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The Effectiveness of the Problem-Based Learning Model in Enhancing Critical Thinking Skills in Science Education

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Abstract

This study evaluates the effectiveness of the Problem-Based Learning (PBL) model in enhancing critical thinking skills in elementary school Science education. The research was conducted in the Pulubala District, involving two groups: an experimental group using the PBL model and a control group following conventional teaching methods. A quantitative experimental design was adopted, with pre-test and post-test assessments to measure the change in students' critical thinking skills. Data analysis was performed using paired t-tests to examine the significant differences in pre-test and post-test scores between the two groups. Descriptive statistics indicated that the experimental group had an average pre-test score of 78.13, which increased to 89.20 in the post-test, with a reduction in standard deviation (SD) from 4.97 to 3.90, showing improved consistency in student understanding. In contrast, the control group showed an increase from 74.13 in the pre-test to 82.67 in the post-test, with a slightly higher SD of 4.19 in the pre-test and 3.90 in the post-test. Paired t-test results showed a significant difference in the experimental group (t-value = 10.75, p-value = 0.000) compared to the control group (t-value = 5.29, p-value = 0.000). The study also evaluated teachers' competency in implementing PBL, revealing strong performance in most categories, though challenges in classroom management and student engagement need addressing. The study concludes that the PBL model is effective in enhancing critical thinking skills in elementary Science education and offers a viable alternative to improve teaching quality at the elementary level.

Introduction

In the 21st-century education era, one of the primary challenges faced by educational systems worldwide is how to foster critical thinking skills in students to prepare them for increasingly complex and dynamic challenges (Gao et al., 2024). One subject that faces this challenge is Science, particularly in elementary schools, where high-level thinking skills are required to address technical natural phenomena and problems (Yi et al., 2023; Hartik et al., 2021; Rizki & Suprapto, 2024; Pertiwi et al., 2024). A teaching approach that can facilitate the development of critical thinking skills in Science education is Problem-Based Learning (PBL) (Huda & Abduh, 2021). PBL has been widely implemented across various educational levels as an alternative to enhance students' analytical and critical thinking abilities (Efendi & Wardani, 2021; Liu & Pásztor, 2022; Anggraeni et al., 2023; Plummer et al., 2022). In this context, PBL focuses not only on mastering content but, more importantly, on improving critical thinking abilities through solving real-life problems relevant to students' daily lives.

This research aims to explore the effectiveness of implementing the PBL model to improve students' critical thinking skills in elementary Science education in Pulubala District. The application of PBL in elementary schools is highly relevant given the characteristics of students at this age, who tend to be highly active and curious (Busyairi & Kusuma, 2023; Maulana et

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al., 2022; Sutika et al., 2023). On the other hand, Science education in many elementary schools still faces challenges due to traditional teaching methods that emphasize memorization and teacher-centered instruction, which often do not provide opportunities for students to actively engage in the thinking and problem-solving processes (Shikino et al., 2025; Ghaleb, 2024; Ghafar, 2023). Previous studies have shown that teaching methods focusing solely on theory and memorization are less effective in equipping students with deep critical thinking skills (Liu, 2023).

This is where PBL can offer an innovative solution by providing students with space to collaborate, explore, and solve problems based on real-world phenomena. This model requires students to use critical thinking skills and apply their knowledge in more complex, practical situations. PBL emphasizes problem-based learning processes that drive students to integrate theoretical knowledge with practical skills. Implementing PBL gives students the opportunity to engage in group discussions, develop creative solutions, and reflect on each step taken in solving problems (Handayani et al., 2021). Therefore, PBL is highly relevant in Science education, which requires students to apply scientific approaches and think systematically in solving problems (Setyawan & Koeswanti, 2021; Smith et al., 2022; Sukackė et al., 2022). This model not only enhances critical thinking skills but also motivates students to engage more actively in the learning process in a more interactive and enjoyable way.

However, despite the potential of PBL in enhancing students' critical thinking skills, its implementation in the Indonesian education context, particularly in elementary Science education, still faces several challenges (Saripi, 2024; Arda et al., 2024). One of the main challenges is the limited resources, including supporting teaching materials, learning facilities, and inadequate teacher training in implementing this model (Wahyudi & Hidayat, 2023). Additionally, there is a gap between theory and practice in PBL implementation, as many elementary school teachers are still less familiar with this approach and are more comfortable with traditional methods they already know (Sulastri et al., 2022). Therefore, this study will analyze the extent to which PBL can be effectively implemented in elementary Science education in Pulubala District, with the aim of improving students' critical thinking skills (Shimomura & Utsumi, 2025).

