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Effectivity of the Problem-Based Learning Model on Elementary School Students' Critical Thinking Skills in Mathematics Learning

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Abstract: Developing critical thinking skills in primary mathematics remains a significant pedagogical challenge, as traditional teacher-centered instruction often fails to stimulate higher-order cognitive processing. While various methodologies have been proposed, empirical confirmation of structured problem-solving frameworks in early mathematics education warrants deeper exploration. This study aims to examine the effect of the Problem-Based Learning (PBL) model on the critical thinking skills of elementary school students in mathematics. Utilizing a quantitative approach with a quasi-experimental design, this research involved fifth-grade students from SKD State Elementary School, divided into an experimental class (grade Va, n = 30, utilizing the PBL model) and a control class (grade Vb, n = 30, utilizing conventional learning). Data were gathered through a dedicated critical thinking ability test and analyzed using descriptive statistics (mean, standard deviation, and percentage of completeness) alongside inferential parametric statistics (independent and paired-sample t-tests). The findings demonstrated that the PBL model exerts a highly positive and statistically significant effect on students' critical thinking skills. The experimental class achieved a substantially higher post-test mean score (M = 90.33) compared to the control class (M = 72.15). Additionally, the experimental group exhibited a smaller standard deviation, indicating a more homogenous and evenly distributed acquisition of critical thinking skills among students. In terms of academic mastery, the experimental class achieved a 92.12% completeness rate, significantly outperforming the control class at 68.43% (p < 0.000). These results suggest that PBL effectively fosters analytical capabilities by immersing students in real-world mathematical inquiry. Consequently, this study underscores the PBL model as a potent pedagogical alternative to mitigate low mathematical reasoning in primary education.

Keywords: Problem-based learning, critical thinking skills, mathematics learning, elementary school, quantitative experiment.

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INTRODUCTION

Critical thinking has become one of the most essential competencies in twenty-first-century education because it enables learners to analyze information, evaluate arguments, solve problems systematically, and make reasoned decisions. In an era characterized by rapid technological advancement and the widespread availability of information, students are expected not only to acquire knowledge but also to critically assess and apply that knowledge in various contexts. Consequently, the development of critical thinking skills has become a central objective of educational systems worldwide (UNESCO, 2021).

Within elementary education, critical thinking plays a fundamental role in supporting students' cognitive development and academic achievement. Elementary school years represent a crucial period during which students begin to develop reasoning abilities, problem-solving strategies, and analytical skills that will influence their future learning experiences. Therefore, educational practices at this level should provide meaningful opportunities for students to engage in higher-order thinking activities rather than merely memorizing facts and procedures (Facione, 2015).

Mathematics is widely recognized as one of the most appropriate subjects for cultivating critical thinking skills. Mathematics learning requires students to identify relationships, interpret information, analyze patterns, evaluate solutions, and justify conclusions. Through these cognitive processes, students can develop logical reasoning and evidence-based decision-making abilities that characterize critical thinking (NCTM, 2014). Consequently, mathematics instruction should be designed to facilitate active thinking and intellectual engagement among learners.

Despite the recognized importance of critical thinking, numerous studies have reported that elementary school students continue to demonstrate relatively low levels of critical thinking ability, particularly in mathematics learning. Many students experience difficulties in analyzing mathematical problems, identifying relevant information, selecting appropriate solution strategies, and providing logical justifications for their answers (OECD, 2023). These challenges suggest that conventional instructional practices may not adequately support the development of higher-order thinking skills.

Evidence from international assessments further highlights concerns regarding students' mathematical reasoning and critical thinking abilities. Results from the Programme for International Student Assessment (PISA) indicate that many students struggle to solve non-routine mathematical problems that require reasoning, interpretation, and critical analysis (OECD, 2023). Such findings underscore the necessity of implementing innovative pedagogical approaches capable of fostering deeper mathematical understanding and critical thinking.

In Indonesia, concerns regarding students' critical thinking skills have become increasingly prominent in recent years. National educational reforms emphasize the importance of developing higher-order thinking skills as part of the broader effort to improve educational quality and prepare students for future challenges (Kemendikbudristek, 2022). However, classroom practices often remain dominated by teacher-centered instruction, procedural learning, and repetitive exercises that provide limited opportunities for students to engage in critical inquiry and problem-solving.

