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The Effectiveness of Problem-Based Learning in Enhancing Reflective-Critical Thinking Skills of Elementary School Students in Science Learning

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Abstract

The cultivation of reflective and critical thinking skills in elementary science education poses a difficulty, as traditional instructional techniques often restrict students' cognitive engagement and metacognitive awareness. This study seeks to examine the efficacy of problem-based learning (PBL) in improving the reflective and critical thinking abilities of fifth-grade elementary students in scientific education. This research utilized a quantitative methodology with a quasi-experimental design, namely the non-equivalent control group design. The sample comprised 90 students who were randomly allocated to experimental and control groups. The instrument employed was a test of 23 valid items, conducted as both a pre-test and a post-test. Data analysis was performed utilizing descriptive statistics, normality and homogeneity assessments, n-gain analysis, and t-tests. The study's results demonstrate that the experimental group achieved markedly superior post-test scores (M = 83.91; SD = 6.32) in contrast to the control group (M = 70.24; SD = 7.15), with a significance level of p = 0.000. The n-gain value for the experimental group (0.61) was into the moderate range, whereas the control group (0.29) was classified in the low category. These findings indicate that PBL is beneficial in enhancing students' skills in problem identification, hypothesis formulation, evidence analysis, and reflective thinking. This study's originality resides in the empirical validation of PBL implementation at the primary school level, a topic that has seldom been thoroughly examined. The results suggest the need for curriculum change, pedagogical innovation, and professional development for educators in inclusive and reflective fundamental scientific education.

INTRODUCTION

Cultivating reflective and critical thinking abilities is a fundamental component of 21st-century educational frameworks (Rubtsov & Ulanovskaya, 2020). In the context of swift technological progress, intricate societal challenges, and a plethora of information, the capacity for profound, thoughtful, and critical thinking has emerged as an essential requirement rather than a mere choice. Higher-order thinking skills are universally acknowledged as crucial for prudent decision-making, efficient problem-solving, and active engagement in global society (Lu et al., 2022). In the realm of science education, which necessitates inquiry, logical reasoning, and evidence-based argumentation, the enhancement of reflective-critical thinking skills is becoming increasingly imperative (Bassachs et al., 2020). This is particularly applicable at the elementary school level, where foundational cognitive structures are developed, and nurturing students' capacity to examine, evaluate, and reflect on scientific phenomena is an educational obligation that must not be overlooked (Chu et al., 2023). Nonetheless, basic science education, particularly in Indonesia, is predominantly characterized by conventional methodologies. Teacher-centered instruction, rote memorization, and limited inquiry-based activities foster passive environments. Consequently, students forfeit the chance to attain profound comprehension and neglect to cultivate self-reflection and critical thinking abilities regarding the content they encounter (Annisa 2022).

International data from PISA 2018 show that Indonesian students' average science literacy score is 389, far below the OECD average of 489. Additionally, reading scores of 371 vs. 487 and mathematics scores of 379 vs. 487 place Indonesia as a country with low performance but high equity (OECD, 2019). These results indicate that students' critical thinking and science literacy skills are still weak nationally. For the local context of Pekanbaru City, available data from the Central Statistics Agency of Pekanbaru show general indicators but not specific indicators of science literacy (Centeral Agency Statistics, 2023). Nevertheless, a mapping study of science literacy skills in elementary schools in Pekanbaru City (grade 5, n=50) showed a high average science literacy score of 78.3%, with no significant differences based on gender, ethnicity, occupation, or parental education (Annisa, 2022). However, these results are based on a limited sample and may not reflect the general conditions of other elementary schools in Pekanbaru, Indonesia. Based on the national PISA data (score 389), it can be concluded that Indonesian students, including those in Pekanbaru, are below the standard. Meanwhile, local research in Pekanbaru indicates variations in the results, with some schools even showing high literacy levels, but this does not reflect a broader representation. These issues are exacerbated by limited teacher training, pressure to complete the curriculum, and a lack of widespread pedagogical innovations that can stimulate active and reflective learning.