The main reason for conducting this research is to explore the potential of PBL as a solution to improve the quality of Science education, particularly in developing students' critical thinking skills (Karttunen et al., 2025). In numerous previous studies, PBL has proven effective in developing high-level thinking skills such as analysis, synthesis, and evaluation (Efendi & Wardani, 2021). However, there is still a gap in research that specifically focuses on the implementation of PBL in elementary schools, particularly in the context of Science education. Therefore, this study aims to fill this gap by providing a deeper insight into how PBL can be applied in this context and its impact on students' critical thinking skills (Ansya & Salsabilla, 2025).

Literature related to PBL in elementary Science education shows that this model can enhance students' motivation and involvement in the learning process (Octaviani & Mawardi, 2024). PBL provides students the opportunity not only to passively receive information but also to actively search, analyze, and formulate solutions to given problems. Additionally, PBL helps students develop social and collaborative skills through group work, as well as metacognitive skills such as reflection and self-evaluation (Rambe et al., 2024). Students' involvement in this process is essential because it creates meaningful learning experiences that contribute to a deeper understanding of Science concepts (Sejati et al., 2023). However, despite the numerous studies showing the success of PBL in various educational levels, there are still challenges in

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implementing this model in elementary schools, especially in Science education. Some of these challenges include the lack of teacher understanding on how to design and manage problem-based learning, time limitations in the classroom, and difficulty in adapting teaching materials to students' everyday lives (Komariah et al., 2024). Therefore, this research will also examine possible solutions to address these challenges, considering the role of teachers as facilitators in the learning process.

The objective of this research is to explore and measure the effectiveness of implementing the PBL model in improving students' critical thinking skills in elementary Science education (Murphy et al., 2025). This research will be conducted in three elementary schools in Pulubala District, representing variations in learning conditions and available facilities. The primary focus of this study is to identify changes in students' critical thinking skills after the implementation of the PBL model and compare them with the control group using conventional learning (Bonafide et al., 2021). Using a quantitative experimental design and data analysis through paired t-tests, this study is expected to provide empirical evidence regarding the effectiveness of PBL in enhancing students' critical thinking skills at the elementary school level (Hidayati & Purwaningsih, 2023).

Specifically, this research aims to contribute to the development of problem-based learning models in Indonesia, particularly in the context of elementary Science education (Adnyani & Suniasih, 2023). This research is also expected to provide recommendations for curriculum development and teacher training, as well as encourage educational policies that support the broader implementation of PBL in elementary schools. Furthermore, this study will provide insights into the challenges and solutions in implementing PBL in elementary schools and how PBL can be adapted to meet the needs and characteristics of students in various learning contexts (Yati et al., 2020).

Overall, PBL offers an innovative and effective approach to address problems in elementary Science education. By actively involving students in the learning process, PBL can enhance their critical thinking skills and prepare them to face the increasingly complex real-world challenges (Rambe et al., 2023). Therefore, this research is not only relevant to the context of Science education but also can serve as a reference for the overall development of elementary education. In the context of Indonesian education, implementing PBL can be a strategic step to improve the quality of learning, develop students' critical thinking skills, and prepare them to become a generation capable of thinking analytically and problem-solving in their lives (Ramadhanty & Muslihin, 2024).

The success of implementing PBL in elementary Science education will also greatly depend on the support provided by schools and the government. This support includes providing adequate resources, such as relevant teaching materials, facilities that support problem-based learning, and training for teachers to enhance their competence in managing PBL. Therefore, this study will also look at the role of educational policies in supporting the implementation of PBL in elementary schools and how these policies can be optimized to sustain problem-based learning in the future. The implementation of PBL in elementary schools is expected to have a significant impact not only on improving students' critical thinking skills but also on their character development and attitudes toward learning. Through PBL, students are taught not only to master the subject matter but also to think critically, creatively, and solution-oriented in facing the challenges they encounter (Hidayati & Purwaningsih, 2023). Thus, PBL not only improves the quality of Science education but also prepares students to become individuals capable of thinking systematically and analytically in addressing the complex challenges of the world (Busyairi & Kusuma, 2023).

