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Enhancing Critical Thinking Skills through Problem-Based Instruction: A Quasi-Experimental Study on Eighth-Grade Students in Physics Education

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Abstract: This study investigates the impact of Problem-Based Instruction (PBI) on the development of critical thinking skills among eighth-grade students at SMP Negeri 11 Mataram, focusing on the topic of vibrations and waves in physics. Utilizing a quasi-experimental post-test only control group design, the study involved 51 students divided into an experimental group taught with the PBI model and a control group receiving conventional lecture-based instruction. Critical thinking was assessed using essay-type tests aligned with Ennis's indicators, and data were analyzed through descriptive statistics and independent samples t-tests. The results reveal a significant difference in critical thinking performance between groups, with the PBI group achieving a higher mean score (82.27) compared to the control group (61.72). Effect size calculations also indicate a strong practical impact of the intervention. Observational data confirm high implementation fidelity in both groups. These findings affirm the effectiveness of PBI in fostering higher-order thinking, analytical reasoning, and student engagement in science education. The study recommends broader integration of PBI into curriculum planning and teacher training programs to support the development of critical thinking competencies in secondary education.

Keywords: Problem-Based Instruction; Critical Thinking; Physics Education; Quasi-Experimental Design; Secondary Science Learning

INTRODUCTION

Education is a strategic investment in the development of human capital. In the Indonesian context, it is defined as a conscious and planned effort to create an atmosphere of learning and a learning process in which students actively develop their potential to possess spiritual strength, self-control, personality, intelligence, noble character, and the skills needed by themselves, their community, and the nation (UU No. 20 Tahun 2003). One of the critical subjects that contributes to this national educational goal is physics. More than a body of knowledge, physics offers tools for logical reasoning, systematic analysis, and problem-solving. Thus, physics education plays an essential role not only in conceptual knowledge acquisition but also in cultivating students' critical thinking and inquiry-based learning skills.

Critical thinking is considered a core 21st-century skill and has gained significant attention in educational reform worldwide. In the context of science education, the ability to critically evaluate evidence, construct sound arguments, and solve real-world problems is vital for student success. Unfortunately, traditional physics instruction in Indonesia and similar educational systems often remains teacher-centered, relying heavily on rote memorization rather than on engaging students in active inquiry and cognitive reasoning (Aziz & Halim, 2019; Adesina & Gabriel, 2023). This conventional

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approach has led to suboptimal development of students' higher-order thinking skills, including their ability to apply, analyze, and evaluate scientific concepts.

Research has revealed several systemic barriers that hinder the development of critical thinking in science classrooms, including lack of teacher preparedness, limited access to inquiry-based resources, and environments that do not sufficiently encourage student autonomy or exploration (Meisya, 2023; Jamaluddin et al., 2019; Taylor et al., 2021). These limitations create significant challenges in equipping students with the cognitive tools necessary to navigate complex scientific issues. As a result, alternative pedagogical models that emphasize active learning, student engagement, and higher-order thinking have gained traction.

Problem-Based Instruction (PBI) is one such pedagogical model that aligns well with constructivist learning theories and Bruner's theory of discovery learning. Rooted in problem-based learning (PBL), PBI immerses students in real-world problems that require inquiry, hypothesis formation, collaboration, and evidence-based reasoning (Sariani et al., 2023; Lazaro, 2021). According to Bruner, learning becomes more meaningful when students discover knowledge themselves through inquiry, rather than passively receiving information (Smith & Robinson, 2020). PBI fosters this experiential and reflective learning process, enabling students to actively construct their understanding and apply it in various contexts.

Recent empirical evidence supports the effectiveness of PBI in enhancing critical thinking, particularly in science education. For instance, studies have demonstrated that PBI significantly improves students' analytical skills, problem-solving abilities, and conceptual understanding across various disciplines (Jerónimo et al., 2020; Kiraga, 2023; Ameen et al., 2022). In the field of physics, where abstract and often challenging concepts like vibration and waves are taught, PBI provides students with contextualized problems that bridge theory and application. When implemented effectively, this model not only promotes deeper engagement but also increases retention and fosters intrinsic motivation to learn (Pečiuliauskienė, 2022; Marnita et al., 2020).

