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The Effectiveness of Problem-Based Learning Models in Improving Students' Critical Thinking Skills

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Abstract

In the 21st century, enhancing students' critical thinking skills is crucial for developing high-quality human resources. In physics education, students often struggle to analyze problems, apply concepts, and draw logical conclusions, indicating a limited ability to think critically. This issue is often associated with teacher-centered learning methods. This study investigates the effectiveness of the Problem-Based Learning (PBL) model in enhancing students' critical thinking skills in the context of static fluids. Using a quasi-experimental design, 72 grade XI science students were divided into control and experimental groups. The experimental group received PBL instruction, while the control group followed traditional methods. Data from pre-tests and post-tests were analyzed using independent sample t-tests. Results showed that the experimental group had significantly higher critical thinking scores. This finding suggests that PBL effectively fosters students' critical thinking by encouraging inquiry, collaboration, and real-world problem solving

Keywords: Problem-based learning; critical thinking skills; 21st century learning.

INTRODUCTION

Critical thinking skills are essential for students to navigate the complexities of the 21st century, enabling them to analyze information, solve problems, and make informed decisions (Samadun & Dwikoranto, 2022). In physics education, these skills are particularly crucial as the subject demands logical reasoning, conceptual understanding, and application of knowledge to real-world phenomena (Anggraeni et al., 2023). However, despite their significance, national and international assessments reveal that students' critical thinking abilities remain suboptimal, especially in STEM fields (OECD, 2019; Barta et al., 2022). This gap underscores the urgent need for pedagogical interventions that foster higher-order thinking.

Problem-Based Learning (PBL) has been widely recognized as a model that bridges the gap between theoretical knowledge and critical thinking. By centering learning on authentic problems, PBL encourages students to engage in inquiry, collaboration, and reflection—key processes that align with the cognitive dimensions of critical thinking (analysis, evaluation, and inference) (Hidayati et al., 2024; Dila & Suyanto, 2023). Empirical studies in science education demonstrate that PBL's student-centered approach enhances conceptual understanding while developing metacognitive skills (Nicholus et al., 2023; Saputro, 2021).

Despite PBL's theoretical promise, its effectiveness in diverse educational contexts remains a topic of debate. Some studies report significant improvements in critical thinking (e.g., Fita et al., 2021; Qondias et al., 2022), while others highlight challenges such as inadequate teacher preparation or mismatched curricular demands (Pelawi & Sinulingga, 2016; Masruro et al., 2021). For instance, Sari et al. (2021) found that the success of PBL depends heavily on contextual factors, such as class size and resource availability. These inconsistencies indicate a need for further research to validate PBL's efficacy in specific settings, such as physics classrooms in Indonesian high schools.

Recent meta-analysis studies (e.g., Anggraeni et al., 2023; Yu & Zin, 2023) have consolidated evidence supporting the effectiveness of Problem-Based Learning (PBL), while still emphasizing the need for local studies to address implementation gaps. In response to this, this study aims to investigate the impact of PBL on critical thinking skills in a context that has been rarely studied, namely physics education in Indonesia, specifically focusing on the topic of static fluids. The approach used is a quasi-experimental design with strict methodological controls, including pre-tests and post-tests as well as validated instruments, to address methodological limitations in previous studies (Belmekki et al., 2024; Monticone, 2021). The intervention in this study is also aligned with the Indonesian national curriculum, ensuring high practical relevance. The results obtained are expected to provide empirical data that enriches the discourse on the adaptability and effectiveness of PBL.

MATERIALS AND METHODS

Time and Place

This section describes the research methods used to investigate the effectiveness of the Problem-Based Learning (PBL) model in enhancing students' critical thinking skills. It includes the research design, participants, instruments, procedures, and data analysis techniques applied throughout the study.

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Research Design

This study adopted a quasi-experimental research design, specifically the non-equivalent control group design, to examine the effectiveness of the Problem-Based Learning (PBL) model in enhancing students' critical thinking skills in physics. In this design, participants were assigned to two groups: an experimental group and a control group, without randomization. This approach was selected due to practical constraints in the classroom setting, such as predetermined class structures and schedules (Belmekki, 2023).

The experimental group received instruction through the PBL model, emphasizing student-centered learning, active inquiry, problem-solving, and real-world application of physics concepts. Conversely, the control group was taught using a conventional direct instruction approach dominated by lectures and teacher explanations (Nicholus, 2023).