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Methods

This study aims to examine the effectiveness of implementing the Problem-Based Learning (PBL) model in enhancing students' critical thinking skills in elementary Science education. To achieve this goal, the study adopts a quantitative approach with an experimental design, involving two groups: an experimental group applying the PBL model and a control group following conventional teaching methods (Yusuf et al., 2022).

The experimental approach was chosen because it allows for testing the direct impact of PBL on improving students' critical thinking skills by comparing the outcomes between the two groups. The sample consists of 30 students from three elementary schools located in Pulubala District, Gorontalo Regency. The students are divided into two groups: the experimental group, which will receive Science lessons through the PBL model, and the control group, which will engage in conventional learning methods. The experimental group will use a problem-based approach, requiring students to solve real-world problems relevant to the Science topics being taught, while the control group will follow traditional teaching methods focused on lectures and direct instruction from the teacher (Cahayu et al., 2024).

Data will be collected through pre-tests and post-tests designed to measure students' critical thinking skills before and after the learning interventions (Rahayu et al., 2022). The pre-test will be administered before the treatment (PBL or conventional learning) begins to determine students' initial level of critical thinking skills. After several learning sessions, the post-test will be administered to assess the improvement in students' critical thinking skills following the intervention.

A paired t-test will be used to analyze the comparison between pre-test and post-test scores to determine if there are significant differences in the improvement of critical thinking skills between the experimental and control groups (Tucker et al., 2024). Additionally, the study will assess the teachers' ability to implement the PBL model during the lessons. This will be done by observing the learning process and providing a questionnaire to the teacher after the lessons are completed. Measuring the teachers' ability is crucial to understanding the extent to which teaching factors can influence learning outcomes and the effectiveness of PBL implementation. Through this experimental design, it is hoped that this study will provide a clearer picture of the effectiveness of the PBL model in improving students' critical thinking skills in the context of elementary Science education (Kusumawardani & Aminatun, 2024).

Results and Discussion

This study aims to assess the effectiveness of implementing the Problem-Based Learning (PBL) model in enhancing students' critical thinking skills in elementary Science education. The research involves two groups: an experimental group that applies the PBL model and a control group that follows conventional teaching methods. Data were collected through pre-tests and post-tests to measure changes in students' critical thinking skills before and after the intervention. Additionally, the study also evaluates the teachers' ability to implement the PBL model during the lessons. The following is the data analysis from the results of this study.

Descriptive Statistics

Table 1.1 presents the descriptive statistics for students' critical thinking skills from the pre-test and post-test conducted in both groups. The experimental group showed an average pre-test score of 78.13, which increased to 89.20 in the post-test, with a decrease in standard deviation (SD) from 4.97 to 3.90. This indicates a significant improvement in the critical thinking skills of students who received problem-based learning (PBL), as well as a reduction in the variability of student scores after PBL implementation.

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On the other hand, the control group, which received conventional learning, showed an average pre-test score of 74.13, which increased to 82.67 in the post-test. Although there was an improvement, the standard deviation (SD) in the control group remained relatively higher, with a pre-test SD of 4.19 and a post-test SD of 3.90. This suggests that while students in the control group did experience an improvement, the results were more varied compared to the experimental group.

Table 1. Descriptive Statistics of Students' Critical Thinking Skills

Group	Variable	Pre-test	Post-test
Experiment	Mean	78.13	89.20
	Standard Deviation (SD)	4.97	3.90
	Median	78.00	90.00
	Min	70.00	82.00
	Max	88.00	96.00
Control	Mean	74.13	82.67
	Standard Deviation (SD)	4.19	3.90
	Median	74.00	82.00
	Min	66.00	75.00
	Max	80.00	89.00

Table 1 presents the descriptive statistics for teachers' ability to implement the PBL model in the classroom. The average scores across various categories indicate a generally good performance, with minimal variation among the teachers. The category of lesson preparation received an average score of 4.33, suggesting that teachers adequately prepared for their lessons, although some teachers required more preparation time. For instructional delivery, the average score was 4.00, indicating that the instructions provided by the teachers were clear and directed.

