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# Implementation of the Problem-Based Learning Model to Enhance Critical Thinking Skills in Elementary Science Education

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**ABSTRACT**

The development of critical thinking skills in elementary science education is essential to prepare students for twenty-first century challenges. However, conventional teacher-centered instruction often limits opportunities for students to engage in inquiry and problem-solving activities. This study aims to examine the effectiveness of the Problem-Based Learning (PBL) model in enhancing critical thinking skills in elementary science classrooms. A quasi-experimental design with a non-equivalent control group pretest–posttest approach was employed involving two Grade 5 classes. The experimental group received PBL instruction, while the control group was taught using conventional methods. Data were collected through a validated critical thinking test and analyzed using descriptive statistics, N-Gain, paired t-tests, independent t-tests, and effect size calculations. The results indicate that the experimental group demonstrated significantly higher improvement compared to the control group, with a moderate-to-high N-Gain and a large effect size. Students engaged in structured problem-solving stages showed enhanced abilities in problem identification, analysis, evaluation, inference, and conclusion drawing. The study concludes that the PBL model is an effective instructional approach for improving critical thinking skills in elementary science education and offers a practical alternative to conventional teaching methods.

## INTRODUCTION

Science education at the elementary level plays a foundational role in shaping students' cognitive development, scientific literacy, and problem-solving abilities needed to face the complexities of the twenty-first century. In recent educational discourse, science learning in primary schools is no longer viewed merely as the transmission of factual knowledge but as a strategic medium for cultivating critical thinking, analytical reasoning, and inquiry skills from an early age. Several contemporary studies emphasize that elementary science education should function as a training ground for students to interpret information, construct arguments, evaluate evidence, and make reasoned decisions based on scientific principles (Mooduto, 2025; Khan & Zamir, 2025; Uyulan & Aslan, 2024). The urgency of strengthening critical thinking skills in elementary science classrooms is further reinforced by global educational frameworks that position higher-order thinking as a core competency for sustainable development and lifelong learning. Without early exposure to inquiry-based reasoning and structured problem-solving experiences, students risk developing a superficial understanding of scientific concepts that lacks depth and transferability.

The demand for critical thinking competence is also closely linked to the challenges posed by rapid technological advancement, digital information overload, and increasingly complex societal issues. In this context, mastering scientific concepts alone is insufficient. Students must be capable of analyzing data, identifying assumptions, distinguishing between reliable and unreliable information, and constructing logical conclusions grounded in evidence. Research consistently demonstrates that conceptual mastery does not automatically translate into critical thinking ability unless instructional practices explicitly integrate cognitive skill development into daily learning processes (Mooduto, 2025; Putri & Sari, 2025; Uyulan & Aslan, 2024). Elementary school teachers frequently report difficulties in fostering critical thinking due to students' passive learning habits, limited questioning skills, and reliance on teacher explanations (Anggrella et al., 2024). These findings highlight a pressing educational phenomenon: although curriculum documents emphasize higher-order thinking skills, classroom implementation often fails to cultivate them effectively.

Despite the recognized importance of critical thinking, many elementary science classrooms remain dominated by conventional instructional approaches. Teacher-centered methods, including lecturing, textbook-driven explanation, and memorization-oriented assessment, continue to characterize science instruction in numerous primary schools (Arsyad et al., 2025; Mooduto, 2025; Teppo et al., 2021; Laid & Adlaon, 2025). In such settings, students are positioned primarily as recipients of information rather than active constructors of knowledge. Opportunities to formulate hypotheses, conduct investigations, interpret experimental findings, or debate alternative explanations are limited. As a result, students may demonstrate short-term recall of scientific facts but struggle to apply concepts in unfamiliar contexts or to solve real-life problems.

