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Differences in Students' Critical Thinking and Collaboration Skills between Problem-Based Learning and Discovery Learning in Physics

Mawarni Saputri[1*], Saminan Saminan[1], Ziaun Nisa[1]
[1]Department of Physics Education, Universitas Syiah Kuala, Indonesia

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Corresponding author: mawarni_saputri@usk.ac.id

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ABSTRACT
Critical thinking and collaboration are essential 21st-century competencies. However, recent PISA results indicate that students' critical thinking skills remain low, a condition also found at SMA 15 Adidarma Banda Aceh. Therefore, this study aimed to examine the effect of the Problem-Based Learning (PBL) model on students' critical thinking and collaboration skills in physics learning on the topic of Heat and Temperature. This study employed a quantitative approach with a non-equivalent control group design. The participants were two Grade XI classes. The experimental group was taught using the PBL model, while the control group received instruction through the Discovery Learning model. Data were collected through pretest and posttest essay tests to measure critical thinking skills, while collaboration skills were assessed using observation sheets. Critical thinking data were analyzed using an independent samples t-test, whereas collaboration data were analyzed descriptively using percentage analysis. The results showed a significant difference in critical thinking skills between the experimental and control groups $t_{count}(1.800) > t_{table}(1.684)$*, with the experimental group achieving better results. In addition, students' collaboration skills in the PBL class were categorized as very good. It can be concluded that the PBL model has a significant positive effect on improving students' critical thinking and collaboration skills. Therefore, PBL is recommended as an effective instructional alternative for physics teachers to promote higher-order thinking and collaborative learning competencies.*

INTRODUCTION

The demands of 21st-century education require students to master the 4C competencies: critical thinking, communication, collaboration, and creativity. Among these competencies, critical thinking and collaboration are considered fundamental skills because they enable learners to analyze information, solve problems logically, communicate ideas, and work effectively with others (Al Kandari, 2020). These competencies are increasingly necessary in academic settings and future workplaces characterized by rapid technological change and complex global challenges (Marcos et al., 2024). Therefore, schools are expected to transform learning practices from content transmission into competency-oriented instruction.

However, the reality on the ground shows that students' higher-order thinking skills remain inadequate. The Programme for International Student Assessment (PISA) 2022 released by OECD reported that Indonesian students' performance in mathematics, reading, and science is still relatively low compared with many participating countries. Since PISA tasks require reasoning, problem solving, and conceptual understanding, these findings indicate that students' critical thinking skills need substantial improvement (OECD, 2023; Azis & Ardiansyah, 2024; Van, 2021). This condition becomes increasingly urgent because weak critical thinking may hinder students' readiness to face higher education, scientific literacy demands, and future employment competition.

In addition to critical thinking, collaboration has become an equally important educational activities, but is also needed as a basic life skill that is important for humans to have as social beings. Collaboration refers to the ability to work productively with others, share responsibilities, exchange ideas, and achieve common goals. Students who possess strong collaboration skills tend to demonstrate better engagement, communication, and collective problem-solving abilities (Aslan, 2021; Wahyuni, 2024). Consequently, modern learning environments should facilitate the simultaneous development of critical thinking and collaboration.

Physics is one of the subjects that strongly requires these two competencies. Learning physics involves understanding abstract concepts, analyzing relationships among variables, interpreting phenomena, conducting investigations, and solving contextual problems systematically (Saputri, 2022). Many physics concepts cannot be mastered through memorization alone; instead, students need logical reasoning and collaborative discussion to construct conceptual understanding. Therefore, physics classrooms should adopt learning models that actively engage students in inquiry and teamwork and to facilitate students in practicing their skills especially critical and collaborative thinking.

Nevertheless, preliminary observations at SMA 15 Adidarma Banda Aceh indicated that physics instruction was still dominated by conventional learning approaches. Conventional teaching often emphasizes explanation, note-taking, and individual exercises, while students have limited opportunities to discuss ideas, challenge arguments, or collaboratively solve authentic problems. Learning activities mainly consisted of teacher explanations, note-taking, and individual assignments, with limited opportunities for discussion, collaborative problem-solving, and reflective learning. As a result, the implementation of deep learning principles was not yet optimal. This condition was reflected in the relatively low average physics achievement score of 65, while group work often relied on the efforts of only a few students rather than genuine collaboration among all group members.