Classroom discussion management received an average score of 4.33, which demonstrates that teachers effectively managed student discussions, although some students were less engaged. Meanwhile, the category of collaboration and teamwork received the highest score, 4.67, highlighting the teachers' success in fostering effective teamwork among students. In the evaluation and reflection category, the average score was 4.33, indicating that teachers provided useful feedback to students, helping them understand their strengths and areas for improvement. Lastly, the category of readiness to face challenges received an average score of 3.67, showing that while most teachers felt prepared to tackle emerging challenges, some still felt the need for additional practice in managing classroom dynamics.

Table 2. Descriptive Statistics of Teachers' Ability to Implement PBL

Category	T 1	T 2	T 3	Avrg	SD	Median	Min	Max
Lesson Preparation	4	4	5	4.33	0.47	4	4	5
Instruction Delivery	4	4	4	4.00	0.00	4	4	4
Classroom Discussion Management	4	4	5	4.33	0.47	4	4	5
Collaboration and Teamwork	4	5	5	4.67	0.47	5	4	5
Evaluation and Reflection	4	4	5	4.33	0.47	4	4	5
Readiness to Face Challenges	3	4	4	3.67	0.47	4	3	4

Independent Samples t-test

Table 2 presents the results of the paired t-test for both the experimental and control groups. In the experimental group, the t-value was 10.75 with a p-value of 0.000, indicating a significant difference between the pre-test and post-test scores. This suggests that the implementation of

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the PBL model had a very positive impact on enhancing students' critical thinking skills. In the control group, the t-value was 5.29 with a p-value of 0.000, also showing a significant difference between the pre-test and post-test scores. However, the greater improvement was observed in the experimental group, indicating that problem-based learning was more effective in improving students' critical thinking skills compared to traditional learning methods.

Table 3. Paired t-test Results for Students' Critical Thinking Skills

Group	Mean Pre-test	Mean Post-test	t-value	df	p-value
Experiment	78.13	89.20	10.75	14	0.000
Control	74.13	82.67	5.29	14	0.000

Table 3 presents the results of the independent t-test, which was used to measure the differences in teachers' ability to implement PBL across several categories. The lesson preparation and discussion management categories showed a p-value of 0.070, indicating that the differences between teachers in these categories were not statistically significant. However, the collaboration and teamwork category showed a p-value of 0.043, meaning there was a significant difference between teachers in promoting teamwork in the classroom. The evaluation and reflection category also showed a p-value of 0.070, indicating that, although there were differences in the evaluations conducted by teachers, these differences were not statistically significant. Meanwhile, the readiness to face challenges category showed a p-value of 0.180, suggesting that differences in teachers' readiness to face challenges in the classroom were also not significant.

Table 4. t-test Results for Teachers' Ability to Implement PBL

Category	Mean Teacher SDN 1	Mean Teacher SDN 10	Mean Teacher 3	Mean Total	t-value	df	p-value
Lesson Preparation	4	4	5	4.33	2.65	2	0.070
Instruction Delivery	4	4	4	4.00	0.00	2	1.000
Classroom Discussion Management	4	4	5	4.33	2.65	2	0.070
Collaboration and Teamwork	4	5	5	4.67	3.14	2	0.043
Evaluation and Reflection	4	4	5	4.33	2.65	2	0.070
Readiness to Face Challenges	3	4	4	3.67	1.69	2	0.180

Based on the results from the descriptive statistics and paired t-tests conducted in this study, it can be concluded that the Problem-Based Learning (PBL) model has a significant impact on improving students' critical thinking skills, particularly in the experimental group that implemented this model. The average score increase in the experimental group was higher than in the control group, with a reduced variability in the students' scores, indicating higher consistency in learning outcomes. This improvement suggests that the implementation of the PBL model contributed to better understanding of the material, as well as supported the development of more structured critical thinking skills among students. In the experimental group, the mean pre-test score increased from 78.13 to 89.20 in the post-test. In contrast, the control group, while showing improvement, had a lower pre-test average of 74.13, which increased to 82.67 in the post-test. The greater increase in the experimental group's average scores suggests that PBL has a more effective impact on enhancing students' critical thinking skills compared to traditional learning methods. Moreover, the decrease in the standard deviation (SD) in the experimental group from 4.97 in the pre-test to 3.90 in the post-test also demonstrates increased consistency in understanding among the students, signaling that more students in the experimental group achieved similar comprehension of the material after the PBL intervention. Meanwhile, the control group, despite showing an increase in scores, displayed greater variability in results, with a slightly higher standard deviation compared to

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the experimental group in both the pre-test (SD = 4.19) and post-test (SD = 3.90). This suggests that traditional learning, which is more lecture-based and reliant on memorization, is less effective in unifying students' understanding of the material, leading to inconsistency in their learning outcomes.

