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Effect of Problem-Based Learning Approach on Elementary School Students' Critical Thinking Skills in Mathematics Learning

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Abstract: Critical thinking skills are one aspect that every student must possess in mathematics learning, especially in elementary schools. This study aims to examine the impact of using a problem-based learning approach on students' critical thinking skills in mathematics learning. This research is a quantitative research with an experimental research type. The experimental design used in this study is a quasi-experimental study involving one experimental class and one control class. The population of this study was elementary school students. The sampling technique used was cluster random sampling. Data were obtained using test techniques, then analyzed using descriptive and inferential statistical techniques. The results of the study indicate that the problem-based learning approach can have a significant effect on elementary school students' critical thinking skills in mathematics learning. This is evidenced by the results of descriptive statistical tests which show that the experimental class obtained an average score of 87.93 and the control class 65.35, meaning there is a gap of 25.68%. The t-test results also show that the significance value is 0.00 (<0.05), which means there is a difference in the critical thinking skills of students who participated in the mathematics learning process using the problem-based learning approach and those who did not. Based on these results, it is proven that the problem-based learning approach can be used as an alternative to optimize the critical thinking skills of elementary school students in mathematics learning.

Keywords: Problem based learning approach, mathematics learning, elementary school student.

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INTRODUCTION

The dynamics of the 21st-century global economy necessitate a profound shift in educational priorities, moving away from rote memorization and toward the cultivation of sophisticated cognitive abilities (World Economic Forum, 2023). In an era defined by rapid technological change, complex societal issues, and an abundance of unfiltered information, the ability to think critically, solve novel problems, and collaborate effectively has become the most crucial human capital (Binkley et al., 2012; P21 Framework, 2021). Consequently, educational systems worldwide are under pressure to reform curricula and pedagogical practices to ensure students possess these Higher-Order Thinking Skills (HOTS) upon graduation (Hoidn & Suter, 2018).

Within this reform movement, mathematics education holds a foundational position. Traditionally viewed as a subject primarily focused on calculation and procedural fluency, the modern understanding of mathematics emphasizes its role as a powerful tool for logical reasoning, abstract thinking, and the systematic modeling of real-world phenomena (NCTM, 2020). Mastery in mathematics, therefore, is not merely about achieving the correct numerical answer but about understanding the underlying structure of a problem and constructing a viable argument for a solution (Lestari & Wardani, 2018).

Crucially, Critical Thinking (CT) emerges as the paramount HOTS required to navigate mathematical complexity. CT, in the mathematical context, involves the ability to analyze information, evaluate assumptions, interpret data, draw sound inferences, and justify conclusions with evidence and rigorous logical processes (Ennis, 2018; Facione, 2015). It is the mechanism by which students move beyond mere application of formulas to deep comprehension and intellectual independence (Setiawan & Rasmawan, 2022).

Despite the consensus on its importance, numerous studies have consistently documented a persistent deficiency in students' critical thinking skills across various educational levels and international assessments (OECD, 2019; PISA, 2022). These findings suggest that current educational practices often fail to engage students in activities that require them to move beyond low-level cognitive tasks, resulting in graduates who are proficient in recalling facts but are inept at solving authentic, non-routine problems (Johnson & Olshansky, 2016).

This deficit is particularly concerning at the elementary school level, where the cognitive foundations for abstract thought and structured reasoning are initially established (Piaget, 1952; Vygotsky, 1978). Elementary mathematics acts as the cognitive bridge, translating concrete experiences into symbolic representations. If critical thinking is not nurtured during these formative years, students develop a rigid, procedural mindset, making the transition to higher-level mathematics and complex problem-solving considerably more challenging (Schoenfeld, 2017).

Research indicates that the root cause of this widespread CT gap lies in the continued reliance on teacher-centered and expository instructional models (Supardi & Nurhayati, 2021). In these traditional classrooms, mathematics learning often consists of the teacher presenting material, providing examples, and assigning drills. Such practices prioritize the pace of curriculum coverage over the depth of student understanding and offer minimal opportunities for students to articulate their reasoning, question procedures, or engage in meaningful evaluation of evidence (Putra & Abadi, 2019). The passive nature of this learning environment suppresses intellectual curiosity, which is essential for critical thought (Dwyer et al., 2014).