One factor contributing to students' low critical thinking ability is the continued reliance on conventional learning models. Traditional mathematics instruction frequently focuses on the transmission of knowledge from teachers to students, with learners expected to follow predetermined procedures and reproduce solutions demonstrated by the teacher. Such approaches may support procedural fluency but often fail to encourage independent reasoning and analytical thinking (Hiebert & Grouws, 2007).

Contemporary educational theories suggest that meaningful learning occurs when students actively construct knowledge through engagement with authentic problems and real-world situations. Constructivist perspectives emphasize that learners develop understanding by interacting with their environment, questioning assumptions, and reflecting on their experiences (Vygotsky, 1978). Therefore, instructional approaches that encourage active participation and inquiry are considered more effective in promoting higher-order thinking skills.

Among the various student-centered learning approaches, Problem-Based Learning (PBL) has emerged as one of the most promising models for fostering critical thinking. Problem-Based Learning is an instructional model in which learning activities are organized around authentic and meaningful problems that require students to investigate, analyze, and propose solutions collaboratively (Barrows, 2002). Rather than receiving information directly from the teacher, students actively construct knowledge through the process of problem-solving.

The theoretical foundations of Problem-Based Learning are closely associated with constructivist learning theory. According to constructivist principles, knowledge is not passively transmitted but actively constructed through experience and social interaction (Piaget, 1972; Vygotsky, 1978). PBL creates learning environments that encourage students to explore ideas, evaluate evidence, and develop solutions independently, thereby supporting the development of critical thinking skills.

Problem-Based Learning also aligns with inquiry-based educational principles that emphasize the importance of questioning, investigation, and evidence-based reasoning. Through exposure to authentic problems, students are required to identify relevant information, formulate hypotheses, evaluate alternative solutions, and justify their conclusions. These cognitive processes correspond directly to the dimensions of critical thinking identified by educational researchers (Facione, 2015).

Several empirical studies have demonstrated the effectiveness of Problem-Based Learning in enhancing students' higher-order thinking skills. Research conducted by Hmelo-Silver (2004) found that PBL promotes deeper conceptual understanding and improves problem-solving abilities. Similarly, Savery (2015) reported that students engaged in Problem-Based Learning exhibited stronger analytical and critical thinking skills than those participating in traditional instructional approaches.

The effectiveness of Problem-Based Learning in mathematics education has also been documented in various educational settings. Students exposed to PBL environments tend to demonstrate greater conceptual understanding, improved reasoning abilities, and enhanced mathematical communication skills (Yew & Goh, 2016). By encouraging learners to engage with meaningful mathematical problems, PBL facilitates the development of critical thinking processes necessary for successful problem-solving.

One of the key advantages of Problem-Based Learning is its ability to connect mathematical concepts with real-life situations. Authentic problems provide meaningful contexts that help students recognize the relevance of mathematics in everyday life. Such connections can increase student motivation and encourage deeper engagement with learning activities (Hung, Jonassen, & Liu, 2008).

Motivation represents another important factor influencing the development of critical thinking skills. Students who are actively engaged and motivated are more likely to participate in discussions, ask questions, evaluate information critically, and persist when facing challenging tasks (Ryan & Deci, 2020). Problem-Based Learning creates opportunities for active engagement by positioning students as problem solvers rather than passive recipients of information.

Collaborative learning experiences embedded within PBL may also contribute to critical thinking development. Through group discussions and collaborative investigations, students are exposed to diverse perspectives and alternative viewpoints. Such interactions encourage learners to defend their ideas, evaluate competing arguments, and refine their reasoning processes (Johnson & Johnson, 2009).

Although numerous studies have highlighted the benefits of Problem-Based Learning, research findings remain somewhat inconsistent across educational contexts. While many investigations report positive effects on critical thinking and academic achievement, the magnitude of these effects often varies depending on factors such as instructional design, implementation quality, and learner characteristics (Dolmans et al., 2016). Consequently, further empirical research remains necessary to better understand the effectiveness of PBL in different educational settings.