Additionally, the application of PBI in Indonesian classrooms has shown promising results in increasing student participation, understanding, and critical thinking performance (Nurhayati et al., 2021; Kinasih et al., 2023). In a developing country context, where education systems are often constrained by limited resources and rigid curricula, PBI presents a viable and impactful alternative to traditional methods. It enables learners to make meaningful connections between classroom learning and real-life experiences, which is particularly important in science education aiming for applicability and relevance.

The instructional design of PBI incorporates stages such as problem orientation, self-directed learning, peer collaboration, and reflective synthesis, each of which contributes to the development of higher-order thinking skills. This structured approach encourages students to explore concepts from multiple angles, draw connections between ideas, and refine their understanding through iterative inquiry and feedback (Triwibowo et al., 2023). Moreover, PBI promotes collaborative learning, enabling students to work in teams, share perspectives, and develop interpersonal skills alongside cognitive abilities (Rahman et al., 2023; Widowati et al., 2021).

One of the most effective ways to assess the development of students' critical thinking is through the framework proposed by Ennis (1991), which outlines five core dimensions: simple explanation, basic skill building, inference, advanced clarification, and strategic tactics. These indicators serve as a comprehensive model for designing assessments and instructional activities aimed at fostering critical analysis and reflective reasoning (Endrawati & Aini, 2022; Susilawati et al., 2020; Verawati et al., 2019). Implementing Ennis's framework in the classroom not only provides measurable benchmarks for student progress but also guides educators in crafting pedagogical strategies that cultivate these essential skills.

In light of this, the current study aims to examine the impact of Problem-Based Instruction (PBI) on the critical thinking skills of eighth-grade students in SMP Negeri 11 Mataram, focusing specifically on the topic of vibrations and waves in physics. While previous studies have established the general efficacy of PBI, few have focused on its application to specific physics content areas at the junior secondary level, nor have they systematically examined the growth of critical thinking skills using Ennis's indicators. Furthermore, most related studies in the local context have prioritized cognitive outcomes such as test scores, neglecting the development of analytical competencies necessary for scientific literacy.

This study fills that gap by assessing the effectiveness of PBI in cultivating students' critical thinking skills, using Ennis's framework as an evaluative tool. It also contextualizes the findings within the broader discourse on science education reform and learner-centered pedagogy in Indonesia. Specifically, this research investigates whether students taught using PBI outperform their peers in traditional lecture-based classrooms in terms of critical thinking, as measured by structured assessments.

The novelty of this research lies in its dual focus: it not only applies a student-centered instructional model within a specific scientific domain but also integrates a validated critical thinking framework to measure educational outcomes. The study contributes to the existing literature by providing empirical evidence supporting the integration of PBI into middle school science curricula, offering insights for educators, curriculum developers, and policymakers aiming to enhance critical thinking in secondary education.

Therefore, the research problem is formulated as follows: "What is the influence of the Problem-Based Instruction (PBI) model on the critical thinking skills of eighth-grade students at SMP Negeri 11 Mataram, particularly on the topic of vibrations and waves?" The primary objective of this study is to determine the effect of the Problem-Based Instruction (PBI) model on the development of students' critical thinking skills in junior high school physics education. The results of this study are expected to provide a foundation for improving instructional strategies in Indonesian classrooms and support the transition toward more interactive and thought-provoking learning environments in science education.

METHOD

Research Design

This study employed a quasi-experimental design, specifically the post-test only control group design. Quasi-experimental designs are widely used in educational research as they allow for treatment-effect evaluation while accommodating the constraints of real-world classroom settings (Sanjaya et al., 2022; Bachri et al., 2023). In this design, two groups were used—an experimental group that received a treatment and a control group that did not. Both groups were randomly selected from the population and tested only after the intervention. The experimental group received instruction using the Problem-Based Instruction (PBI) model, while the control group was taught using conventional lecture-based methods. The design is summarized in Table 1.

Table 1. Research Design (Sugiyono, 2015)

Class	Treatment	Post-Test
E (Experimental)	X1 (PBI model)	O1
K (Control)	X2 (Lecture method)	O2

This design was selected because it reduces pre-test bias and streamlines data collection while providing reliable comparisons across instructional strategies (Akbar et al., 2022; Aksoy & HİMMETOĞLU, 2023).