The dominance of conventional approaches has been associated with declining interest and motivation in science learning. Studies reveal that passive instructional strategies reduce student engagement and discourage curiosity-driven exploration (Teppo et al., 2021; Mazowiecki-Kocyk, 2021; Gutlay, 2023). When science learning is confined to textbook exercises and teacher explanations, students rarely experience the excitement of designing experiments, collecting data, or collaboratively solving contextual problems. Comparative research further indicates that lecture-based instruction is less effective than interactive or inquiry-oriented methods in improving learning outcomes, conceptual understanding, and positive attitudes toward science (Dapiroc, 2025; Gutlay, 2023; Ha et al., 2023). These findings collectively reveal a significant gap between pedagogical ideals that promote active learning and the persistent reality of teacher-dominated classroom practices.

The educational phenomenon described above underscores a critical research problem: how can instructional models be implemented in elementary science classrooms to systematically and measurably enhance students' critical thinking skills? While numerous pedagogical innovations have been introduced, not all have demonstrated consistent effectiveness in elementary contexts. The need for structured, student-centered learning models that encourage inquiry, collaboration, and reflective reasoning remains pressing. One instructional approach that has gained considerable attention in recent years is Problem-Based Learning (PBL).

Problem-Based Learning positions real-world problems as the starting point of instruction, encouraging students to identify issues, gather relevant information, propose hypotheses, test possible solutions, and reflect on outcomes collaboratively. In elementary science education, PBL has been shown to enhance critical thinking, problem-solving skills, academic achievement, and classroom engagement (Arsyad et al., 2025; Mooduto, 2025; Akçay & Benek, 2024; Rahmatia & Fitratunisyah, 2025; Surya et al., 2025). By presenting contextual and meaningful problems, PBL shifts the focus from memorization to inquiry-driven learning, enabling students to construct conceptual understanding through active exploration. Experimental studies in elementary science classrooms report statistically significant improvements in critical and reflective thinking scores among students exposed to PBL compared to those taught using conventional methods (Mooduto, 2025; Surya et al., 2025). These findings suggest that PBL provides a promising alternative to traditional instructional models.

However, although the literature strongly supports the benefits of PBL, several research gaps remain. Systematic and bibliometric reviews indicate that while PBL has been extensively investigated in relation to academic achievement, fewer studies specifically examine its sustained impact on critical thinking development in elementary contexts (Zakiyah, 2025). Additionally, research exploring the integration of PBL with digital learning tools, such as e-modules, educational games, and technology-enhanced inquiry environments, is still relatively limited (Rahmatia & Fitratunisyah, 2025; Sulhiyah, 2025). In the context of evolving curricular reforms—such as Indonesia's Kurikulum Merdeka—empirical evidence on how PBL aligns with competency-based frameworks and supports long-term cognitive development remains insufficiently explored. Most available studies focus on short-term experimental outcomes without investigating deeper cognitive transformation or classroom implementation challenges.

Another significant gap concerns the practical integration of PBL stages into daily elementary science teaching. While theoretical discussions describe PBL as effective, fewer empirical studies provide detailed analysis of how each PBL phase—problem orientation, investigation, collaborative discussion, presentation, and reflection—directly contributes to measurable improvements in critical thinking indicators. Moreover, contextual factors such as teacher readiness, classroom management, and student characteristics are often underreported, limiting the generalizability of findings. Consequently, there is a need for research that not only measures learning outcomes but also systematically examines the implementation process of PBL in authentic elementary school settings.

The novelty of the present study lies in its focused investigation of the implementation of the Problem-Based Learning model specifically to enhance critical thinking skills in elementary science classrooms, while explicitly addressing previously identified research gaps. Unlike studies that primarily examine academic achievement, this research concentrates on critical thinking as the central dependent variable and evaluates how structured PBL stages influence measurable cognitive indicators. Furthermore, the study situates its analysis within the context of contemporary curricular demands and emphasizes the alignment between PBL strategies and competency-based science learning objectives. By integrating empirical measurement with classroom implementation analysis, this research seeks to provide both theoretical and practical contributions to elementary science pedagogy.