Both groups underwent a pre-test before the intervention to determine baseline levels of critical thinking. Following the instructional intervention, a post-test was administered to assess the students' learning outcomes. By comparing the pre-test and post-test results across both groups, this research aimed to determine whether implementing the PBL model led to statistically significant improvements (Essien, 2024).

This research design is appropriate for evaluating instructional interventions in real educational settings where complete experimental control is not feasible. It enables the identification of causal relationships between the teaching model and student outcomes while maintaining the ecological validity of the classroom context.

Population and Sample

The population of this study consisted of all Grade XI students in the science stream at SMA Negeri 2 Mataram. Using purposive sampling, a total of 72 students were selected and divided equally into two groups: 1) Experimental group: 36 students from Class XI Science 5. 2) Control group: 36 students from Class XI Science 4. The sampling decision was based on academic comparability, readiness to learn, teacher assignment, and curriculum alignment (Baden, 2022). The independent variable in this study was the PBL teaching model, and the dependent variable was the students' critical thinking skills.

Research Instrument

The primary instrument used in this study was a critical thinking test consisting of eight open-ended (essay-type) questions, designed to assess students' critical thinking abilities—specifically focusing on the cognitive skills of analysis and evaluation. The questions were developed based on established theoretical frameworks and indicators of critical thinking competence, and were contextualized within the topic of static fluids in physics. The instrument underwent expert review and rigorous pilot testing to ensure content validity (Barta, 2022). Further validation involved statistical analyses: item validity was assessed using Pearson's Product-Moment correlation, while reliability was evaluated using Cronbach's Alpha for the essay questions and KR-20 for any multiple-choice items. Additionally, item analysis for difficulty level and discrimination power was conducted to ensure overall quality and effectiveness of the test (Barta, 2022; Ntumi, 2023; Monticone, 2021).

Before their use in the actual study, both instruments underwent a pilot test and were statistically analyzed using IBM SPSS 23. The validation process involved (Li, 2023):

- Item validity testing using Pearson's Product-Moment correlation.
- Reliability testing using Cronbach's Alpha for essay tests and Kuder-Richardson (KR-20) for multiple-choice items (Ntumi, 2023).
- Item difficulty analysis, to determine the appropriateness of the items for the target student population.
- Discriminating power analysis, to ensure each item could effectively distinguish between high- and low-performing students.

Only items that met acceptable thresholds for validity, reliability, difficulty level, and discrimination index were included in the final instruments. This ensured that the tools used in the study were psychometrically sound and aligned with the research's learning objectives (Monticone, 2021).

Implementation Procedures of Research

The research procedure was conducted systematically in three consecutive phases to ensure the validity and reliability of the study. In the preparation phase, the researcher conducted classroom observations and interviews with physics teachers to gain insight into existing instructional practices and identify learning difficulties commonly encountered in teaching the topic of static fluids. These initial findings helped inform the development of appropriate instructional strategies. In parallel, a comprehensive literature review was conducted to establish the theoretical foundation for applying the Problem-Based Learning (PBL) model to improve students' critical thinking skills. Based on these insights, the researcher developed PBL-based instructional modules that are aligned with the national physics curriculum and target critical thinking indicators. To ensure the accuracy of the data collection tools, the critical thinking test instrument was reviewed by subject matter experts and pilot-tested with students of similar characteristics. The results of the pilot study were used to revise and refine the test items to meet standards of validity and reliability (Matos, 2023; Yu, 2023; PayanCarreira, 2022).

In the implementation phase, both the experimental and control groups were administered a pre-test to measure their baseline critical thinking abilities. The experimental group received instruction using the PBL model, which emphasized inquiry, collaborative learning, and solving real-world problems related to the concept of static fluids. In contrast, the control group received traditional lecture-based instruction, focused primarily on teacher explanations and textbook exercises. The intervention was carried out over four classroom sessions, each lasting two class periods (2 × 45 minutes). After completing all sessions, both groups were administered a post-test using the same instrument to assess the development of their critical thinking skills as a result of the instructional treatment (Yaayin, 2024).

Finally, in the data analysis phase, all collected data from the pre-test and post-test were organized, coded, and analyzed using appropriate statistical techniques. This analysis was conducted using IBM SPSS Statistics software to determine whether the implementation of the PBL model had a statistically significant effect on students' critical thinking performance. Hypothesis testing procedures were applied to interpret the findings and draw conclusions regarding the effectiveness of the instructional model (Vrbin, 2022).

