions in unfamiliar mathematical contexts. Ultimately, fostering these skills contributes not only to more effective problem-solving but also to the formation of an analytical mindset that is valuable across academic and real-world settings.

One promising instructional model to support the development of critical thinking is Problem-Based Learning (PBL). This approach positions students at the center of the learning experience, fostering active engagement with meaningful problems that reflect real-world scenarios (Sofyan & Komariah, 2016). PBL promotes both individual and collaborative problem-solving, and enhances students' comprehension of mathematical concepts through higher-order thinking. Nugraha (2018) presented empirical findings that PBL significantly contributes to strengthening critical thinking, especially in cognitive processes. Rooted in constructivist theory, PBL emphasizes students' active role in constructing their own knowledge and interpreting concepts in their own terms. Moreover, Problem-Based Learning (PBL) encourages a shift in instructional approach, where teachers facilitate learning by presenting real-world problems that require students to engage in critical analysis, reasoning, and decision-making. This method directly supports the development of students' critical thinking skills by promoting active inquiry and reflective thought processes (Sugrah, 2020).

Drawing upon the various findings discussed, this study seeks to conduct an in-depth analysis of the implementation of problem-based learning in enhancing high school students' mathematical critical thinking skills. The research is expected to make a meaningful contribution to the development of more effective, innovative, and contextually relevant instructional strategies in mathematics education in Indonesia. Furthermore, the findings of this study may serve as a valuable reference for educators in adopting learning models that are more interactive, intellectually stimulating, and focused on nurturing students' critical thinking abilities—ultimately aiming to improve both the quality of mathematics instruction and the overall standard of education.

METHODS

This research was conducted at SMA X involving grade XI students during the odd semester of the 2024/2025 academic year. The study employed a **quasi-experimental method** with a **pre-test and post-test control group design** (Creswell, 2018). From a total of ten available classes, two were randomly selected as the research sample. Class XI.3 was designated as the experimental group, receiving instruction using the **Problem-Based Learning (PBL)** model, while class XI.2 served as the control group, taught using conventional methods. The selection of these classes aimed to evaluate the effectiveness of the PBL model in improving students' **mathematical critical thinking skills**.

Table 1. Research Design

Class	Treatment	Posttest
Control	-	O_2
Experiment	X	O_2

Description:

X : Problem Based Learning

O_2 : Posttest

The posttest instruments consisted of essay-type questions specifically designed to assess students' critical thinking skills in mathematics. These questions were constructed based on established indicators of critical thinking, including interpretation (the ability to understand and explain mathematical information), analysis (the ability to examine ideas and identify relationships), evaluation (the ability to assess arguments and justify procedures), and inference or conclusion drawing (the ability to derive logical conclusions from given data). A total of five essay questions were administered in the posttest, with each item aligned to one or more of these indicators to ensure a comprehensive measurement of students' critical thinking abilities.

During the data analysis phase, several statistical tests were conducted to validate the research findings. First, a normality test was applied to determine whether the data were normally distributed. This was followed by a homogeneity test to assess the equality of variances between the experimental and control groups. Once these assumptions were met, an independent samples t-test was performed to examine whether there was a statistically significant difference in critical thinking outcomes between the two groups. The test used a significance level of $\alpha = 0.05$, with degrees of freedom (df) calculated using the formula $df = (n_1 + n_2 - 2)$. The results of this analysis served as the basis for evaluating the effectiveness of the Problem-Based Learning (PBL) model in enhancing students' mathematical critical thinking skills.

RESULTS

Based on the research conducted in both the experimental and control classes where the experimental class implemented problem based learning and the control class followed conventional methods pretest and posttest data were collected to serve as the foundation for analysis. The data obtained from these tests are presented in Table 2 below.

Table 2. Initial Mathematical Critical Thinking Data (*Pretest*)

Characteristic Statistics					
	N	**Min**	**Max**	**Mean**	**Std. Deviation**
Pretest Experiment	30	46,00	67,00	55,8667	6,26283
Pretest Control	30	44,00	63,00	52,5000	5,38036
Valid N (listwise)	30				

The descriptive statistics of students' initial mathematical critical thinking skills as assessed by the pretest prior to any kind of treatment being administered to either group are shown in Table 2. The experimental group, which received problem-based learning, consisted of 30 students with scores ranging from a min of 46.00 to a max of 67.00. The average (mean) pretest score for this group was 55.87 with a standard deviation of 6.26. Meanwhile, the control group, which was taught using conventional methods, also consisted of 30 students with scores ranging from 44.00 to 63.00. The average pretest score in the control group was 52.50 with a standard deviation of 5.38. These results indicate that both groups had relatively comparable initial abilities in mathematical critical thinking, although the experimental group showed a slightly higher average score. This suggests that the groups were sufficiently equivalent at the outset to proceed with further analysis of the effects of the instructional interventions.