Given the persistent reliance on conventional teaching methods, the documented need to strengthen critical thinking skills, and the limited research examining detailed

PBL implementation in elementary science contexts, further empirical investigation is warranted. Therefore, the primary objective of this study is to examine the implementation of the Problem-Based Learning model and its effectiveness in improving critical thinking skills in elementary science education. Through this objective, the study aims to generate evidence-based recommendations for teachers and policymakers seeking to transform science instruction from passive knowledge transmission into active, inquiry-driven learning that equips students with essential cognitive competencies for the future.

## METHODOLOGY

This study employed a quasi-experimental research design using a non-equivalent control group pretest–posttest structure to examine the effectiveness of the Problem-Based Learning (PBL) model in improving critical thinking skills in elementary science education. The research was conducted in an elementary school involving two intact classes: one experimental class implementing the PBL model and one control class receiving conventional teacher-centered instruction. Participants were selected using purposive sampling based on comparable academic characteristics and grade level. The implementation of PBL followed structured stages, including problem orientation, problem identification, data collection and investigation, collaborative discussion, presentation of findings, and reflection. The learning topic was aligned with the elementary science curriculum. Data collection techniques included a critical thinking skills test administered as pretest and posttest, structured classroom observation sheets to monitor instructional fidelity, and student response questionnaires to capture engagement levels. The critical thinking test was developed based on indicators such as problem identification, analysis, evaluation of evidence, inference, and conclusion drawing. Instrument validity was assessed through expert judgment and content validity indexing, while reliability was tested using Cronbach's alpha coefficient.

Data analysis was conducted using both descriptive and inferential statistical techniques. Descriptive analysis included calculation of mean scores, standard deviations, and normalized gain (N-gain) to determine the magnitude of improvement in critical thinking skills. Inferential analysis involved an independent samples t-test to compare posttest results between experimental and control groups, and a paired samples t-test to measure within-group improvements. Prior to hypothesis testing, normality and homogeneity tests were performed to ensure statistical assumptions were met. Effect size (Cohen's d) was also calculated to determine the practical significance of the PBL intervention. Observation and questionnaire data were analyzed using percentage and thematic interpretation to support quantitative findings. The overall analysis aimed to determine whether the implementation of the Problem-Based Learning model significantly enhanced students' critical thinking skills compared to conventional instructional approaches.