This study was prompted by the necessity to tackle a substantial difficulty in elementary education: cultivating pupils' reflective-critical thinking abilities in science learning. Problem-Based Learning (PBL) has emerged as an effective educational strategy. Grounded in constructivist theory, Project-Based Learning (PBL) promotes independent student learning through the exploration of intricate real-world issues, collaborative efforts, and the construction of new knowledge (Levy & Mensah, 2021). Students are no longer passive recipients of knowledge; they actively pursue solutions, generate hypotheses and reflect on their learning results. These activities aim to enable students to interrogate assumptions, assess evidence, integrate information, and formulate alternative solutions. The primary elements of the PBL approach are well connected to the requirements of reflective and critical thinking, rendering it a viable educational model for use in elementary science classrooms (Van Peppen et al., 2021).

This study addresses the inadequate reflective and critical thinking skills of elementary school pupils in science education, which can be attributed to the prevalence of traditional teaching techniques. The current curriculum prioritizes the acquisition of concepts and procedural information, neglecting the cultivation of metacognitive skills, including reflection and critical analysis. Moreover, educators frequently find themselves constrained by the necessity to cover the curriculum, which hinders their ability to adopt new, student-centered pedagogical approaches aimed at fostering higher-order thinking skills. Conversely, there is limited empirical data on the direct influence of systematic PBL implementation on the cultivation of reflective-critical thinking among elementary school pupils, particularly within the context of Indonesian education, which possesses distinct cultural attributes and a unique learning framework.

The urgency of this research lies not only in its theoretical aspects but also in its long-term impact on the national education system. Basic education is the initial stage of forming ways of thinking, attitudes toward learning, and intellectual habits (Xu et al. 2023). If students are not introduced to reflective and critical thinking early on, developing these skills in subsequent levels of education will become increasingly complex. Moreover, global challenges such as the climate crisis, pandemic, and digital revolution demand a young generation that understands science and can evaluate information wisely, think openly, and make responsible decisions (Demircioglu et al., 2023). Therefore, science education must be designed to convey concepts and cultivate reflective and critical scientific thinking from the elementary school level onwards.

Previous studies have provided empirical evidence of the effectiveness of PBL in improving the quality of learning. Soleimani and Aghazadeh (2024) stated that PBL encourages the development of self-directed learning, deep conceptual understanding, and critical thinking skills. In contrast, Sepúlveda-Vallejos (2023) found that PBL improves cognitive understanding and forms high self-reflection

skills in a clinical context through an experimental study of nursing students. Meanwhile, Orakcı and Khalili (2025) emphasized that the essence of PBL's success lies in the facilitator's ability to stimulate open-ended questions and group reflection. In the context of teacher education, Nurhayati (2023) emphasized that PBL strengthens prospective teachers' pedagogical and metacognitive abilities through classroom context-based problem solving. In the context of teacher education, Muvid (2022) showed that the implementation of PBL encourages student teachers to be more prepared to face the complexity of the classroom because they are accustomed to analyzing situations, making decisions, and reflecting on the impact of the teaching strategies they select. Similar findings were reported by Lambropoulos and Pitsou (2020), who emphasized the importance of facilitator support in building a culture of reflection and open discussion in the PBL process. They concluded that reflection in PBL is not a byproduct but rather the core of the learning process.

This study is important for filling the literature gap by empirically investigating the influence of PBL on the development of elementary school students' reflective and critical thinking skills in science learning. Many previous studies have emphasized cognitive learning outcomes or learning motivation and have not systematically examined these two thinking skills. Additionally, few comprehensive instruments have been developed to measure reflective and critical thinking skills in an integrated manner at the elementary-education level. Therefore, this study is expected to contribute to the development of instruments, instructional designs, and new conceptual understandings in science education.