Two student-centered instructional models that are widely discussed in science education are Problem-Based Learning (PBL) and Discovery Learning. PBL engages students in solving authentic problems through investigation, discussion, and evidence-based reasoning, while the teacher acts as a facilitator (Liu, 2022). Discovery Learning encourages students to discover concepts independently through exploration and guided activities. Both models are believed to support active learning; however, they differ in instructional focus. PBL emphasizes collaborative problem solving in real contexts, whereas Discovery Learning emphasizes concept formation through exploration.

Previous studies have shown positive effects of PBL and Discovery Learning on learning outcomes. However, limited studies directly compare the effectiveness of PBL and Discovery Learning in improving both critical thinking and collaboration skills simultaneously in physics learning. Most studies focus only on cognitive achievement, examine one model separately, or do not specifically address physics topics such as Heat and Temperature. This represents an important research gap.

The novelty of this study lies in three aspects. First, it directly compares PBL and Discovery Learning as two active learning models in physics instruction. Second, it measures their effects simultaneously on two essential 21st-century competencies: critical thinking and collaboration. Third, it provides empirical evidence from the Indonesian senior high school context, particularly SMA 15 Adidarma Banda Aceh, where comparative studies of this kind remain limited.

Therefore, this study aimed to investigate the effect of Problem-Based Learning compared to Discovery Learning in enhancing students' critical thinking and collaboration skills in physics learning. The findings are expected to contribute to the selection of more effective instructional strategies for improving 21st-century competencies in secondary physics education.

METHOD

Research Design

This study employed a quantitative quasi-experimental design using a non-equivalent control group design. Two intact classes participated in the study: the experimental group received Problem-Based Learning (PBL), while the comparison group was taught using Discovery Learning. A pretest and posttest were administered to both groups to measure students' critical thinking skills, whereascollaboration skills were assessed through classroom observations during the intervention. The research design is presented in Table 1.

Table 1. Research Design

	Pretest	Treatment	Posttest
Experimental	O_1	PBL	O_2
Control	O_1	Discovery Learning	O_2

Research Procedure and Participants

The study was conducted at SMA 15 Adidarma Banda Aceh, Indonesia, during the 2025 academic year. The population consisted of all Grade XI science-track students, comprising three classes: XI IPAS I, XI IPAS II, and XI IPAS III. The sample was selected using purposive sampling based on class characteristics, academic score distribution, and school recommendations. A total of 42 students participated in the study. Class XI IPAS III (22 students) was assigned as the experimental group, while Class XI IPAS I (20 students) was assigned as the control group. The overall research procedure is illustrated in Figure 1.