Table 3. Percentage Score of Initial Mathematical Critical Thinking Ability on Each Indicator

A Measure of the Ability to Think Critically in Mathematics	**% of Students Answering Correctly**	
	Experiment	**Control**
Interpretation	55,20%	40,25%
Analysis	60,30%	65,80%
Evaluation	50,80%	50,30%
Inference/Conclusion	44,90%	45,20%

Table 3 presents the percentage scores of students' initial mathematical critical thinking abilities based on four indicators: interpretation, analysis, evaluation, and inference/conclusion. The data show that in the interpretation indicator, 55.20% of students in the experimental class answered correctly, while only 40.25% of students in the control class did so. For the analysis indicator, the control class scored slightly higher at 65.80% compared to 60.30% in the experimental class. In the evaluation indicator, the scores between the two groups were relatively similar, with 50.80% in the experimental class and 50.30% in the control class. Meanwhile, for the inference/conclusion indicator, the control class achieved 45.20%, which was slightly higher than the 44.90% scored by the experimental class. These results suggest that the initial mathematical critical thinking abilities of students in both classes varied across different indicators, with no consistent dominance by either group before the implementation of the learning treatment.

Table 4. Final Mathematical Critical Thinking Data (*Postest*)

Descriptive Statistics					
	N	**Min**	**Max**	**Mean**	**Std. Deviation**
Pretest Experiment	30	77,00	100,00	88,0000	6,34089
Pretest Control	30	70,00	92,00	78,8667	5,89408
Valid N (listwise)	30				

Table 4 presents the final data on students' mathematical critical thinking abilities as measured in the posttest. It includes descriptive statistics for two groups: the experimental class and the control class, each consisting of 30 students. The experimental class obtained a minimum score of 77.00 and a maximum score of 100.00, with a mean (average) score of 88.00 and a standard deviation of 6.34. Meanwhile, the control class had a slightly lower range, with scores ranging from 70.00 to 92.00. The mean score for the control group was 78.87, with a standard deviation of 5.89.

Table 5. Percentage of Final Mathematical Critical Thinking Ability Score on Each Indicator

A Measure of the Ability to Think Critically in Mathematics	% of Students Answering Correctly	
	Experiment	**Control**
Interpretation	93,60%	70,80%
Analysis	85,25%	79,90%
Evaluation	82,40%	77,20%
Inference/Conclusion	83,50%	74,75%

Table 5 presents the percentage of students in the experimental and control groups who answered correctly for each indicator of mathematical critical thinking ability in the posttest. The indicators assessed include Interpretation, Analysis, Evaluation, and Inference/Conclusion. The data show that students in the experimental group consistently outperformed those in the control group across all indicators.

For the Interpretation indicator, 93.60% of students in the experimental group answered correctly, compared to only 70.80% in the control group, marking the largest gap in performance. In terms of Analysis, 85.25% of experimental students achieved correct answers, while 79.90% of control group students did the same. The Evaluation indicator saw 82.40% correct responses in the experimental group, versus 77.20% in the control group. Finally, for Inference/Conclusion, 83.50%

of students in the experimental group responded correctly, while the control group achieved a lower percentage of 74.75%.

Table 6. Normality Test Results of Initial Mathematical Critical Thinking Ability Data

Tests of Normality				
		Shapiro-Wilk		
	Class	Statistic	df	Sig.
Mathematical Critical Thinking Ability	Pretest Experiment	0,957	30	0,265
	Pretest Control	0,963	30	0,367

The experimental class pretest had a significance value of 0.265, whereas the control class pretest had a significance value of 0.367, according to the results of the normality test. According to the test criteria, H_0 is acceptable because both values are more than 0.05. This suggests that the experimental and control classes' pretest results for mathematical critical thinking abilities are regularly distributed.