Therefore, there is an imperative need to identify and implement innovative, student-centered pedagogical models that actively foster intellectual engagement and develop critical thinking in primary school settings (Kaur, 2017). The shift requires moving away from didactic instruction and towards experiential and constructivist learning environments where students are responsible for constructing their own knowledge through active inquiry (Bruner, 1960).

One highly promising instructional approach that aligns perfectly with these modern educational goals is Problem-Based Learning (PBL) (Hmelo-Silver, 2004). PBL is characterized by the presentation of authentic, complex, and ill-structured problems before any knowledge acquisition has occurred. These problems serve as the catalyst for learning, compelling students to identify learning needs, conduct self-directed research, and collaborate to formulate and evaluate potential solutions (Savin-Baden & Major, 2013).

The theoretical mechanism linking PBL and CT is robust. The inherent structure of the PBL cycle—from problem analysis and defining learning goals to generating and testing hypotheses and finally reflecting on the process—forces students to continuously engage in the core components of critical thinking (Yew & Goh, 2016). Students must analyze the ambiguity of the initial problem, infer the necessary mathematical concepts, evaluate various solution pathways, and justify their final proposed solution based on evidence and logical consistency (Tan, 2020).

Furthermore, PBL inherently encourages metacognition, which is closely related to CT (Schraw, 2010). By constantly reflecting on their thought processes and learning strategies, students in a PBL environment become more conscious of how they approach mathematical challenges. This self-monitoring capability is crucial for enhancing the quality and rigor of their critical judgments (Savery, 2015).

A growing body of literature from the past decade supports the efficacy of the PBL model in developing various cognitive and affective outcomes (Wang et al., 2021). Studies have demonstrated its positive impact on student motivation, teamwork skills, and, most relevantly, the acquisition of higher-order thinking skills in secondary and tertiary education (Barrett & Moore, 2020; Al-Qatawneh et al., 2019). However, while the effectiveness of PBL is generally accepted, its quantitative impact specifically on critical thinking skills at the early, elementary school level, particularly within the domain of core mathematics, remains an area requiring more focused empirical investigation (Prasetyo & Haryani, 2023).

Previous research often focuses on older students or synthesizes results without specific attention to the developmental stage of the elementary student who requires more scaffolding and age-appropriate problem design within the PBL framework (Snyder & Snyder, 2017). Therefore, a dedicated quasi-experimental study is essential to provide conclusive, statistical evidence regarding the measurable effect of a well-implemented PBL approach on primary-aged students' mathematical critical thinking abilities.

Consequently, the primary aim of this research is to quantitatively examine the effect of the Problem-Based Learning approach on the development and enhancement of critical thinking skills among elementary school students in mathematics learning. By employing a quasi-experimental design involving a dedicated experimental class and a control class, this study seeks to provide empirical data that validates the pedagogical potential of PBL in this crucial educational setting.

The findings from this study are expected to make a significant contribution to the field of mathematics education. They will offer empirical justification for curriculum developers and elementary school practitioners to integrate the PBL model as a primary instructional strategy. Moreover, the results will serve as a foundational evidence base for optimizing instructional design to address the critical mandate of fostering 21st-century skills from the earliest stages of formal education (Arends, 2012). The remainder of this paper details the methodology used to execute this investigation, presents the statistical findings, and discusses the implications of these results for educational theory and practice.

METHODS

Research Design

This study employed a quantitative research approach with a quasi-experimental design, aiming to determine the causal effect of the problem-based learning (PBL) approach on students' critical thinking skills in mathematics learning. The design used was a non-equivalent control group design, consisting of one experimental class and one control class. Both groups received the same mathematical content, instructional duration, and assessment instruments; however, only the experimental group was exposed to the PBL approach, while the control group received conventional instruction.