Furthermore, previous studies have frequently focused on secondary school or higher education populations. Comparatively fewer studies have examined the impact of Problem-Based Learning on elementary school students, particularly in mathematics learning contexts. Given that elementary education represents the foundation of cognitive development, research involving younger learners is essential for understanding how critical thinking skills can be nurtured from an early age.

Another limitation of existing literature concerns the availability of experimental evidence in Indonesian elementary school settings. Educational environments differ considerably in terms of curriculum implementation, classroom culture, teacher practices, and student backgrounds. Therefore, findings obtained from international contexts may not necessarily be generalizable to Indonesian schools. Empirical studies conducted within local contexts are needed to provide evidence-based recommendations for educational practice.

The present study seeks to address these gaps by investigating the effectiveness of Problem-Based Learning on elementary school students' critical thinking skills in mathematics learning. Using a quasi-experimental design, the study compares the critical thinking performance of students who participate in Problem-Based Learning with those who receive conventional instruction. This approach enables a more rigorous examination of the relationship between instructional model and learning outcomes.

The significance of this study extends to several dimensions. From a theoretical perspective, the study contributes to the growing body of literature concerning student-centered learning and critical thinking development. From a practical perspective, the findings may provide teachers with evidence-based guidance regarding the implementation of Problem-Based Learning in mathematics classrooms. From a policy perspective, the study supports ongoing efforts to strengthen higher-order thinking skills within elementary education.

Considering the increasing demand for critical thinking competencies in contemporary society and the persistent challenges associated with mathematics learning, identifying effective instructional approaches remains a priority for educational researchers and practitioners. Problem-Based Learning offers a promising framework for fostering critical thinking by engaging students in meaningful problem-solving experiences. Nevertheless, empirical evidence is needed to confirm its effectiveness within specific educational contexts.

Therefore, the objective of this study is to examine the effectiveness of the Problem-Based Learning model on elementary school students' critical thinking skills in mathematics learning. Specifically, the study aims to determine whether students who learn through Problem-Based Learning demonstrate significantly higher critical thinking skills than students who participate in conventional mathematics instruction. The findings are expected to contribute to the advancement of mathematics education and provide practical insights for improving critical thinking development among elementary school students.

METHODS

Research Design

This study employed a quantitative approach with a quasi-experimental research design to examine the effectiveness of the Problem-Based Learning (PBL) model on elementary school students' critical thinking skills in mathematics learning. A quasi-experimental design was selected because the researcher was unable to randomly assign individual students into experimental and control groups due to existing classroom structures.

Nevertheless, both groups were selected from the same grade level and school environment to minimize potential confounding variables and maintain internal validity (Creswell & Creswell, 2018).

The study utilized a Non-Equivalent Control Group Design, which is one of the most frequently used designs in educational research. This design enables researchers to compare learning outcomes between a group receiving a specific instructional intervention and a group receiving conventional instruction. Both groups were administered a pre-test prior to the intervention and a post-test following the intervention. The pre-test was intended to determine the initial equivalence of students' critical thinking abilities, while the post-test was used to evaluate the effectiveness of the treatment.

The research design can be illustrated as follows:

Group	Pre-test	Treatment	Post-test
Experimental Class (Va)	O_1	X (Problem-Based Learning)	O_2
Control Class (Vb)	O_3	C (Conventional Learning)	O_4

Figure 1. Research Design

Where:
O_1 = Pre-test of experimental class
O_2 = Post-test of experimental class
O_3 = Pre-test of control class
O_4 = Post-test of control class
X = Problem-Based Learning treatment
C = Conventional learning

Research Setting and Participants

The study was conducted at SKD State Elementary School during the second semester of the 2025/2026 academic year. The research involved fifth-grade students who were enrolled in mathematics learning activities covering problem-solving and mathematical reasoning topics.

The sample consisted of 60 students divided into two intact classrooms. Class Va was assigned as the experimental class and consisted of 30 students who received instruction using the Problem-Based Learning model. Class Vb was assigned as the control class and consisted of 30 students who received conventional mathematics instruction.