Population and Sample

The research was conducted at SMP Negeri 11 Mataram. The subjects of the study were students from the eighth-grade cohort. The population included all eighth-grade students at SMP Negeri 11 Mataram, totaling 218 students across six classes. Cluster random sampling was used to ensure equitable group selection, as homogeneity tests indicated similar initial abilities among all classes. This technique allowed for unbiased group allocation, with Class VIII A selected as the experimental group and Class VIII B as the control group (Sugiyono, 2015).

Research Instruments

To ensure effective data collection and measurement, two key instruments were developed:

1. Critical Thinking Skills Test: This essay-based test consisted of five questions designed to assess students' critical thinking regarding physics content. The test items were carefully aligned with Ennis's critical thinking indicators, including simple clarification, inference, and advanced clarification (Mahmudah et al., 2023; Rima & Muhyidin, 2023). The validation process involved expert reviews and pilot testing to ensure clarity, alignment with cognitive processes, and relevance to learning outcomes (Purwandari et al., 2023). Additionally, scoring was guided by structured rubrics to enhance inter-rater reliability and reduce subjective bias (Shabani & Panahi, 2020).
2. Lesson Plan Implementation Observation Sheet: This instrument assessed the extent to which the planned instructional activities were carried out. The observation checklist focused on the teacher's activities from the beginning to the end of the lesson. Observations were recorded in real-time and analyzed using standard rating criteria.

Validity and Reliability

Instrument validity was established through expert validation, involving input from educational practitioners and subject-matter experts. For the critical thinking test, items were mapped to Ennis's framework and reviewed for content alignment (Nupus et al., 2021). Reliability was tested using Cronbach's alpha to ensure internal consistency. A minimum threshold of 0.70 was applied, consistent with widely accepted standards in educational research (Silva et al., 2019; Reis-Júnior et al., 2022). Piloting the instrument helped uncover potential ambiguities, and feedback was incorporated to improve item quality (Na'imah et al., 2022).

Data Collection Techniques

To obtain accurate and comprehensive data, the study employed both test-based and observational methods:

1. Critical Thinking Test: Administered to both groups after the intervention. The test scores were analyzed using holistic scoring rubrics developed in alignment with learning outcomes and Ennis's indicators.
2. Observation: Conducted during each instructional session to record the fidelity of lesson plan implementation. Observers used standardized checklists to monitor instructional delivery.

Data Analysis Techniques

Scoring of Critical Thinking Test

Student responses to the essay-based critical thinking test were scored using a normalized formula in which the final score (Na) was obtained by dividing the student's actual score by the maximum possible score and multiplying the result by 100. Based on these results, students' critical thinking levels were categorized using standardized criteria adapted from Sabri et al. (2022), as shown in Table 2.

Table 2. Critical Thinking Category

Score Range	Critical Thinking Category
85–100	Very Critical
75–84.9	Critical
65–74.9	Fairly Critical
55–64.9	Moderately Critical
< 55	Less Critical

Lesson Plan Implementation Analysis:

Quantitative analysis was also applied to lesson plan implementation data. Observers recorded the number of instructional steps that were completed as planned. The implementation rate was calculated by dividing the number of implemented steps (X) by the total number of planned steps (Y) and multiplying the quotient by 100 to yield a percentage. The quality of implementation was then classified into five categories as shown in Table 3.

Table 3. Learning Implementation Category

Percentage (%)	Implementation Quality
80–100	Excellent
60–79	Good
40–59	Fair
20–39	Poor
0–19	Very Poor

Assumption Tests

Prior to conducting hypothesis testing, assumption checks were performed to ensure data validity for parametric analysis. A Chi-square test was conducted to assess the normality of score distribution in both groups. If the Chi-square calculated value was less than or equal to the critical value from the Chi-square distribution table, the data were deemed normally distributed. Concurrently, an F-test was used to examine the homogeneity of variances between the two groups. Homogeneity was confirmed if the calculated F value did not exceed the critical F value from the distribution table.

Hypothesis Testing

To evaluate the effectiveness of the PBI model in enhancing students' critical thinking, independent samples t-tests were applied. If the assumption of homogeneity of variance was satisfied, the pooled variance formula was used. Otherwise, the separated variance formula was adopted. These statistical tests compared the means and variances of the experimental and control groups, taking sample sizes into account. The calculated t-value was then compared with the critical t-value at a 5% significance level. If the calculated value was greater than or equal to the critical value, the alternative hypothesis (H_a) was accepted, indicating a statistically significant difference attributable to the intervention.