Table 7. Normality Test Results of Final Mathematical Critical Thinking Ability Data

Tests of Normality				
		Shapiro-Wilk		
	Class	Statistic	df	Sig.
Mathematical Critical Thinking Ability	Postest Experiment	0,978	30	0,766
	Postest Control	0,956	30	0,243

The experimental class posttest had a significance value of 0.766, while the control class posttest had a significance value of 0.243, according to the results of the normality test. According to the test criteria, H_0 is approved since both values are higher than 0.05. This demonstrates the normal distribution of the data from the posttest of the experimental and control classes' students' mathematical critical thinking abilities.

Tabel 8. Homogeneity Test Results of Initial Mathematical Critical Thinking Ability Data

Test of Homogeneity of Variance					
		Levene Statistic	df1	df2	Sig.
Mathematical Critical Thinking Ability	Based on Mean	1,098	1	58	0,299

A significant value of 0.299 was found for both the control and experimental classes based on the posttest data homogeneity test findings that were examined using SPSS. Based on the test criteria, it may be inferred that the data from both groups are homogeneous because this value is more than 0.05.

Tabel 9. Results of Homogeneity Test of Final Mathematical Critical Thinking Ability Data

Test of Homogeneity of Variance					
		Levene Statistic	df1	df2	Sig.
Mathematical Critical Thinking Ability	Based on Mean	0,216	1	58	0,644

The control and experimental classes received a significance value of 0.644 based on the posttest data homogeneity test findings that were examined using SPSS. The data from the two groups can be considered homogeneous as this value is higher than 0.05. The assumption of homogeneity necessary for additional statistical analysis is satisfied since this demonstrates that the variance between the experimental class and the control class is essentially the same.

Tabel 10. Results of Hypothesis Test Analysis of Students' Final Mathematical Critical Thinking Ability

Independent Samples Test				
		t-test for Equality of Means		
		df	Sig. (2-tailed)	Mean Difference
Mathematical Critical Thinking Ability	Equal variances assumed	58	0,000	9,13333
	Equal variances not assumed	57,693	0,000	9,13333

After using SPSS to examine the findings of the Independent Samples Test, a significance value (Sig. 2-tailed) of 0.000 was determined. According to the test criteria, H_0 is rejected while H_a is acceptable since the significance value is less than 0.05. This demonstrates that following treatment, there is a notable difference in the mathematical critical thinking abilities of the students in the experimental and control groups. Therefore, it can be said that the experimental class's learning approach significantly enhances students' capacity for mathematical critical thought.

DISCUSSION

This study aims to investigate the impact of the Problem-Based Learning (PBL) approach on the development of high school students' mathematical critical thinking skills. The research findings reveal a significant difference between the experimental group, which utilized the PBL model, and the control group, which followed conventional teaching methods. Initial pretest results indicated that both groups had comparable levels of mathematical critical thinking, with the experimental group averaging 55.86 and the control group averaging 52.50. However, following the intervention, posttest scores showed a notable improvement in the experimental group, which achieved an average score of 88.00, while the control group averaged 78.86. This demonstrates the effectiveness of the PBL model in enhancing students' mathematical critical thinking abilities.

An analysis of the percentage scores across different critical thinking indicators further supports this finding. Students in the PBL group showed greater improvements than those in the control group across all indicators of critical thinking: interpretation, analysis, evaluation, and inference. For the *interpretation* indicator, the experimental group improved significantly from 55.20% to 93.60% a gain of 38.40 percentage points while the control group rose from 40.25% to 70.80%, showing a smaller increase of 30.55 points. In terms of *analysis*, the experimental group increased from 60.30% to 85.25% (a 24.95-point gain), whereas the control group improved from 65.80% to 79.90% (a gain of 14.10 points). Regarding *evaluation*, the experimental group improved from 50.80% to 82.40% (a 31.60-point increase), while the control group went from 50.30% to 77.20%, gaining 26.90 points. Lastly, in the *inference* indicator, the experimental group showed an improvement from 44.90% to 83.50% (a gain of 38.60 points), while the control group increased from 45.20% to 74.75% (a gain of 29.55 points).