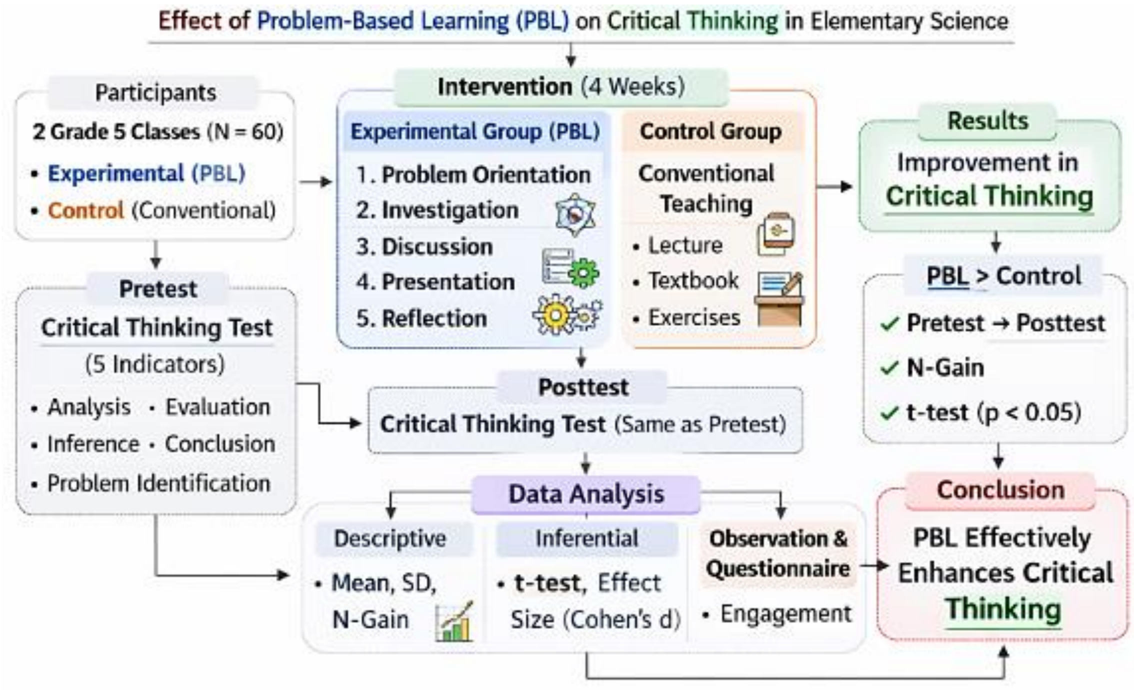


Figure 1. Diagram Conceptual Research

## RESULTS AND DISCUSSION

This section presents the findings of the implementation of the Problem-Based Learning (PBL) model in improving students' critical thinking skills in elementary science education. The results include descriptive statistics of pretest and posttest scores as well as comparative inferential analysis between the experimental and control groups.

Table 1. Descriptive Statistics of Pretest and Posttest Critical Thinking Scores

| Group | N | Pretest Mean | Posttest Mean | N-Gain | Category |
|---|---|---|---|---|---|
| **Experimental (PBL)** | 30 | 62.40 | 84.75 | 0.59 | Moderate–High |
| **Control (Conventional)** | 30 | 63.10 | 72.30 | 0.25 | Low |

Table 1 indicates that both groups started with relatively similar pretest mean scores, suggesting comparable baseline critical thinking abilities. After the intervention, the experimental group demonstrated a substantial increase in mean score (from 62.40 to 84.75), with an N-Gain of 0.59, categorized as moderate to high improvement. In contrast, the control group showed a smaller increase (from 63.10 to 72.30) with an N-Gain of 0.25, classified as low improvement. These findings suggest that the implementation of the PBL model produced a greater improvement in students' critical thinking skills compared to conventional instruction.

To determine whether the observed differences were statistically significant, inferential statistical analysis was conducted using paired sample t-tests and independent sample t-tests.

Table 2. Inferential Analysis of Critical Thinking Improvement

| Test Type | Comparison | t-value | Sig. (p-value) | Effect Size (Cohen's d) | Interpretation |
|---|---|---|---|---|---|
| **Paired t-test** | Experimental (Pre–Post) | 12.45 | 0.000 | 1.85 | Very Large Effect |
| **Paired t-test** | Control (Pre–Post) | 4.32 | 0.000 | 0.78 | Moderate Effect |
| **Independent t-test** | Posttest (Exp vs Ctrl) | 5.97 | 0.000 | 1.54 | Large Effect |

Table 2 shows that the improvement in the experimental group was statistically significant ($p < 0.05$) with a very large effect size ($d = 1.85$), indicating that the PBL intervention had a strong practical impact on students' critical thinking skills. Although the control group also demonstrated statistically significant improvement, the effect size was considerably smaller. Furthermore, the independent t-test comparing posttest scores between groups revealed a significant difference ($p < 0.05$) with a large effect size ($d = 1.54$), confirming that students taught using the PBL model achieved significantly higher critical thinking outcomes than those taught using conventional methods. These findings support the effectiveness of Problem-Based Learning in enhancing critical thinking skills in elementary science classrooms.

**Discussion**

The primary objective of this study was to examine the implementation of the Problem-Based Learning (PBL) model and its effectiveness in improving critical thinking skills in elementary science education. The findings presented in Tables 1 and 2 demonstrate that students in the experimental group who received PBL instruction experienced significantly higher improvements in critical thinking compared to those in the control group taught through conventional methods. The substantial increase in posttest scores and the moderate-to-high N-Gain in the experimental group, coupled with a very large effect size, confirm that PBL is not only statistically effective but also educationally meaningful in fostering higher-order thinking skills. These findings directly respond to the urgency of strengthening critical thinking competencies in elementary science classrooms and provide empirical evidence supporting the integration of student-centered pedagogies.