Data Analysis Techniques

The quantitative data collected from the pre-test and post-test were analyzed using IBM SPSS Statistics version 23 to evaluate the impact of the Problem-Based Learning (PBL) model on students' critical thinking skills. Prior to conducting inferential analysis, assumption tests were carried out to ensure the suitability of parametric statistical procedures. The Shapiro-Wilk test was used to assess the normality of the data distribution for both the experimental and control groups. A p-value greater than 0.05 indicated that the data were normally distributed and met the assumption for normality (Yagin, 2024). To determine whether the data met the assumption of homogeneity of variances, the Levene's test was employed. If the resulting p-value exceeded 0.05, it was concluded that the variances between the two groups were equal, making it appropriate to proceed with independent parametric testing (Das, 2022).

Before the primary intervention was conducted, the test instrument underwent a comprehensive validation process. This included item validity analysis using Pearson Product-Moment correlation and reliability testing using Cronbach's Alpha for essay items and the Kuder-Richardson Formula 20 (KR-20) for multiple-choice items. Additionally, item difficulty and discrimination indices were calculated to ensure that each question was appropriate for the target population and capable of distinguishing between high- and low-achieving students (Karim, 2021).

Following these preparatory steps, an independent sample t-test was used to compare the post-test scores of students in the experimental and control groups. This test determined whether any observed differences in mean scores were statistically significant and attributable to the instructional intervention using the PBL model. All statistical analyses in this study were performed at a significance level of $\alpha = 0.05$, meaning that results were considered statistically significant if the p-value was less than or equal to 0.05 (Osman, 2021).

RESULT AND DISCUSSION

Result

Critical Thinking Skills

The effectiveness of the Problem-Based Learning (PBL) model in enhancing students' critical thinking skills was evaluated through pre-test and post-test scores. Before the intervention, the experimental and control groups demonstrated comparable baseline abilities. The mean pre-test score for the experimental group was 65.67, while the control group achieved a mean score of 61.25. These results indicate that both groups started with similar critical thinking skills, and neither group met the school's minimum mastery criterion (KKM ≥ 80). The results of the Critical Thinking Skills Pre-test are presented in Table 1.

Table 1. The results of the critical thinking pre-test.

Class	N	Highest value	Lowest value	Average
Experiment	36	86	43	65,67
Control	36	81	47	61,25

After implementing the instructional intervention over four sessions, a post-test was administered. The experimental group's mean post-test score improved substantially to 81.33, surpassing the KKM. In contrast, the control group only reached a mean score of 67.14, which remained below the threshold. The results of the post-test on critical thinking skills are presented in Table 2.

Table 2. The results of the critical thinking post-test.

Class	N	Highest value	Lowest value	Average
Experiment	36	93	61	81,33
Control	36	83	55	67,14

To verify the assumptions for statistical testing, homogeneity and normality tests were conducted on both pre-test and post-test data. The results confirmed that the data were homogeneous (Levene's test: $p = 0.068$ for the pretest, $p = 0.071$ for the posttest). They were usually distributed (Shapiro-Wilk: $p > 0.05$ for all test instances), thereby meeting the criteria for parametric testing. The results of the homogeneity and normality tests are presented in Tables 3 and 4.

Table 3. Homogeneity test results of critical thinking.

Ability	Class	N	Sig.	Description
Pre-test	experiment	36	0,068	Homogen
	control	36	0,068	Homogen
Post-test	experiment	36	0,071	Homogen
	control	36	0,071	Homogen

The results of this normality test will determine the suitability of parametric tests. If the significance value (p-value) is greater than 0.05, the data is considered to be normally distributed and meets the requirements for further analysis using the T-Test. The complete results of the normality test are presented in Table 4. Subsequently, an independent sample t-test was used to examine the statistical significance of the differences in post-test scores between the two groups. The result showed a significance value of $p = 0.000$ ($p < 0.05$), indicating a statistically significant difference between the experimental and control groups. This finding provides strong evidence that using the PBL model significantly enhances students' critical thinking skills compared to the traditional lecture-based approach.

Table 4. Normality test results of critical thinking.