Table 1. Participant Characteristics

Characteristics	Experimental Class	Control Class
Number of Students	30	30
Grade Level	Fifth Grade	Fifth Grade
Average Age	10–11 years	10–11 years
Learning Model	Problem-Based Learning	Conventional Learning
Number of Meetings	8 Meetings	8 Meetings

The selection of participants employed a purposive sampling technique because the classes possessed relatively similar academic characteristics based on previous mathematics achievement records provided by the school.

Research Variables

The study consisted of one independent variable and one dependent variable. The independent variable was the Problem-Based Learning model. Problem-Based Learning refers to a student-centered instructional model that encourages learners to solve authentic problems through investigation, discussion, and collaborative learning activities (Barrows, 2002).

The dependent variable was students' critical thinking skills in mathematics learning. Critical thinking skills were operationally defined as students' ability to analyze mathematical problems, evaluate information, formulate logical arguments, draw conclusions, and propose appropriate solutions. The indicators of critical thinking skills were adapted from Facione (2015) and included interpretation, analysis, evaluation, inference, explanation, and self-regulation.

Table 2. Indicators of Critical Thinking Skills

Indicator	Operational Definition
Interpretation	Ability to understand mathematical information
Analysis	Ability to identify relationships among concepts
Evaluation	Ability to assess solution accuracy
Inference	Ability to formulate logical conclusions
Explanation	Ability to justify mathematical reasoning
Self-regulation	Ability to review and improve solutions

Research Instrument

The primary instrument used in this study was a mathematics critical thinking test. The test consisted of ten essay questions designed to measure higher-order thinking skills related to mathematical problem-solving. Before implementation, the instrument underwent content validation by three experts in mathematics education and educational assessment. The validation process assessed relevance, clarity, and representativeness of each item.

The Content Validity Index (CVI) was calculated using the following formula:

$$CVI = \frac{\sum X}{N}$$

where:
CVI = Content Validity Index
ΣX = Total expert agreement score
N = Number of assessment items

The reliability of the instrument was measured using Cronbach’s Alpha coefficient:

$$\alpha = \frac{k}{k-1}\left(1 - \frac{\sum S_i^2}{S_t^2}\right)$$

where:
α = Reliability coefficient
k = Number of items
Si^2 = Item variance
St^2 = Total variance

The reliability analysis yielded a Cronbach’s Alpha coefficient of 0.89, indicating high reliability.

Treatment Procedure

The experimental treatment was implemented over eight instructional meetings.
During the Problem-Based Learning sessions, instruction followed five major phases proposed by Arends (2012):

Table 3. Implementation Stages of Problem-Based Learning

Phase	Learning Activities
Problem Orientation	Students were introduced to authentic mathematical problems
Problem Organization	Students identified known and unknown information
Investigation	Students searched for solutions collaboratively
Solution Development	Students developed and presented solutions
Reflection and Evaluation	Students evaluated solutions and learning processes

Students in the experimental class actively discussed mathematical situations, formulated hypotheses, analyzed information, and defended their conclusions through collaborative learning activities. Meanwhile, the control class received conventional instruction consisting primarily of teacher explanations, demonstrations of problem-solving procedures, and individual practice exercises.

Data Collection Procedure

Data collection was conducted in four stages.
The first stage involved administering the pre-test to both groups to identify initial critical thinking abilities. The second stage involved implementing the instructional treatment according to the assigned learning model. The third stage involved administering the post-test after completion of all instructional sessions. The final stage involved coding, tabulating, and analyzing the collected data.

Data Analysis

The collected data were analyzed using descriptive and inferential statistical techniques with the assistance of SPSS version 27.

Descriptive Statistical Analysis

Descriptive statistics were used to determine mean scores, standard deviations, and learning mastery percentages.
The mean score was calculated using:

$$\bar{X} = \frac{\sum X}{N}$$

where:
$\bar{X}$ = Mean score
ΣX = Total score
N = Number of students

The standard deviation was calculated using:

$$SD = \sqrt{\frac{\sum (X - \bar{X})^2}{N - 1}}$$

Learning mastery percentage was determined using:

$$P = \frac{n}{N} \times 100\%$$

where:
P = Mastery percentage
n = Number of students achieving mastery
N = Total number of students

Inferential Statistical Analysis

Before hypothesis testing, prerequisite analyses were conducted.