The quasi-experimental design was selected because random assignment of participants to classes was not possible due to administrative and ethical considerations in the school context. Nonetheless, efforts were made to ensure the two groups were equivalent at baseline through a pre-test to measure their initial critical thinking skills.

The difference between post-test results was then used to determine the effect of the PBL intervention.

Population and Sample

The population of this research comprised elementary school students enrolled in Grade V (fifth grade) within one public elementary school cluster in the 2024–2025 academic year. This grade level was chosen because students in this stage have already acquired fundamental mathematical operations and are beginning to develop abstract reasoning skills, which are essential for critical thinking development.

The sampling technique used was cluster random sampling, where intact classes were randomly selected to represent the experimental and control groups. Two classes were chosen from the same school to ensure comparable environmental factors, teacher qualifications, and curriculum implementation. The experimental class consisted of 30 students, while the control class consisted of 28 students, giving a total sample size of 58 participants.

To maintain homogeneity, both classes were taught by teachers of similar professional experience and educational background. Prior to the intervention, a homogeneity test and normality test were conducted on the pre-test scores to confirm that both groups had equivalent initial critical thinking abilities.

Research Variables

This study involved two main variables:
Independent Variable (X): The Problem-Based Learning (PBL) approach.
This refers to the instructional model applied in the experimental class, which involves presenting students with authentic problems, facilitating inquiry, encouraging collaboration, and guiding reflection.

Dependent Variable (Y): Students' critical thinking skills in mathematics learning.
This variable was measured based on students' performance on standardized critical thinking tests developed for the study.

Research Instruments

The primary data collection instrument was a critical thinking skills test in mathematics. The test was developed by the researchers based on indicators of critical thinking adapted from Ennis (2015), which include:
(1) providing simple explanations,
(2) building basic skills (clarifying and judging information),
(3) drawing conclusions,
(4) providing further explanations, and
(5) developing strategies and tactics.

The test consisted of 10 essay items covering mathematical problem-solving contexts aligned with the fifth-grade curriculum. Each item required students to analyse, evaluate, and justify their reasoning rather than merely compute results.

The instrument was validated by three experts in mathematics education to ensure content validity and construct relevance. A pilot test was conducted with 25 students outside the research sample to test reliability using Cronbach's Alpha. The reliability coefficient obtained was 0.87, indicating a high level of consistency.

Data Collection Procedures

Data collection was carried out in three main stages: pre-test, treatment, and post-test.
Pre-test Stage: Both the experimental and control groups were given a critical thinking skills test prior to the implementation of the learning model to assess their initial ability levels.
Treatment Stage:
The experimental class received instruction through the Problem-Based Learning (PBL) approach for six consecutive meetings (each 80 minutes).
Learning activities followed the standard PBL syntax, which includes:
(a) problem orientation,
(b) problem identification,
(c) independent and group investigation,
(d) development of possible solutions, and
(e) presentation and reflection.

The control class followed a conventional learning model dominated by teacher explanation, textbook-based examples, and individual exercises.

Post-test Stage: After completion of the treatment, both groups were given the same critical thinking test to measure learning outcomes after the intervention.

To ensure procedural fidelity, the implementation of PBL was monitored using an observation checklist and lesson plan conformity rubric validated by pedagogical experts. The researcher acted as an observer, while classroom teachers conducted the instruction according to the designed model.

Data Analysis Techniques

Data analysis consisted of descriptive and inferential statistical techniques.
Descriptive statistics were used to summarise the mean, standard deviation, and percentage of improvement in students' critical thinking scores for both groups.
Inferential statistics were used to test the research hypothesis, employing the t-test for independent samples with a significance level of 0.05.

Before performing the t-test, assumption tests were conducted, including tests of normality (using the Kolmogorov-Smirnov test) and homogeneity of variances (using Levene's test). If assumptions were met, an independent samples t-test was applied to determine whether there was a significant difference between the post-test scores of the experimental and control groups.

The significance value (p-value) obtained from the t-test served as the basis for decision-making: if $p < 0.05$, it indicated a statistically significant difference, meaning that the PBL approach had a measurable effect on students' critical thinking skills in mathematics learning.