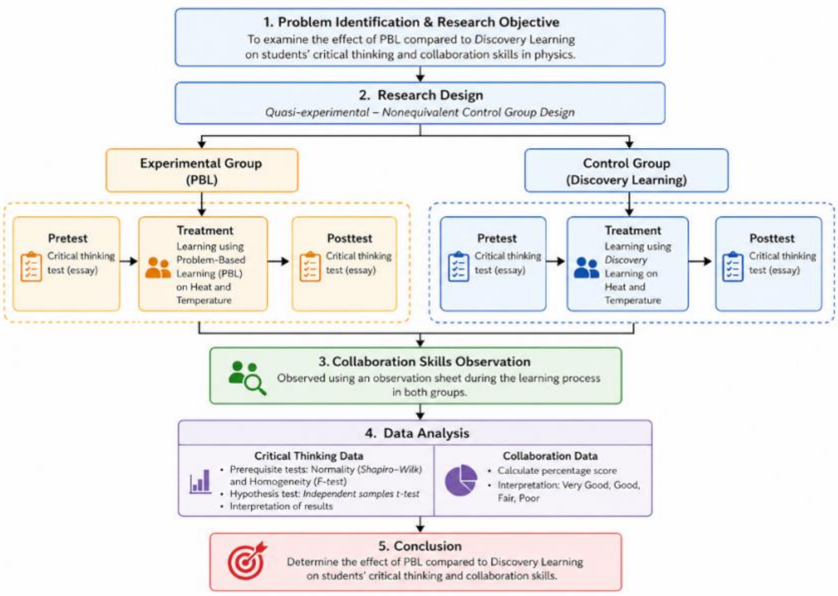

Fig.1. Research flowchart

Research Instruments

Two types of instruments were used in this study: test and non-test instruments. Prior to implementation, both instruments were validated by experts in physics education to ensure their content validity and suitability for the research objectives. Based on the validation results, all instrument items were declared valid and appropriate for data collection. Students' critical thinking skills were measured using five essay questions administered in the pretest and posttest. The items were developed based on critical thinking indicators adapted from Ennis (2011) like shown in Table 2.

Table 2. Blueprint of Critical Thinking Skills Test Instrument

No	Critical Thinking Indicator	Topic	Item Number	Number of Items
1	Providing Simple Explanation	Heat Transfer	1	1
2	Managing Strategies and Tactics	Thermal Expansion	2	1
3	Drawing Conclusions	Thermal Expansion	3	1
4	Giving Further Explanation	Heat Transfer	4	1
5	Building Basic Skills	Black's Principle	5	1
Total				5

The non-test instrument used in this study was an observation sheet employed to determine the extent of improvement in students' collaboration skills after both classes received the learning model treatment, including the experimental class and the control class. Students' collaboration skills were assessed using an observation sheet during classroom activities. The indicators were adapted from Greenstein (2012), like shown in Table 3.

Table 3. Blueprint of Collaboration Skills Observation Instrument

No	Collaboration Skill Indicator	Item Number	Number of Items
1	Working productively with group members	1 and 2	2
2	Balancing speaking and listening	3 and 4	2
3	Demonstrating adaptability and compromise	5 and 6	2
4	Respecting others' ideas	7 and 8	2
5	Cooperating to solve problems and generate ideas	9 and 10	2
Total			10

Data Analysis

Critical thinking skills

Pretest and posttest data were analyzed using descriptive and inferential statistics. Prior to hypothesis testing, the data were subjected to: *Normality test* using the Shapiro–Wilk test and *Homogeneity test* using Levene's/F-test.

After the assumptions were met, an independent samples *t-test* was used to determine whether there was a significant difference in critical thinking skills between the experimental and control groups. The significance level was set at $\alpha = 0.05$.

Collaboration skills

Collaboration data were analyzed descriptively using percentage scores formula as follows:

$$\text{Percentage} = \frac{obtained\ score}{maximum\ score}\ x100\% \quad (1)$$

The percentage scores were interpreted using the following criteria in Table 4.

Table 4. Percentage Criteria for Scoring Students' Collaboration Skills

Percentage (%)	**Category**
81.25–100	Very Good
62.50–81.24	Good
43.75–62.49	Fair
25.00–43.74	Poor

RESULTS AND DISCUSSION

Instrument Validity Test Results

Prior to data collection, all research instruments, including the teaching module, student worksheets (LKPD), collaboration skills observation sheet, and critical thinking test, were validated by two experts in physics education. The average validation scores ranged from 3.30 to 3.68, indicating that all instruments met the criteria of very valid and were suitable for use in the study.

Normality Test Result

The normality test aims to determine whether the data from the two tested samples come from a normally distributed population or not. The normality test used in this study was the Microsoft Excel-assisted Shapiro–Wilk test. A summary of the normality test results is presented in the Table 5.

Table 5. Normality Test Results

	Pretest Score		**Posttest Score**	
	Experiment class	Control class	Experiment class	Control class
$\propto$	0.05	0.05	0.05	0.05
n	22	20	22	20
W_{count}	0.916	0.950	0.947	0.954
W_{table}	0.911	0.905	0.911	0.905
Distribution type	Normal	Normal	Normal	Normal

Based on Table 6, the results of the Shapiro–Wilk normality test show that all calculated W values for both the pretest and posttest are greater than the W table values, in both the experimental class and the control class, at a significance level of $\alpha = 0.05$. This indicates that the data are normally distributed, so the data can be further analyzed using parametric tests.