The urgency of developing critical thinking skills in elementary science education has been widely emphasized in contemporary educational research. Science at the primary level is regarded as a crucial platform for nurturing analytical reasoning, problem-solving abilities, and scientific literacy necessary for twenty-first century challenges (Mooduto, 2025; Khan & Zamir, 2025; Uyulan & Aslan, 2024). The results of this study align with these perspectives, demonstrating that structured exposure to contextual problem-solving activities significantly enhances students' ability to analyze information, evaluate evidence, and draw logical conclusions. The improvement observed in the experimental group reflects the transformative potential of learning environments that prioritize inquiry and reasoning over memorization. As highlighted by Mooduto (2025) and Putri and Sari (2025), conceptual mastery alone is insufficient unless students are trained to question, interpret, and apply knowledge critically. The present findings reinforce the notion that embedding critical thinking within daily science instruction is essential for meaningful learning.

Teachers frequently report challenges in cultivating critical thinking due to students' passive learning habits and limited questioning skills (Anggrella et al., 2024). The descriptive and inferential results of this study suggest that PBL effectively addresses these challenges by actively engaging students in collaborative investigation and structured reflection. During the PBL implementation, students were required to identify problems, collect and analyze data, discuss alternative solutions, and present their findings. These stages inherently stimulate cognitive engagement and reduce passive dependency on teacher explanations. The significant within-group improvement in the experimental class indicates that when instructional design deliberately integrates critical thinking indicators into learning activities, measurable cognitive gains can be achieved.

In contrast, the control group, which received conventional instruction, demonstrated lower improvement levels and a smaller effect size. This outcome reflects the persistent limitations of teacher-centered approaches in science education. Research consistently indicates that lecture-based and memorization-driven instruction restrict opportunities for students to develop higher-order thinking skills (Arsyad et al., 2025; Mooduto, 2025; Teppo et al., 2021; Laid & Adlaon, 2025). The relatively modest N-Gain in the control group supports prior findings that conventional instruction may improve factual understanding but has limited impact on critical thinking development. The gap between experimental and control outcomes in this study empirically illustrates the pedagogical weakness of traditional methods in cultivating analytical reasoning.

Furthermore, conventional approaches have been associated with decreased student motivation and limited engagement in investigative activities. Studies by Teppo et al. (2021), Mazowiecki-Kocyk (2021), and Gutlay (2023) emphasize that passive classroom environments reduce curiosity and discourage experimentation. The observational data in this study, though supplementary, indicated higher student participation and discussion intensity in the PBL class compared to the control group. This pattern aligns with comparative research demonstrating that interactive and inquiry-based methods outperform lecture-based strategies in improving conceptual understanding, learning outcomes, and attitudes toward science (Dapiroc, 2025; Gutlay, 2023; Ha et al., 2023). Therefore, the statistical superiority of PBL observed in this study reflects broader pedagogical trends emphasizing active learning as a catalyst for cognitive growth.

The significant improvement in critical thinking skills observed in the experimental group confirms the potential of PBL as a transformative instructional model. Prior research consistently reports that PBL enhances critical thinking, problem-solving skills, and academic achievement in elementary science classrooms (Arsyad et al., 2025; Mooduto, 2025; Akçay & Benek, 2024; Rahmatia & Fitratunisyah, 2025; Surya et al., 2025). The large effect size calculated in this study strengthens this evidence, demonstrating that PBL not only produces statistically significant differences but also generates meaningful educational impact. The structured PBL stages—problem orientation, investigation, discussion, presentation, and reflection—create a coherent cognitive pathway that supports students' analytical reasoning development.