The novelty of this study lies in the in-depth exploration of the dimensions of reflective-critical thinking as part of teacher professional competence in the context of implementing PBL specifically in science courses. This study not only measures the effectiveness of PBL in the framework of cognitive learning outcomes, but also pays attention to how students conduct self-evaluations, construct arguments, and develop metacognition during the learning process. This is important as a justification that the success of PBL lies in achieving academic grades and transforming students' ways of thinking as prospective educators. Furthermore, the results of this study are expected to be an important reference for curriculum development and instructional design in Teacher Training Institutions in national and international contexts. The implementation of measurable and targeted PBL can help produce elementary school teachers who are reflective, critical, and adaptive to changing circumstances.

Project-Based Learning (PBL) is an educational approach that prioritizes student engagement, prompting students to actively investigate, deliberate, and contemplate authentic issues (C. C. Liu et al., 2022). In addition, PBL promotes active knowledge construction among students by engaging them in the exploration of complicated topics, facilitating peer discussions, and encouraging them to reflect on

their learning experiences (Ho et al., 2023). Based on this concept, this study aims to design and implement PBL-based science learning tools that are appropriate for the characteristics and cognitive development levels of elementary school students, measure students' reflective and critical thinking skills before and after the intervention using valid and reliable instruments, and analyze the impact of problem-based learning on the improvement of these two skills quantitatively and qualitatively. This strategy aims to generate empirical information that reinforces the theoretical framework of PBL and offers practical insights for educators, curriculum developers and education policymakers.

METHODS

This study used a quantitative approach with a quasi-experimental design of the Nonequivalent Control Group Design type. This approach was chosen because the researcher did not have complete control over the process of assigning students to the experimental and control groups, as is common in the context of formal education in elementary schools, which already have fixed class divisions. However, this design allows for a valid measurement of the treatment's impact on the dependent variable by comparing pre- and post-test scores between two statistically equivalent groups. This design was considered most suitable for evaluating the effectiveness of pedagogical interventions, specifically Problem-Based Learning (PBL), in enhancing reflective-critical thinking skills without disrupting the natural classroom setting.

The study population comprised all fifth-grade children from public elementary schools in Pekanbaru. Sampling was performed using random sampling methods to reduce class selection bias and guarantee that each class had an equal probability of being chosen as either the experimental or control group. The study comprised a sample size of 90 students, partitioned into 45 students in the experimental group (who underwent PBL-based learning) and 45 students in the control group (who experienced conventional learning). The randomization process employed a class lottery method, initiated by assessing starting ability equivalence based on prior scientific test scores. The preliminary equality test findings demonstrated no major discrepancies among the chosen classes; hence, class selection was deemed valid and representative of the population.

The main tool utilized in this study was a reflective-critical thinking skills assessment comprising 25 essay questions administered during both the pre- and post-test phases. This assessment was constructed based on indications of reflective (Bassachs et al., 2020) and critical thinking (Rubtsov & Ulanovskaya, 2020) extracted from contemporary literature and tailored to the fifth-grade science curriculum, as follows: The instrument development method encompassed content validation via expert assessment and empirical evaluation through validity and

reliability testing. The subsequent table displays the metrics of the testing instrument employed.

Table 1. Indicators of Reflective-Critical Thinking Skills

Indicators	Description of Developed Test Items
Identifying problems	Students can articulate problems derived from the exhibited scientific occurrences.
Formulating hypotheses	Students can construct logical inferences based on preliminary knowledge.
Analyzing information and evidence	Students can evaluate the credibility of material and discern pertinent evidence.
Drawing logical conclusions	Students formulate conclusions substantiated by data or empirical evidence.
Reflecting on thinking processes	Students articulate their cognitive processes or the measures they have undertaken.

This study employed quantitative data analysis using descriptive and inferential statistical methods to assess the efficacy of Problem-Based Learning (PBL) intervention in enhancing students' reflective and critical thinking abilities. The analytical procedure encompassed the evaluation of the quality of the instruments, validation of fundamental statistical assumptions, and testing of hypotheses in accordance with the data attributes and experiment aims. The content validity of the instruments was evaluated by expert judgment by three lecturers specializing in scientific education and learning assessment to confirm that the indicators were suitable for the assessed constructs. Empirical validity was assessed using the Pearson Product-Moment correlation, with items considered valid if the significance value (p) < 0.05 and the correlation coefficient (r) > 0.30 (Heppt et al., 2023).