Ability	Class	N	Sig.	Description
Pre-test	experiment	36	0,200	Normally distributed
	control	36	0,063	Normally distributed
Post-test	experiment	36	0,063	Normally distributed
	control	36	0,111	Normally distributed

These results suggest that the PBL model, which emphasizes inquiry, real-world problems, and active student engagement, creates a more conducive environment for developing higher-order thinking skills, such as analysis and evaluation, essential components of critical thinking.

T-Test Results

The statistical test was conducted using the Independent Sample T-Test to determine the effectiveness of the Problem-Based Learning (PBL) model on improving students' critical thinking skills. This test aims to determine whether there is a statistically significant difference between the experimental group, which uses the PBL model, and the control group, which uses conventional learning methods. The data analyzed came from the post-test results of students' critical thinking skills after the treatment was given. The complete results of the T-test are shown in Table 5.

Table 5. Independent Sample t-test Results

Dependent Variable	F	df	Sig. (2-tailed)
Critical Thinking Skills	0,228	70	0,000

Based on the results of the Independent Sample T-Test in the Table above, a significance value (Sig. 2-tailed) of 0.000 was obtained, which means it is smaller than 0.05. This indicates a statistically significant difference between the experimental group and the control group in terms of critical thinking skills. Thus, it can be concluded that the Problem-Based Learning model is significantly more effective in improving students' critical thinking skills than conventional learning methods. These results reinforce the view that a learning approach that emphasizes real-world problem-solving, collaboration, and active exploration greatly supports the development of high-level thinking skills, especially analysis and evaluation, at the core of critical thinking.

Discussion

The findings of this study demonstrate that implementing the Problem-Based Learning (PBL) model significantly improves students' critical thinking skills in physics, particularly in the context of static fluids. The results of the independent sample t-test confirmed that students in the experimental group, who were taught using the PBL model, achieved significantly higher post-test scores than those in the control group, who received conventional lecture-based instruction (Fita, 2021).

The observed improvement in critical thinking skills can be attributed to the core characteristics of the PBL model, which emphasize active problem-solving, inquiry-based exploration, and collaborative learning. These aspects provide a learning environment that encourages students to engage deeply with the content, analyze information, evaluate solutions, and reflect on their thought processes. This supports the development of higher-order thinking skills, as previously highlighted in studies by Dila & Suyanto (2023) and Hidayati et al. (2024), which found that students exposed to PBL showed greater proficiency in analytical and evaluative reasoning.

When learning static fluid concepts in physics, students were encouraged to actively explore, discuss, and solve contextual problems. This engagement enabled them to connect abstract ideas to real-world applications, internalize concepts more effectively, and construct meaningful understanding. Such outcomes are less likely to be achieved through passive, teacher-centered instructional models.

Furthermore, the results reinforce the view that instructional approaches aligned with 21st-century learning principles, such as PBL, are essential for equipping students not only with knowledge but also with the cognitive abilities necessary for real-life decision-making and complex problem-solving. By promoting questioning, reflection, and justification, PBL fosters deeper processing and long-term knowledge retention.

Overall, this study's findings provide empirical support for integrating Problem-Based Learning into physics instruction. The shift from teacher-centered to student-centered learning models, as exemplified by PBL, can significantly enhance students' critical thinking capabilities. This suggests the importance of creating classroom environments that encourage autonomy, inquiry, and meaningful engagement, particularly in science subjects that often involve complex and abstract concepts.

CONCLUSION

The significant improvement observed in the experimental group highlights the potential of the PBL model to support the development of students' higher-order thinking processes within the specific educational context of SMAN 2 Mataram. The model's core components—student-centered learning, real-world problem-solving, collaborative discussions, and reflective inquiry—created a learning environment that encouraged deeper conceptual understanding and enhanced students' ability to analyze, evaluate, and reason logically.

These findings align with previous studies that emphasize the effectiveness of active learning models in fostering essential 21st-century skills. However, since the study was conducted exclusively with students from Class XI IPA at SMAN 2 Mataram, the results should be interpreted within this context. Generalizations to other schools or student populations should be made cautiously, as different institutional environments, academic backgrounds, or classroom dynamics may yield different outcomes.

Therefore, while the PBL model shows promise in enhancing critical thinking among students at SMAN 2 Mataram, future research should explore its implementation in diverse educational settings and subjects. Further studies could also investigate the long-term impact of PBL on students' cognitive and academic development to provide more comprehensive evidence for its integration into science education curricula.

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