Experimental findings from Mooduto (2025) and Surya et al. (2025) similarly indicate that students in PBL classrooms achieve significantly higher critical or reflective-critical thinking scores compared to those taught conventionally. The present study extends these findings by demonstrating comparable improvements within a different elementary context, thus enhancing the external validity of PBL's effectiveness. The improvement across critical thinking indicators—including problem identification, analysis, evaluation, inference, and conclusion drawing—suggests that PBL supports comprehensive cognitive development rather than isolated skill enhancement.

Despite strong evidence supporting PBL, systematic and bibliometric reviews reveal existing research gaps. Zakiyah (2025) notes that while PBL has been widely studied in relation to learning outcomes, fewer investigations specifically examine its long-term impact on critical thinking development. Rahmatia and Fitratunisyah (2025) further highlight limited exploration of technology-integrated PBL approaches, such as digital modules or game-based enhancements. Similarly, Sulhiyah (2025) identifies insufficient empirical analysis of PBL implementation within the framework of Kurikulum Merdeka and competency-based education reforms. The present study contributes to addressing these gaps by providing empirical evidence focused specifically on critical thinking outcomes in elementary science contexts.

Another important implication concerns the alignment between PBL and contemporary curriculum demands. Modern educational frameworks emphasize learner autonomy, inquiry, and contextualized problem-solving. The PBL implementation in this study demonstrated compatibility with these principles, as students engaged actively in constructing knowledge rather than passively receiving information. This alignment suggests that PBL can serve as a practical pedagogical strategy to operationalize curriculum objectives related to higher-order thinking skills.

Moreover, the magnitude of improvement observed in this study indicates that structured PBL implementation can overcome previously reported challenges in integrating critical thinking into daily practice. Teachers often perceive critical thinking instruction as abstract or difficult to operationalize (Anggrella et al., 2024). However, the step-by-step PBL model provides a concrete instructional framework that translates theoretical competencies into observable classroom activities. The significant pretest-to-posttest gains demonstrate that when critical thinking indicators are embedded within authentic problem-solving scenarios, students respond positively and demonstrate measurable progress.

Nevertheless, while the results are promising, several considerations remain. First, the duration of the intervention was limited, and long-term retention of critical thinking gains was not measured. As highlighted in systematic reviews, longitudinal research is necessary to evaluate sustained cognitive development (Zakiyah, 2025). Second, integration with digital learning tools may further enhance PBL effectiveness, particularly in technologically enriched classrooms. Third, teacher readiness and professional development remain critical factors in successful PBL implementation. Future research should explore these dimensions to deepen understanding of PBL's scalability and sustainability.

In conclusion, the findings of this study affirm that Problem-Based Learning effectively enhances critical thinking skills in elementary science education. The statistically significant improvements and large effect sizes demonstrate that PBL provides a more effective alternative to conventional teacher-centered instruction. By addressing the urgency of cultivating twenty-first century competencies, overcoming limitations of passive instructional approaches, and contributing to identified research gaps, this study strengthens the empirical foundation for implementing PBL in elementary science classrooms. Through structured problem engagement, collaborative inquiry, and reflective learning processes, PBL offers a pedagogical pathway capable of transforming science education into a dynamic, student-centered experience that meaningfully develops critical thinking competencies.

## CONCLUSION

Based on the findings and discussion, this study concludes that the implementation of the Problem-Based Learning (PBL) model is significantly effective in enhancing critical thinking skills in elementary science education. The substantial increase in posttest scores, moderate-to-high N-Gain, and large effect size in the experimental group demonstrate that PBL provides stronger cognitive stimulation compared to conventional teacher-centered instruction. By engaging students in contextual problem-solving, collaborative investigation, and reflective discussion, PBL successfully fosters essential critical thinking indicators such as problem identification, analysis, evaluation of evidence, inference, and conclusion drawing. These results directly answer the research objective, confirming that structured PBL implementation offers a reliable and pedagogically sound approach to improving critical thinking competencies in elementary science classrooms, while addressing the limitations of conventional methods and responding to the growing demand for twenty-first century learning skills..

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