Subsequently, normality assessments were conducted using the Shapiro–Wilk test on the pre- and post-test scores for both the experimental and control groups, given that the sample size was less than 100. Data were deemed normal if $p > 0.05$. A non-parametric technique was employed. Homogeneity was assessed using Levene's test on post-test results to verify the equality of variance among groups. If $p > 0.05$, the data satisfied the assumption of homogeneity (Orhan & Çeviker, 2023). An independent t-test was employed to assess the difference in post-test means between the experimental and control groups, assuming that the data were regular and homogenous. The null hypothesis asserts the absence of a significant difference, whereas the alternative hypothesis posits a substantial difference attributable to PBL therapy. A significance level (p) of less than 0.05 implied that the treatment had a statistically significant effect. This amalgamation of techniques guarantees that data analysis is performed thoroughly, accurately, and in accordance with the methodological criteria in evidence-based quantitative educational research.

All research protocols in this study conformed to the ethical requirements for investigations involving human subjects. Prior to data collection, authorization

was acquired from the school principal and classroom educators, and informed consent was obtained from the guardians of the pupils. Participants were guaranteed that their participation was voluntary and that their identities would be kept confidential. All data were gathered exclusively for academic purposes, and the students' responses were handled with utmost confidentiality. Moreover, the allocation of students to the experimental and control groups was executed equitably, without interfering with their academic schedules. Ethical concerns were maintained at each stage to guarantee the rights, dignity, and welfare of all participants, particularly minors, in accordance with institutional rules and research ethics protocols.

RESULTS

The results in this section are based on students' replies to a structured assessment tool specifically created to evaluate reflective and critical thinking abilities within the realm of science education. The instrument comprised 23 verified open-ended essay items, presented as both a pre-and post-test to students in the experimental and control groups. Each item was developed according to five fundamental indicators: problem identification, hypothesis formulation, information and evidence analysis, logical conclusion derivation, and reflective thinking. These items were modified to accommodate the cognitive growth of fifth-grade children and linked with the scientific curriculum subject addressed throughout the intervention. The open-ended questions aimed to thoroughly capture students' reasoning processes, facilitating a more precise evaluation of their higher-order thinking skills. The replies were assessed using rubrics created for each indicator, ensuring uniformity in scoring and facilitating a comprehensive examination of students' advancement across the specified dimensions.

The subsequent table displays the average pre- and post-test scores of students for each indicator of reflective-critical thinking skills. Data were collected from two groups: an experimental group that underwent Problem-Based Learning (PBL) intervention and a control group that engaged in traditional learning methods. This presentation aims to ascertain the degree of PBL's impact on enhancing the attainment of each indicator of higher-order thinking skills in primary school students.

Table 2. Comparison of Pre-test and Post-test Scores

Indicators of Reflective-Critical Thinking Skills	Pre-test		Post-test	
	Experimental	Control	Experimental	Control
Identifying problems	58.0	57.0	84.0	70.0
Formulating hypotheses	59.0	58.0	85.0	71.0
Analyzing information and evidence	57.0	56.0	86.0	72.0
Drawing logical conclusions	56.0	55.0	83.0	68.0

Reflecting on thinking processes	60.0	59.0	87.0	70.0
Average	58.0	57.0	85.0	70.2
N-Gain (Mean)	58.47	57.82	83.91	70.24
N-Gain Category			0.61	Low / Moderate

The examination of pre-test, post-test, and N-Gain data demonstrated that the implementation of Problem-Based Learning (PBL) markedly enhanced elementary school students' reflective-critical thinking abilities across all assessed variables. Prior to the intervention, the average pre-test scores for the experimental and control groups on each indicator were nearly identical; for instance, in the "identifying problems" category, the experimental group achieved a score of 58, while the control group scored 57. Similarly, for the "reflecting on thinking processes" indicator, the scores were 60 and 59, respectively. This similarity suggests that both groups possessed comparable initial ability levels, enhancing the experiment's validity and facilitating a more credible attribution of post-test outcomes to the PBL intervention. Post-treatment, the experimental group exhibited a substantial increase in scores across all metrics.