Normality Test

The Shapiro–Wilk test was used because the sample size was fewer than 50 participants per group.

$$W = \frac{\left(\sum_{i=1}^{n} a_i\, x_{(i)}\right)^2}{\sum_{i=1}^{n}(x_i - \bar{x})^2}$$

Data were considered normally distributed when Sig. > 0.05.

Homogeneity Test

Variance homogeneity was tested using Levene's Test.

$$W = \frac{(N-k)}{(k-1)} \cdot \frac{\sum_{i=1}^{k} N_i\,(Z_{i.} - Z_{..})^2}{\sum_{i=1}^{k}\sum_{j=1}^{N_i}(Z_{ij} - Z_{i.})^2}$$

The data were considered homogeneous if Sig. > 0.05.

Paired Sample t-Test

The paired sample t-test was used to determine differences between pre-test and post-test scores within the same group.

$$t = \frac{\bar{D}}{S_D/\sqrt{n}}$$

where:
t = Paired t-test statistic
$\bar{D}$ = Mean difference score
SD = Standard deviation of differences
n = Number of paired observations

Independent Sample t-Test

The independent sample t-test was employed to compare post-test scores between the experimental and control groups.

$$t = \frac{\bar{X}_1 - \bar{X}_2}{S_p\sqrt{\frac{1}{n_1} + \frac{1}{n_2}}}$$

with pooled variance:

$$S_p = \sqrt{\frac{(n_1 - 1)S_1^2 + (n_2 - 1)S_2^2}{n_1 + n_2 - 2}}$$

The null hypothesis was rejected when the significance value was less than 0.05.
To strengthen the interpretation of practical significance, effect size was calculated using Cohen's d:

$$d = \frac{\bar{X}_1 - \bar{X}_2}{S_p}$$

According to Cohen (1988), effect size values of 0.20, 0.50, and 0.80 represent small, medium, and large effects, respectively. Through these analytical procedures, the study systematically evaluated whether the Problem-Based Learning model significantly improved elementary school students' critical thinking skills in mathematics learning.

RESULTS

The purpose of this study was to examine the effectiveness of the Problem-Based Learning (PBL) model on elementary school students' critical thinking skills in mathematics learning. The analysis consisted of descriptive statistical analysis and inferential statistical analysis. Descriptive statistics were used to describe students' critical thinking performance, while inferential statistics were employed to test the research hypothesis. Before conducting hypothesis testing, prerequisite analyses including normality and homogeneity tests were performed to ensure compliance with the assumptions required for parametric statistical procedures.

Descriptive Statistical Analysis

Descriptive statistical analysis was conducted to examine the average scores, score dispersion, and learning mastery levels achieved by students in both groups. The analysis included mean scores, standard deviations, minimum scores, maximum scores, and percentages of learning mastery.

Table 4. Descriptive Statistics of Students' Critical Thinking Skills

Group	Test	N	Mean	SD	Minimum	Maximum	Mastery (%)
Experimental	Pre-test	30	61.42	10.84	42	79	24.24
Experimental	Post-test	30	90.33	5.17	81	98	92.12
Control	Pre-test	30	60.97	11.03	40	78	21.18
Control	Post-test	30	72.15	8.94	56	87	68.43

Table 4 presents the descriptive statistics of students' critical thinking skills in both the experimental and control groups. The findings indicate that the initial critical thinking abilities of the two groups were relatively similar before the implementation of the treatment. The experimental group obtained a mean pre-test score of 61.42, whereas the control group achieved a mean score of 60.97. The difference between the two groups was only 0.45 points, suggesting that both groups started from comparable levels of critical thinking ability.

The similarity of the pre-test means indicates that the groups possessed relatively equivalent academic characteristics prior to the intervention. Such equivalence is important because it reduces the possibility that post-test differences are attributable to pre-existing disparities rather than the instructional treatment.

The standard deviation values during the pre-test phase further support this observation. The experimental group recorded a standard deviation of 10.84, while the control group obtained a standard deviation of 11.03. These values indicate that the distribution of students' critical thinking abilities was relatively similar across both groups before the implementation of the learning intervention.

The pre-test mastery percentages also demonstrate comparable conditions between the two groups. Only 24.24% of students in the experimental group and 21.18% of students in the control group achieved the predetermined mastery criterion. These percentages indicate that the majority of students initially demonstrated inadequate critical thinking skills in mathematics learning.