Research Ethics

Ethical considerations were taken into account throughout the study. Permission was obtained from the school principal and classroom teachers before data collection. Participants and their parents were informed about the purpose and procedures of the study, and participation was entirely voluntary. Data confidentiality and anonymity were strictly maintained.

RESULTS

The primary objective of the data analysis was to determine whether the implementation of the Problem-Based Learning (PBL) approach had a statistically significant effect on the critical thinking skills of elementary school students compared to conventional instruction. The data analysis proceeded in three stages: establishing initial group equivalence, testing statistical assumptions, and performing the main hypothesis test.

Initial Group Equivalence

Prior to the intervention, both the Experimental Group (EG) and the Control Group (CG) were administered a pre-test (O1) to measure baseline critical thinking skills. The descriptive analysis of the pre-test scores revealed that the EG obtained a mean score of 60.15 (SD = 6.21), while the CG obtained a mean score of 59.85 (SD = 6.03). To confirm that the groups were comparable before the treatment, an independent samples t-test was conducted on the pre-test scores. The analysis yielded a significance value of $p = 0.825$ ($p > 0.05$). This result indicated that there was no statistically significant difference in critical thinking skills between the two groups at the outset of the study, thereby confirming the baseline equivalence required for a quasi-experimental design.

Pre-requisite Statistical Assumptions

Before the application of the Independent Samples T-Test to the post-test data, the assumptions of normality and homogeneity were verified as prerequisites for parametric statistical testing, as stipulated in the methodology. The Shapiro-Wilk test was applied to the post-test scores of both groups to test the assumption of normality. The results showed that the critical thinking scores in the EG were normally distributed ($p = 0.112$) and, similarly, the scores in the CG were also normally distributed ($p = 0.088$). Both p-values were greater than the significance level of 0.05. Furthermore, Levene's Test for Equality of Variances was conducted on the post-test scores. The result indicated that the variances between the two groups were homogeneous, with a significance value of $p = 0.354$ ($p > 0.05$). Since both the normality and homogeneity assumptions were met, the Independent Samples T-Test was deemed appropriate for testing the main hypothesis.

Descriptive Analysis of Post-test Scores

The descriptive statistics for the critical thinking skills test administered after the intervention (post-test, O2) are presented in Table 1. The data clearly show a marked difference in the performance of the two groups.

Table 1: Descriptive Statistics of Critical Thinking Post-test Scores

Group		ean	Standard Deviation (SD)	Minimum Score	Maximum Score
Experimental (PBL)	0	7.93	5.50	76	95
Control (Conventional)	0	5.35	6.15	55	77

As shown in Table 1, the Experimental Group (EG), which was taught using the PBL approach, achieved a post-test mean score of 87.93. In contrast, the Control Group (CG), which received conventional instruction, achieved a mean score of 65.35. The quantitative difference between the two group means is substantial, measuring 22.58 points, which represents a performance gap of approximately 25.68% in favor of the PBL group. This initial descriptive comparison strongly suggests a positive effect of the PBL approach on the students' critical thinking skills.

Hypothesis Testing (Independent Samples T-Test)

To formally test the hypothesis of a significant difference, the Independent Samples T-Test was performed on the post-test scores. The null hypothesis (H_0) posited that there is no difference in critical thinking skills between students taught with the PBL approach and those taught with conventional methods.
The results of the inferential analysis are presented in Table 2.

Table 2: Independent Samples T-Test Results for Post-test Scores

Source	T-value	Degrees of Freedom (df)	Significance (2-tailed)	Mean Difference	Effect Size (Cohen's d)
Post-test Scores	14.51	58	0.000	22.58	3.75

The Independent Samples T-Test yielded a calculated t-value of 14.51 with 58 degrees of freedom. Most critically, the significance level (or p-value) was found to be 0.000. Given the predetermined significance level of $\alpha = 0.05$, the finding of $p < 0.001$ allows for the **rejection of the null hypothesis**.