Post-test scores for the "analyzing information and evidence" indicator improved from 57 to 86, whereas "reflecting on thinking processes" grew from 60 to 87. Notable enhancements were recorded in "formulating hypotheses" (from 59 to 85) and "drawing logical conclusions" (from 56 to 83). Conversely, the control group exhibited only modest enhancements, with an average score variation of 11–13 points per indication per participant. The maximum post-test score in the control group was merely 72 (on the analytical indicator), which was much lower than the performance of the experimental group.

The analysis of the mean scores indicates that the experimental group attained an average post-test score of 85, whereas the control group earned only 70.2. The disparity is additionally evident in the N-Gain calculation, which was 0.61 for the experimental group (moderate to high category) and 0.29 for the control group (low category). This nearly twofold disparity substantiates that PBL enhances learning outcomes and qualitatively fortifies students' cognitive and metacognitive engagement in the educational process. The most significant enhancement was observed in "reflecting on thinking processes," demonstrating that PBL is very effective in prompting students to consciously assess their cognitive processes and problem-solving tactics.

The findings validate that the PBL approach effectively conveys scientific knowledge and facilitates the systematic and comprehensive development of higher-order thinking skills. This underscores the necessity of incorporating PBL into elementary science education to cultivate reflective thinking, reasoning, and scientific decision-making skills from an early age in the future. Educators require support through training to create genuine problem-based activities, develop reflective inquiries, and implement process-oriented evaluations that correspond

with the markers of reflective-critical thinking. Consequently, the findings of this study substantially enhance constructivist learning theory, inform curricular policy changes, and transform pedagogical practices in elementary scientific education.

Normality tests were conducted on the pre- and post-test data from both groups (experimental and control) to ensure that the data had a normal distribution and met the basic assumptions for using parametric statistical tests. The tests used the Shapiro–Wilk method, which is known to be sensitive and more suitable for sample sizes of less than 100 respondents. The analysis showed that all significance values (p) in each group and test type were above the significance level $\alpha = 0.05$, with p-values ranging from 0.151 to 0.415. This indicates no significant difference between the obtained and normal data distributions. Thus, it can be concluded that the data from all groups, both before and after treatment, are typically distributed. This condition provides a strong basis for using parametric statistical analysis, particularly the t-test, to test the differences in post-test scores between the experimental and control groups in a statistically valid manner.

In addition to the normality test, a homogeneity of variance test was conducted using Levene's test to ensure that the data distribution between groups was equivalent. The test results showed that both the pre- and post-test data from the experimental and control groups had significance values above 0.05 ($p = 0.261$ and $p = 0.336$, respectively). This means that there was no significant difference in variance between the two groups, and the assumption of homogeneity of variance was fulfilled. Fulfilling these two basic assumptions—normality and homogeneity—is an essential prerequisite for ensuring the validity of the inferential tests used in this study. Thus, using an independent two-sample t-test to test the effectiveness of problem-based learning (PBL) can be done validly and reliably. This strengthens the internal validity of the study and ensures that the conclusions drawn regarding the impact of PBL on reflective-critical thinking skills are based on accurate statistical procedures and scientific principles.

Table 3. Independent Samples t-test Results on Post-test Scores

Group	N	Mean Score	Standard Deviation (SD)	Sig. (2-tailed)	Interpretation
Experimental	45	83.91	6.32	0.000	Significant
Control	45	70.24	7.15		

An independent samples t-test was conducted to test the hypothesis of whether there was a significant difference between the post-test scores of the experimental group (who received Problem-Based Learning) and the control group (who followed conventional learning). The results of the analysis showed that the average post-test score of the experimental group was 83.91, with a standard deviation (SD) of 6.32. The average post-test score of the control group was 70.24, with a standard deviation (SD) of 7.15. The significance value (2-tailed) was 0.000, which was smaller than the significance level of $\alpha = 0.05$. Based on these results, we concluded that there was a statistically significant difference between the two

groups. Thus, the implementation of Problem-Based Learning has proven to be effective in enhancing elementary school students' reflective and critical thinking skills in science learning compared to conventional learning. These results also support previous findings from the N-Gain analysis, which showed that the experimental group not only experienced higher improvement but also achieved better final performance.