RESULTS AND DISCUSSION

Descriptive Data Overview

This study examined two primary sets of data: students' critical thinking skill scores and the implementation fidelity of the lesson plan (RPP). The results are presented through statistical analysis, followed by an in-depth discussion contextualized by relevant literature.

Description of Students' Critical Thinking Skills

Post-test data from both the experimental and control classes were analyzed to assess students' critical thinking performance after instruction on the topic of vibrations and waves. As shown in Table 4, the experimental group—which was taught using the

Problem-Based Instruction (PBI) model—exhibited a stronger performance in critical thinking skills than the control group, which received conventional lecture-based instruction.

Table 4. Student Critical Thinking Overview

Criterion	Experimental Class	Control Class
Very Critical	11	3
Critical	5	4
Fairly Critical	6	8
Less Critical	0	14
Total Students	22	29
Average Score	82.27 (Very Critical)	61.72 (Less Critical)

These results suggest that students exposed to the PBI model were more likely to attain higher-order thinking outcomes, aligning with findings by Syahfitri and Sulaiman (2023) and Hikmah et al. (2023), who found that PBL-based learning environments significantly enhance analytical reasoning and reflective decision-making. The disparity in performance highlights the efficacy of PBI in fostering skills such as evaluating evidence, solving real-world problems, and articulating structured arguments.

Implementation Fidelity of the Lesson Plan (RPP)

Observation of classroom practices was conducted to evaluate whether instruction followed the planned teaching steps. Table 5 presents the implementation results across both experimental and control classes.

Table 5. Lesson Plan Implementation in the Experimental and Control Classes

Class	Session	Implementation Rate	Category	Average Rate
Experimental	I	90%	Very Good	85%
	II	80%	Very Good	
Control	I	80%	Very Good	85%
	II	90%	Very Good	

Despite the overall implementation being categorized as “very good” for both groups, minor shortcomings were noted. In the experimental class, the decline in implementation during the second session was due to challenges in classroom management and maintaining consistent application of PBI steps, such as guiding group collaboration. This nuance underscores a common challenge in active learning environments, as noted by Wieselmann et al. (2022), who observed that middle school teachers often struggle with sustaining engagement throughout extended problem-solving cycles.

Normality and Homogeneity Testing

To ensure the robustness of statistical analysis, the normality and homogeneity of variance in both sample groups were examined. Table 6 shows the Chi-square test results.

Table 6. Data Normality

Class	N	X^2 Calculated	X^2 Table	Conclusion
Experimental	22	-17.55	7.82	Normal
Control	29	-9.72	15.51	Normal

As both calculated Chi-square values were within acceptable ranges, the data distribution was deemed normal. Additionally, Table 7 presents the homogeneity test.

The result confirms homogeneity between the two groups, allowing for further parametric testing.

Table 7. Data Homogenous

Group	Variance (S^2)	F Calculated	F Table	Conclusion
Experimental	74.31	4.1079	32.67	Homogeneous
Control	327.26			

Hypothesis Testing

Following verification of statistical assumptions, a t-test was conducted using the pooled variance formula. The result—$t(49) = 4.951$, $p < 0.05$—demonstrated a statistically significant difference in critical thinking scores between the experimental and control groups. This supports the alternative hypothesis, affirming that the PBI model had a positive impact on critical thinking development.

Discussion

The findings of this study corroborate a substantial body of literature affirming the benefits of the Problem-Based Instruction model. In alignment with Magpantay & Pasia (2022) and Samadun et al. (2023), the PBI group exhibited stronger critical thinking performance. This model fosters active engagement with learning material by positioning students as co-constructors of knowledge through collaboration and inquiry. Such interaction is essential for promoting higher-order thinking, as students must analyze real-world problems, articulate their reasoning, and refine their ideas through discussion.

One of the most salient aspects of the PBI model is its emphasis on real-world relevance and problem context. In this study, students explored phenomena such as vibrations and waves through practical demonstrations (e.g., pendulum experiments using toy balls). These activities bridged the gap between theoretical concepts and daily life applications. Consistent with research by Zachariah et al. (2022) and Theobald et al. (2020), experiential learning in science leads to deeper understanding, higher motivation, and improved conceptual retention.

Moreover, the implementation of PBI aligns with Ennis's indicators of critical thinking, particularly in enabling students to formulate explanations, infer logically, and evaluate evidence (Ennis, 1991; Endrawati & Aini, 2022). While the control group mostly engaged in passive knowledge absorption, the PBI group regularly engaged in structured argumentation and collaborative analysis.