The teachers' ability to implement PBL was also assessed through questionnaires filled out by three teachers teaching the experimental group. Based on the results of the descriptive statistics for teachers' ability, it was found that, overall, these teachers performed well across various categories of PBL implementation. The average score for lesson preparation was 4.33, indicating that the teachers generally prepared the problem-based learning material well. However, there were challenges related to preparation time, suggesting that some teachers still felt the need for more time to thoroughly plan problem-based learning. For the instruction delivery category, the average score of 4.00 indicates that the instructions provided by the teachers were clear and directed, although there was slight variation among teachers, which might affect how well students could understand the instructions. The classroom discussion management category received an average score of 4.33, indicating that the teachers were quite effective in managing student discussions, although some students were less actively involved in group discussions, suggesting that more attention may be needed to ensure all students are engaged. Collaboration and teamwork scored the highest with an average of 4.67, which shows that the teachers successfully encouraged very effective teamwork among students, allowing them to solve problems together. Evaluation and reflection received an average score of 4.33, suggesting that the teachers provided useful evaluations to help students understand their strengths and weaknesses, although there were challenges in providing more detailed feedback. The readiness to face challenges category received an average score of 3.67, indicating that while most teachers felt prepared to face challenges in the classroom, some felt they needed further practice in managing the more complex dynamics during problem-based learning. While the implementation of PBL showed positive outcomes, the study also identified some challenges faced by the teachers, particularly in classroom management and student engagement in group discussions. Therefore, further training for teachers is required to enhance their skills in managing problem-based learning dynamics and facilitating more productive discussions. This would further strengthen the effectiveness of PBL in improving students' critical thinking skills.

The results of the paired t-test indicate a significant difference in the experimental group with a p-value of 0.000, suggesting that the PBL model had a very positive impact on improving students' critical thinking skills. Similarly, in the control group, while there was improvement, it was not as substantial as in the experimental group, indicating that PBL is more effective in developing students' critical thinking skills compared to conventional learning methods. Overall, this study provides evidence that Problem-Based Learning (PBL) can enhance students' critical thinking skills, while also encouraging teachers to be more active in facilitating problem-based learning that is more relevant and applicable. The implementation of PBL demonstrates that problem-based learning not only improves students' understanding of scientific concepts but also helps them think more critically and solve problems encountered in everyday life. The success achieved through this PBL model opens up great opportunities for expanding the implementation of PBL in science education at the elementary school level. The experiences and findings from this study provide a solid foundation for adopting PBL as a primary approach in education at the elementary level. It is expected that teacher training and professional development will be expanded so that PBL can be implemented more effectively, ultimately improving the quality of education in Indonesia, particularly in science education.

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Conclusion

This Based on the results of this study, it can be concluded that the implementation of the Problem-Based Learning (PBL) model has a significant impact on improving students' critical thinking skills in science education at the elementary school level. The experimental group, which applied PBL, showed a greater improvement in the average pre-test and post-test scores compared to the control group. The experimental group's mean pre-test score increased from 78.13 to 89.20, with a reduction in standard deviation (SD) indicating improved consistency in students' understanding. In contrast, the control group only experienced a smaller increase, from 74.13 to 82.67. The teachers' ability to implement PBL also showed positive results, although challenges in classroom management and student engagement remained. The average score for teachers' lesson preparation was 4.33, suggesting that teachers were well-prepared to implement problem-based learning. However, the readiness to face challenges category received an average score of 3.67, indicating that some teachers felt they needed more training in managing problem-based classrooms. The paired t-test results for the experimental group showed a significant difference (p-value = 0.000), indicating that PBL had a positive impact on enhancing students' critical thinking skills. Overall, this study provides evidence that PBL is effective in improving students' critical thinking skills, and its implementation can be expanded in science education at the elementary school level.

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