DISCUSSION

Interpretation of Research Findings

The findings of this study revealed a comprehensive improvement in students' reflective and critical thinking skills as a result of the Problem-Based Learning (PBL) intervention, with gains evident across all assessed indicators. On the indicator reflecting thinking processes, students in the experimental group showed a significant increase from a pre-test score of 60 to a post-test score of 87. This improvement suggests heightened metacognitive awareness, which is an essential component of developing reflective thinking. According to Flavell's metacognition theory and the framework of Loyens et al. (2023), metacognition is fostered when learners engage in tasks that require continuous monitoring and evaluation of their cognitive strategies. PBL by design provides opportunities for students to reflect on what they learn and how they learn as they navigate complex and open-ended problems.

The analyzing information and evidence indicator showed a similar upward trend, with scores rising from 57 to 86. This reflects a strengthened ability in evidence-based reasoning, aligned with the critical thinking dimensions of analysis and evaluation, as outlined by Liu et al., (2023). Through PBL, students are consistently challenged to assess the credibility and relevance of information, which stimulates deeper analytical engagement and aligns with the social constructivist view that learning occurs most effectively in authentic, inquiry-rich environments (Lu et al. 2022). The performance increase on this indicator also suggests that students were not merely receiving information but were actively interrogating and reconstructing it, which is an essential feature of higher-order thinking.

The indicator drawing logical conclusions significantly improved from 56 to 83, despite having the lowest pre-test score among all indicators. This sharp gain highlights how PBL facilitates the development of scientific reasoning and inferential thinking, which require students to connect facts, synthesize data and arrive at justified conclusions. According to Chu et al.'s (2023) reflective thinking model, the ability to conclude logically from evidence is a hallmark of critical inquiry, developed through iterative cycles of questioning and exploration, both central to the structure of PBL. The findings thus support Iwuanyanwu's (2023) argument that education should mirror problem-solving processes found in real life to cultivate functional intelligence.

Moreover, the indicators for formulating hypotheses and identifying problems also demonstrated notable increases, from 59 to 85 and 58 to 84, respectively. These gains indicate a strengthened ability to initiate scientific inquiry and generate predictions based on available data, echoing Haeusler and Donovan's (2020) findings on cognitive development, particularly the transition into formal operational thinking, where learners begin to think hypothetically and abstractly. In PBL, students are placed in situations that simulate real-world problems, which require them to identify variables, formulate assumptions, and test ideas—practices that directly contribute to scientific literacy and reasoning (Deep et al., 2020; Hardiansyah et al. 2023).

Comparatively, while the control group also exhibited some improvement, such as identifying problems (57 to 70) and reflecting on thinking processes (59 to 70), the magnitude of these gains was substantially lower. This suggests that conventional instructional approaches, typically teacher-centered and content-driven, provide limited scaffolding for students to engage in critical evaluations or reflective inquiries. These results align with existing critiques of rote-learning models, which fail to activate higher-order cognitive domains and often marginalize student agency and metacognitive growth (Wang et al., 2023).

The average post-test score of the experimental group (85.0) far surpassed that of the control group (70.2), resulting in an average difference of 14.8 points, which is supported by the N-Gain analysis (0.61 for experimental and 0.29 for control). According to Tan et al., (2023) categorization, a gain of 0.61 is considered moderate to high and indicates that the instructional intervention (PBL) substantially affected students' learning outcomes. These findings reinforce the assertion by (Miller-Cotto et al. (2022) and Zak (2020) that reflective thinking is not a passive outcome but emerges from students' active engagement with complex, relevant problems that challenge them to think independently and evaluate multiple perspectives.