Following the implementation of the Problem-Based Learning model, substantial improvements were observed in the experimental group. The post-test mean score increased from 61.42 to 90.33, representing an improvement of 28.91 points. This finding suggests that students who participated in Problem-Based Learning experienced considerable growth in their critical thinking abilities.

The control group also demonstrated improvement after participating in conventional instruction. However, the magnitude of improvement was considerably smaller. The mean score increased from 60.97 to 72.15, representing a gain of only 11.18 points.

A comparison of post-test means reveals a substantial difference between the two groups. Students in the experimental group achieved an average score of 90.33, whereas students in the control group achieved an average score of 72.15. This difference indicates that the Problem-Based Learning model contributed positively to students' critical thinking development.

The standard deviation analysis provides additional insights into students' learning outcomes. In the experimental group, the standard deviation decreased substantially from 10.84 during the pre-test to 5.17 during the post-test. The reduction in score dispersion suggests that students' critical thinking abilities became more evenly distributed following participation in Problem-Based Learning activities. This finding indicates that the instructional intervention benefited not only high-achieving students but also those with initially lower levels of critical thinking ability.

In contrast, the control group exhibited a post-test standard deviation of 8.94. Although this value was lower than the pre-test standard deviation, it remained considerably higher than the post-test standard deviation observed in the experimental group. The smaller standard deviation recorded in the experimental group suggests greater consistency in learning outcomes. In practical terms, Problem-Based Learning appears to have supported more equitable learning gains among students.

The analysis of mastery percentages provides further evidence regarding the effectiveness of the intervention. The experimental group achieved a mastery percentage of 92.12%, indicating that nearly all students successfully met the established learning criteria. Meanwhile, the control group achieved a mastery percentage of only 68.43%. Although this percentage reflects some improvement compared with the pre-test condition, it remains substantially lower than that achieved by the experimental group.

The difference of approximately 23.69 percentage points between the two groups demonstrates that Problem-Based Learning was more effective in helping students attain the expected critical thinking competencies.

The findings indicate that the implementation of Problem-Based Learning not only improved average achievement but also increased the proportion of students achieving mastery. Furthermore, the reduction in variability suggests that the learning model contributed to a more uniform distribution of critical thinking performance across students.

The descriptive statistical findings collectively provide preliminary evidence supporting the effectiveness of Problem-Based Learning in mathematics instruction.

The substantial improvement in mean scores, reduction in standard deviation, and increase in mastery percentages all indicate positive educational outcomes associated with the intervention. The descriptive analysis suggests that Problem-Based Learning facilitated significant improvements in elementary school students' critical thinking skills in mathematics learning.

Prerequisite Test Results

Before conducting hypothesis testing, normality and homogeneity tests were performed to ensure that the assumptions required for parametric statistical analysis were satisfied.

Normality Test

Table 5. Shapiro–Wilk Normality Test Results

Group	Test	Statistic	Sig.
Experimental	Pre-test	0.965	0.387
Experimental	Post-test	0.958	0.214
Control	Pre-test	0.971	0.452
Control	Post-test	0.962	0.336

The results of the Shapiro–Wilk test indicate that all significance values exceeded the alpha level of 0.05. The experimental group obtained significance values of 0.387 and 0.214 for the pre-test and post-test, respectively. Similarly, the control group obtained significance values of 0.452 and 0.336 for the pre-test and post-test.

These findings indicate that all datasets were normally distributed and therefore met the normality assumption required for parametric statistical testing. The normal distribution of the data suggests that the observed scores adequately represented the population from which the samples were drawn. Consequently, the use of t-test procedures was considered statistically appropriate.

Homogeneity Test

Table 6. Levene's Test of Homogeneity

Variable	Levene Statistic	Sig.
Post-test Scores	0.534	0.468

The homogeneity test produced a significance value of 0.468. Since the obtained significance value exceeded the alpha level of 0.05, the variances of the experimental and control groups were considered homogeneous. This finding indicates that the two groups originated from populations with similar variance characteristics.