These results suggest that the PBL approach positively influences students' critical thinking development across all aspects, with the most significant gains observed in the *interpretation* and *inference* indicators. These two aspects experienced the largest differences in improvement between the experimental and control groups, which may be attributed to the nature of PBL tasks that often require students to understand complex scenarios (interpretation) and draw logical conclusions based on evidence and inquiry (inference). The structured problem-solving and reflective discussions inherent in PBL likely foster deeper engagement with these cognitive processes, leading to greater improvement compared to traditional learning methods.

The results of the normality and homogeneity tests indicate that the data on students' mathematical critical thinking skills, both before and after the intervention, are normally distributed and homogeneous. Hypothesis testing using the Independent Sample t-Test reveals a significance value (Sig. 2-tailed) of 0.000, which is less than 0.05. This indicates a significant difference between the experimental group and the control group following the implementation of the PBL model. These findings are consistent with previous research, which has shown that the Problem-Based Learning (PBL) approach can enhance students' critical thinking abilities in mathematics. PBL encourages active participation in problem-solving and hands-on learning, fostering greater independence and creativity in approaching mathematical challenges.

The Problem-Based Learning (PBL) method has been widely recognized as effective in promoting critical thinking in mathematics education. According to Hmelo-Silver and Barrows (2006, as cited in Kusumawati, 2022), PBL is designed to enhance problem-solving skills, the ability to utilize learning resources, and self-directed learning. In a PBL setting, students are expected not only to understand the problem thoroughly but also to develop appropriate solutions through structured and reflective thinking. Masrinah (2019) emphasizes that this method is highly effective in sharpening critical thinking because it centers on solving real-life problems that are meaningful and relatable. By engaging with practical situations, students are trained to analyze, assess, and develop contextually relevant solutions.

Numerous studies have confirmed the positive impact of PBL on students' critical thinking development. Herzon (2018) found that PBL contributed significantly to enhancing students' critical thinking skills, while Saputro (2019) demonstrated that this approach improved students' comprehension of mathematical concepts and academic performance at the elementary level. Similarly, research by Aliah Phang et al. (2016) showed that integrating PBL into mathematics instruction through lesson study enhanced students' critical thinking abilities. Rahmah (2019) also reported a positive effect of PBL on high school students' mathematical critical thinking, and Rahayu's (2016) findings further supported the effectiveness of PBL in improving junior high school students' critical thinking in mathematics. Collectively, these studies affirm that PBL can be successfully implemented across various educational levels to foster and strengthen critical thinking in mathematics learning.

Through the Problem-Based Learning (PBL) approach, students are presented with real-life problems that they must work to solve, naturally fostering the development of critical thinking skills as they analyze situations and seek solutions. Amalia (2017) highlights that PBL is an innovative instructional method that promotes active learning and encourages students to be directly engaged in the learning process. As a result, PBL not only enhances students' participation but also plays a significant role in cultivating critical thinking—an essential skill for navigating the complexities of the 21st century, where individuals must solve intricate problems, make informed decisions, and adapt to constant changes across different areas of life.

The findings of this study carry important implications for education, particularly in the field of mathematics instruction. PBL can serve as an effective alternative teaching strategy to enhance students' mathematical critical thinking, and its broader implementation across schools is highly recommended. Educators are encouraged to adopt the role of facilitators, guiding students through the PBL process by presenting meaningful challenges that stimulate deeper thinking. Additionally, curriculum design and teaching resources should incorporate PBL elements to promote more contextual, engaging, and thought-provoking learning experiences.

Despite the study demonstrating the effectiveness of the PBL model in improving students' critical thinking in mathematics, certain limitations must be acknowledged. The research was conducted in a single school with a relatively small sample size, which limits the generalizability of the results. Furthermore, the study was carried out over a short duration, making it difficult to assess the long-term impact of PBL implementation. Future research should consider expanding the scope to include larger sample sizes, diverse school settings, and extended timeframes. It would also be beneficial to explore additional factors that may influence the success of PBL, such as student engagement, motivation, and the overall learning environment.

CONCLUSIONS

Based on the results of the study, it can be concluded that the use of the Problem-Based Learning (PBL) model has a positive and significant effect on students' mathematical critical thinking skills. Students taught through PBL showed greater improvement across all critical thinking indicators interpretation, analysis, evaluation, and inference compared to those taught using traditional methods. These findings highlight that PBL encourages deeper understanding, promotes logical reasoning, and supports the development of systematic problem-solving abilities in mathematics.

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