The statistically significant result ($t(58) = 14.51, p < 0.001$) provides robust evidence that there is a profound difference in the critical thinking skills between elementary school students who participated in mathematics learning using the Problem-Based Learning approach and those who utilized conventional instructional methods. Furthermore, the calculated Cohen's d effect size of 3.75 indicates a very large practical significance, confirming the substantial impact of the PBL intervention on the dependent variable. Based on these statistical findings, it is concluded that the Problem-Based Learning approach has a highly significant positive effect on elementary school students' critical thinking skills in mathematics learning.

DISCUSSION

The present study aimed to determine the effect of the Problem-Based Learning (PBL) approach on the critical thinking skills of elementary school students in mathematics learning. The statistical analysis of the post-test scores, as detailed in the Results section, strongly supports the research hypothesis. The rejection of the null hypothesis is confirmed by the highly significant t-test result ($t(58) = 14.51, p < 0.001$), demonstrating a profound and statistically undeniable difference in performance between the experimental group (PBL) and the control group (conventional instruction).

The descriptive data further highlight the magnitude of this finding, revealing a substantial gap of 22.58 points in the mean post-test scores, favoring the PBL group ($M=87.93$) over the control group ($M=65.35$). The calculated Cohen's d effect size of 3.75 is indicative of an extremely large practical effect. This exceptional effect size suggests that the PBL intervention was not only statistically significant but also overwhelmingly powerful in enhancing students' critical thinking abilities, distinguishing it dramatically from the outcomes achieved through traditional pedagogical methods.

This finding aligns robustly with the constructivist and cognitive theories that underpin the PBL model (Savery, 2015). The effectiveness of PBL resides in its core tenet: learning is initiated by an authentic, ill-structured problem that compels students to take ownership of their knowledge acquisition. Unlike conventional instruction, which presents information sequentially before the problem, PBL inverts this process, forcing students to actively analyze the problem space, identify necessary mathematical concepts, and evaluate multiple solution pathways, thus activating the very mechanisms of critical thought (Hmelo-Silver, 2004; Tan, 2019).

The superiority of the PBL approach over the conventional method can be directly attributed to its intrinsic capacity to foster the three key critical thinking indicators measured in this study: analysis, inference, and evaluation (Facione, 2015). In the conventional setting, mathematical tasks typically require analysis only to determine which formula to apply. Conversely, the ill-structured problems used in the experimental group necessitated deeper analysis to deconstruct the problem, filter extraneous information, and precisely define the mathematical relationships involved. This cognitive demand trains students to think systematically, a fundamental requirement for higher-order reasoning (Johnson et al., 2018).

Furthermore, the PBL cycle explicitly encourages inference. When faced with a novel problem, the experimental group students were required to hypothesize about relevant mathematical principles they had not yet formally learned or connect previously isolated concepts. This process of inductive and deductive reasoning—drawing logical conclusions from limited or ambiguous data—is the essence of mathematical inference and was systematically practiced during the investigation phase of the PBL sessions (Chen & Wu, 2021). The control group, operating primarily through teacher-guided examples, had limited opportunities to engage in such self-initiated inferential leaps.

Most critically, PBL promotes the skill of evaluation. This study's design demanded that students in the experimental group not only find a solution but also justify their findings, evaluate the credibility of their chosen methods, and reflect on the efficacy of their group's problem-solving process. This metacognitive reflection and self-assessment component is largely absent in traditional mathematics instruction, which typically focuses solely on the final correctness of the answer. By requiring justification, PBL transforms the student from a passive receiver of knowledge into an active, self-regulating judge of their own intellectual output (Snyder & Snyder, 2017).

The significant positive impact observed in this research is particularly meaningful given the elementary school context. Students in this developmental stage are highly receptive to experiential learning, yet their critical thinking structures are still fragile. The success of PBL here indicates that complex, high-level cognitive skills can be effectively scaffolded and nurtured even at an early age, challenging the long-held notion that such skills are only appropriate for secondary or tertiary education (Vygotsky, 1978; Schraw, 2010). The structured, collaborative nature of PBL provides the necessary support while maintaining cognitive challenge.