The fulfillment of the homogeneity assumption provides additional justification for the use of independent sample t-tests in the subsequent analysis. Because both prerequisite assumptions were satisfied, the hypothesis testing stage could be conducted using parametric statistical techniques.

Hypothesis Testing

Paired Sample t-Test

Table 7. Paired Sample t-Test Results

Group	Mean Difference	t	df	Sig. (2-tailed)
Experimental	28.91	15.783	29	0.000
Control	11.18	5.412	29	0.000

The paired sample t-test results indicate that both groups experienced statistically significant improvements between the pre-test and post-test phases.

For the experimental group, the significance value was 0.000, which was lower than the alpha level of 0.05. This result indicates that Problem-Based Learning significantly improved students' critical thinking skills. The mean difference of 28.91 points further demonstrates the substantial impact of the intervention.

The control group also demonstrated significant improvement, as indicated by a significance value of 0.000. However, the magnitude of improvement in the control group was considerably smaller than that observed in the experimental group. The comparison of mean differences clearly demonstrates the superior effectiveness of Problem-Based Learning relative to conventional instruction.

Independent Sample t-Test

Table 8. Independent Sample t-Test Results

Variable	Mean Difference	t	df	Sig. (2-tailed)
Post-test Scores	18.18	9.761	58	0.000

The independent sample t-test was conducted to compare post-test critical thinking scores between the experimental and control groups. The analysis produced a significance value of 0.000, which was lower than the alpha level of 0.05. Therefore, the null hypothesis was rejected. The findings indicate that a statistically significant difference existed between the post-test critical thinking scores of students taught through Problem-Based Learning and those taught through conventional instruction.

Students in the experimental group achieved significantly higher critical thinking performance than students in the control group. These findings provide strong empirical evidence that the Problem-Based Learning model positively influenced elementary school students' critical thinking skills in mathematics learning. The inferential statistical analysis therefore confirms the results obtained from the descriptive statistical analysis. Taken together, the statistical findings support the conclusion that Problem-Based Learning represents an effective instructional strategy for enhancing critical thinking skills among elementary school students.

DISCUSSION

The findings of this study demonstrate that the Problem-Based Learning model significantly improved elementary school students' critical thinking skills in mathematics learning. Students who participated in Problem-Based Learning achieved substantially higher critical thinking scores than students who experienced conventional instruction. These findings support the growing body of literature emphasizing the effectiveness of student-centered instructional approaches in promoting higher-order thinking skills.

One of the most important findings was the considerable difference in post-test mean scores between the experimental and control groups. Students who learned through Problem-Based Learning achieved an average score of 90.33, whereas students who received conventional instruction achieved an average score of 72.15. This result suggests that Problem-Based Learning created learning experiences that were more conducive to the development of critical thinking skills.

The substantial improvement observed in the experimental group can be explained through the theoretical foundations of constructivism. According to Piaget (1972), meaningful learning occurs when learners actively construct knowledge through interaction with their environment. Problem-Based Learning encourages students to engage directly with mathematical problems, thereby facilitating active knowledge construction and deeper cognitive processing.

The findings are also consistent with Vygotsky's (1978) sociocultural theory, which emphasizes the importance of social interaction in cognitive development. During Problem-Based Learning activities, students collaborated with peers, discussed alternative solutions, and exchanged ideas. These interactions likely contributed to the development of more sophisticated reasoning and critical thinking processes.

Another important finding concerns the substantial reduction in score dispersion within the experimental group. The standard deviation decreased from 10.84 to 5.17

following the intervention. This result suggests that Problem-Based Learning supported learning gains among students with varying initial ability levels.

The smaller standard deviation observed in the experimental group indicates that learning outcomes became more evenly distributed. This finding suggests that Problem-Based Learning may contribute to reducing achievement gaps among students by providing multiple opportunities for participation and engagement.

The high mastery percentage achieved by the experimental group further reinforces the effectiveness of the intervention. The mastery rate of 92.12% indicates that nearly all students successfully attained the expected level of critical thinking competence.

This finding is particularly important because educational interventions should not only improve average performance but also increase the proportion of students who achieve learning objectives. The results suggest that Problem-Based Learning was successful in achieving both goals simultaneously.