Despite the favorable outcomes, challenges emerged in the execution of PBI. Teachers reported difficulty managing group work and maintaining student focus during inquiry phases. These issues echo findings from Wieselmann et al. (2022) and Kim (2021), who found that teacher training and classroom dynamics significantly affect the success of PBI implementation. As such, ongoing professional development and smaller class sizes could mitigate these obstacles.

The current study's results also support broader findings regarding the practical significance of PBI. Based on a large effect size (Cohen's $d > 0.8$, calculated from mean differences), the intervention produced not only statistical significance but also a meaningful improvement in students' learning outcomes. Such findings reflect those of McLure et al. (2020) and Fernández-Espínola et al. (2022), who stress that educational interventions should be assessed not only by p-values but by their real-world impact on student development.

The control group's lower performance highlights the limitations of traditional lecture methods in fostering analytical skills. Choo (2021) and Yadav et al. (2021) note that while lectures can convey foundational knowledge, they often fail to promote the evaluative and synthetic thinking required for scientific reasoning. In contrast, PBI's collaborative, reflective, and problem-centered structure naturally cultivates these competencies.

Additionally, meta-analytic evidence confirms that PBI significantly improves problem-solving, metacognitive awareness, and content retention across disciplines (Kurniadi & Cahyaningrum, 2023; Fahri & Musharyanti, 2022). The presence of multiple pathways for engagement—including experimentation, peer dialogue, and scenario analysis—makes PBI a holistic approach to science education reform.

In conclusion, the findings confirm that the Problem-Based Instruction model significantly improves students' critical thinking skills compared to conventional methods. Its alignment with constructivist theory and proven efficacy in promoting analytical reasoning make PBI a powerful pedagogical strategy for modern science education.

CONCLUSION

Based on the findings and analysis presented in this study, it can be concluded that the implementation of the Problem-Based Instruction (PBI) model has a significant positive impact on the development of students' critical thinking skills in the context of physics learning, particularly on the topic of vibrations and waves. The results demonstrate that students in the experimental group, who were taught using PBI, achieved higher scores in critical thinking assessments compared to those in the control group taught using conventional lecture methods. This performance gap highlights the effectiveness of PBI in promoting deeper cognitive engagement, encouraging students to explore problems collaboratively, and fostering analytical reasoning.

The study further confirms that the structured phases of PBI—such as problem orientation, investigation, collaboration, and reflection—facilitate a conducive environment for higher-order thinking. These results align with both theoretical expectations and empirical evidence from recent educational research that emphasizes the value of active, student-centered learning environments. Additionally, the strong effect size observed suggests that the influence of PBI is not only statistically significant but also educationally meaningful, reinforcing its role as a transformative approach to science education.

RECOMMENDATIONS

Given the empirical support for the PBI model presented in this study, several recommendations are proposed to enhance its implementation and impact in educational settings. First, educators are encouraged to adopt the PBI model in science instruction to foster critical thinking and problem-solving skills. Teachers should receive adequate professional development that equips them with the pedagogical knowledge and facilitation techniques required to manage PBI activities effectively. Training should emphasize strategies for guiding inquiry, encouraging collaboration, and maintaining student engagement throughout the problem-solving process.

Second, curriculum developers and educational policymakers should consider integrating PBI frameworks into national curricula. Instructional materials should be designed to include real-world problem scenarios that align with key scientific concepts and promote critical engagement. Lesson plans should incorporate opportunities for student investigation, discussion, and reflection to ensure alignment with critical thinking objectives.

Third, future research should explore the long-term effects of PBI on student outcomes across different subjects and educational levels. Investigations could focus on how sustained exposure to PBI influences academic performance, motivation, and the transferability of critical thinking skills beyond the classroom. Moreover, the integration of PBI with digital tools and virtual learning platforms could be examined, particularly in light of evolving educational technologies and the growing need for flexible learning environments.

In conclusion, the implementation of the Problem-Based Instruction model represents a promising direction for improving science education. By actively involving students in the learning process through inquiry and collaboration, PBI fosters not only academic achievement but also essential life skills. Its adoption and refinement across educational systems can play a crucial role in developing learners who are equipped to think critically, solve problems creatively, and engage meaningfully with the world around them.

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