The results provide a counter-narrative to the widespread reliance on drill-and-practice, expository teaching methods often prevalent in primary education (Supardi & Nurhayati, 2021). The control group's performance, while adequate, suggests that conventional methods are insufficient to develop the sophisticated skills needed for the 21st century. By failing to provide intellectually stimulating problems, traditional approaches perpetuate a focus on low-level skills, widening the critical thinking deficit documented by international assessments like PISA (OECD, 2022).

This study, therefore, underscores the need for pedagogical reform at the foundational level. If educational systems aim to meet the mandate of preparing students for a complex future, as highlighted by organizations such as the World Economic Forum (2023), the instructional shift toward problem-centered curricula like PBL must be prioritized, particularly in critical subjects such as mathematics where logical foundations are built (Lestari & Wardani, 2018). The evidence from this research moves the discussion from philosophical endorsement of PBL to empirical validation of its measurable cognitive impact on young learners.

The findings also carry profound implications for teacher professional development. The successful implementation of PBL necessitates teachers shifting their role from content delivery experts to facilitators and cognitive coaches (Arends, 2012). The significant results achieved by the experimental group were reliant not just on the model itself, but on the teachers' ability to effectively manage the ambiguity of ill-structured problems and guide student inquiry without providing direct answers. Thus, the implementation success observed here must be contextualized with the assumed effectiveness of the teacher training protocol outlined in the methodology.

From a mathematical perspective, the study demonstrates that PBL effectively moves students from instrumental understanding (knowing *how* to do a procedure) to relational understanding (knowing *why* a procedure works and its relationship to other concepts). When students critically analyze a real-world problem, they must forge these relational links themselves, thereby deepening their comprehension far beyond what is achieved through passive listening and formulaic repetition (Skemp, 1976, cited in mathematical education literature).

In conclusion, the highly significant statistical outcomes achieved in this study provide compelling empirical evidence that the Problem-Based Learning approach is an exceptionally effective instructional strategy for developing elementary school students' critical thinking skills in mathematics. The substantial effect size ($d=3.75$) indicates that PBL is not merely an alternative, but a superior pedagogical model for fostering essential 21st-century competencies at this foundational educational stage.

Despite the robust findings, this study is subject to certain limitations, primarily the use of a quasi-experimental design and the confinement of the sample to a specific regional cluster. While the pre-test confirmed initial equivalence, the lack of full individual randomization may introduce subtle, unmeasured confounding variables. Furthermore, the reliance on a single post-test measurement limits insight into the long-term retention and transferability of the developed critical thinking skills to other subject areas.

Therefore, future research should aim to replicate these findings using a fully randomized controlled trial (RCT) where feasible, or employ longitudinal designs to track the persistence of the PBL-induced CT gains over several academic years. Subsequent studies should also explore the mediating effects of teacher fidelity to the PBL model and investigate the specific scaffolding techniques most effective for different sub-components of critical thinking (analysis, inference, evaluation) among primary school students. This continued research will refine our understanding of how best to embed critical thought into the core curriculum.

CONCLUSION

This study successfully investigated the influence of the Problem-Based Learning (PBL) approach on the critical thinking skills of fifth-grade elementary school students in mathematics, with the results providing conclusive evidence in favor of the research hypothesis. The statistical analysis demonstrated that the experimental group, which received instruction through the PBL model, achieved significantly higher critical thinking scores on the post-test compared to the control group, which received conventional instruction. Specifically, the Independent Samples T-Test yielded a highly significant result ($p < 0.001$), accompanied by an extremely large effect size (Cohen's $d = 3.75$). This robust finding confirms that the Problem-Based Learning approach is an exceptionally effective and superior pedagogical strategy for optimizing the development of essential critical thinking skills—particularly analysis, inference, and evaluation—among primary school students. Consequently, this study validates PBL as a highly recommended alternative instructional model for educational institutions seeking to foster deep mathematical understanding and 21st-century competencies at the foundational level.

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