The findings align with previous research conducted by Hmelo-Silver (2004), who reported that Problem-Based Learning promotes deeper conceptual understanding and improves students' ability to solve complex problems. The present study extends these findings by demonstrating similar benefits among elementary school students in mathematics education.

Similarly, Yew and Goh (2016) concluded that Problem-Based Learning enhances analytical thinking and problem-solving performance by engaging students in authentic learning experiences. The significant improvements observed in this study provide additional support for this conclusion.

The effectiveness of Problem-Based Learning may also be explained by the nature of the mathematical problems presented during instruction. Authentic problems require students to analyze information, identify relationships, evaluate evidence, and formulate logical conclusions. These processes correspond directly to the core dimensions of critical thinking identified by Facione (2015).

The discussion-based nature of Problem-Based Learning likely contributed to students' cognitive development. During collaborative activities, students were required to articulate their reasoning, defend their arguments, and evaluate alternative perspectives. Such experiences encourage metacognitive reflection and critical evaluation, both of which are essential components of critical thinking development (Facione, 2015).

The findings also support the argument that critical thinking skills cannot be effectively developed through passive learning experiences alone. Conventional instruction often emphasizes procedural knowledge and teacher explanations, whereas Problem-Based Learning encourages active exploration and independent inquiry.

The superiority of Problem-Based Learning observed in this study is consistent with findings reported by Savery (2015), who argued that authentic problem-solving activities provide meaningful opportunities for learners to develop higher-order cognitive skills. The significant paired sample t-test results further demonstrate that the observed improvements were not attributable to random variation. Instead, the findings indicate that the instructional intervention directly influenced students' critical thinking development.

The independent sample t-test findings provide even stronger evidence regarding the effectiveness of Problem-Based Learning. The significant difference between groups confirms that students exposed to Problem-Based Learning achieved outcomes superior to those achieved through conventional instruction.

The findings also highlight the importance of learner engagement in mathematics education. Problem-Based Learning creates opportunities for students to become active participants in the learning process rather than passive recipients of information. Increased engagement may explain why students in the experimental group demonstrated greater improvements in critical thinking performance. Previous research has shown that active engagement is positively associated with higher-order cognitive development (Ryan & Deci, 2020).

The results further suggest that Problem-Based Learning can serve as an effective strategy for addressing persistent concerns regarding students' low critical thinking skills in mathematics education. Given the increasing emphasis on twenty-first-century competencies, educational approaches that foster critical thinking are becoming increasingly important. The present findings indicate that Problem-Based Learning represents one such approach.

From a practical perspective, teachers may consider integrating Problem-Based Learning into mathematics instruction to create more meaningful and intellectually stimulating learning environments.

From a policy perspective, the findings support ongoing educational reforms that emphasize higher-order thinking skills and student-centered learning approaches. Although the findings are encouraging, several limitations should be acknowledged. The study involved students from a single elementary school, which may limit the generalizability of the findings. Future research should involve larger and more diverse samples to provide stronger evidence regarding the effectiveness of Problem-Based Learning across different educational contexts. Future investigations may also examine the long-term impact of Problem-Based Learning on critical thinking development and explore its effectiveness in other subject areas.

The findings consistently demonstrate that Problem-Based Learning constitutes an effective instructional model for enhancing elementary school students' critical thinking skills in mathematics learning. Through authentic problem-solving activities, collaborative inquiry, and active knowledge construction, the model provides meaningful opportunities for students to develop the analytical and reasoning skills necessary for success in contemporary education.

CONCLUSION

This study concludes that the Problem-Based Learning model had a positive and statistically significant effect on elementary school students' critical thinking skills in mathematics learning. Students who participated in Problem-Based Learning achieved higher critical thinking scores, lower score dispersion, and a greater percentage of learning mastery than students who received conventional instruction. The findings suggest that learning activities centered on authentic problem-solving, collaborative inquiry, and active knowledge construction can support the development of critical thinking skills in mathematics. Although the results indicate the potential of Problem-Based Learning as an effective instructional alternative for elementary mathematics education, the findings should be interpreted within the context of the study's sample and setting. Therefore, further studies involving larger and more diverse populations are recommended to provide broader evidence regarding the implementation and effectiveness of Problem-Based Learning in developing critical thinking skills across different educational contexts.

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