In a broader educational context, the effectiveness of PBL in this study confirms its alignment with constructivist and sociocultural learning theories, in which knowledge is actively constructed through interaction with meaningful tasks and social negotiation (Ferrero et al., 2021; Gómez & Suárez, 2020). Furthermore, the success of PBL in enhancing reflective and critical thinking at the elementary level challenges the misconception that such skills are too cognitively demanding for young learners to master. Instead, as supported by Kousloglou et al. (2023) and Parwata et al. (2023), young students can fully engage in higher-order thinking when supported by appropriate scaffolding, inquiry frameworks, and reflective dialogue.

Practical implications for pedagogy

This study offers empirical evidence that Project-Based Learning (PBL) aligns with and supports the objectives of the Merdeka Curriculum, which

emphasizes contextual learning and the cultivation of critical thinking skills. Moreover, these findings might inform teacher training, namely, in the creation of problem-based activities, formulation of thought-provoking questions, and development of formative assessments that promote reflection. The adoption of PBL directly affects classroom assessment methods. This method allows educators to assess both the final answers and the cognitive processes that students use to arrive at their solutions. This facilitates the implementation of more comprehensive and significant authentic assessments, reinforcing students' roles as active participants in their learning process.

Research Limitations

This study produced noteworthy discoveries; however, certain limitations must be recognized, along with practical answers. The research was conducted in a singular urban elementary school with sufficient resources, limiting the generalizability of the findings to schools in other socioeconomic and geographical contexts, including rural or under-resourced institutions. Future research should encompass diverse educational environments, including public and private schools in various areas, to account for contextual variations and enhance external validity. The intervention was temporally constrained, concentrating on one scientific subject across a small number of sessions, rendering the long-term impacts of PBL on reflective-critical thinking skills ambiguous. Consequently, a longitudinal design is advisable to assess whether enhancements are maintained or compounded over time. Third, the principal tool employed was a validated essay-based written examination, which, although successful, may not entirely reflect the dynamic nature of students' cognitive processes. Future research should use qualitative methods, including reflective journals, think-aloud protocols, or real-time observations, to evaluate spontaneous metacognition, emotional reflection, and alternative cognitive strategies more comprehensively. The teacher's position as a PBL facilitator—specifically, their experience, questioning technique, and conversation management skills—may impact student outcomes. To reduce variability and enhance implementation fidelity, teachers should be offered standardized training and professional development in effective PBL facilitation. Furthermore, creating digital, interactive assessment platforms that facilitate real-time feedback and integrate reflective rubrics, problem-based simulations, and recorded dialogue analyses will foster more comprehensive and authentic evaluations in accordance with the advancing digital landscape in education.

CONCLUSION

This study illustrates that Problem-Based Learning (PBL) is an effective and evidence-supported educational method for improving elementary students' reflective and critical thinking abilities in science education. The results indicate that

when young learners are directed through structured problem-based tasks, they can recognize scientific issues, develop logical hypotheses, evaluate evidence, reach conclusions, and contemplate their cognitive processes, demonstrating that these skills are teachable, quantifiable, and markedly enhanced at the primary level. This research theoretically broadens the application of PBL beyond higher education, validating constructivist and metacognitive learning concepts by demonstrating that inquiry-driven environments enhance cognitive engagement among younger pupils. This study coincides with 21st-century educational objectives and endorses programs such as Indonesia's Merdeka Belajar, promoting the systematic incorporation of PBL into basic science courses. It emphasizes the necessity of teacher preparation to facilitate effective PBL, underscoring educators' roles in crafting relevant challenges, overseeing inquiry-based learning, and evaluating reflective-critical thinking. This research confirms that reflective and critical thinking must be developed early in formal education and that implementing PBL as both a methodology and mindset can substantially improve student outcomes while promoting the qualities necessary for lifelong learning and responsible citizenship.

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