Homogeneity Test Result

The homogeneity test was conducted to determine whether the two groups had equal variances. The results of the homogeneity test can be seen in Table 6.

Table 6. Homogeneity Test Result

	Pretest Score		**Posttest value**	
	Experiment Class	Control Class	Experiment Class	Control Class
F_{count}	1.558		1.286	
F_{table}	2.109		2.109	
Distribution type	Homogen		Homogen	

Based on Table 6, the results of the homogeneity test for the pretest show that the calculated F value (1.558) is smaller than the F table value (2.109). Likewise, for the posttest data, the calculated F value (1.286) is also smaller than the F table value (2.109). Therefore, it can be concluded that the data from both groups have homogeneous variances, for both the pretest and posttest.

Hypothesis Test Result

Hypothesis testing was conducted to determine whether there was a significant difference in students' critical thinking skills between the experimental class using the Problem-Based Learning model and the control class using the Discovery Learning model. Since the data were normally distributed and homogeneous, an independent samples t-test was performed using Microsoft Excel at a significance level of α = 0.05. A summary of the results is presented in Table 7.

Table 7. Hypothesis Test Result

Data	n	$\bar{X}$	t_{count}	t_{table}	Conclusion
Experiment class	22	83.636	1.800	1.684	The hypothesis was accepted.
Control class	20	77.000			

Based on Table 7, the hypothesis test results show that the calculated t-value (1.800) is greater than the t-table value (1.684). This indicates that H_0 is rejected and H_a is accepted, meaning that there is a significant difference in the critical thinking skills of students at SMA 15 Adidarma Banda Aceh before and after the implementation of the Problem-Based Learning model.

This finding is consistent with Agustina et al. (2022), who reported that PBL significantly improved students' critical thinking ability. Similarly, Ayub & Doyan (2024) and Ina (2026) found that students taught using PBL achieved significantly higher scores than those in control classes.

The superiority of PBL can be explained theoretically. In PBL, students are confronted with contextual problems requiring them to identify issues, gather evidence, discuss alternatives, justify decisions, and reflect on solutions. These stages directly correspond to core elements of critical thinking: interpretation, analysis, inference, explanation, and self-regulation. In contrast, Discovery Learning often emphasizes independent concept finding. While beneficial for exploration, students with weak prior knowledge may experience difficulty organizing information, leading to less optimal reasoning development. Recent meta-analytic studies also suggest that structured inquiry models such as PBL often outperform minimally guided discovery approaches, especially for novice learners.

Collaborative Skills

A percentage analysis was conducted to examine students' collaboration skills in both groups based on the established indicators and to compare the effectiveness of Problem-Based Learning (PBL) and Discovery Learning (DL). Although both models promote collaborative learning, they differ in their collaborative processes. In PBL, students work interdependently to solve complex problems by sharing responsibilities and integrating individual contributions into a collective solution. In contrast, collaboration in DL is centered on exploratory activities, where students discuss observations, conduct investigations, and construct conclusions together. Therefore, the comparison focused not only on the level of collaboration achieved but also on the extent to which each model fostered active and meaningful group interaction. A summary of the percentage analysis results is presented in Table 8.

Table 8. Results of the Percentage Test of Students' Collaborative Skills

Collaborative Skills Indicator	Experimental Class Score	Percentage (%)	Category	Control Class Score	Percentage (%)	Category
Working productively with group members	81	92%	Very Good	75	85%	Very Good
Students maintain balance between listening and speaking	79	90%	Very Good	73	83%	Very Good
Students demonstrate the ability to adapt and compromise	79	90%	Very Good	75	85%	Very Good

Collaborative Skills Indicator	Experimental Class Score	Percentage (%)	Category	Control Class Score	Percentage (%)	Category
Students appreciate ideas proposed by others	79	90%	Very Good	74	84%	Very Good
Students collaborate to solve problems and generate new ideas	77	87%	Very Good	72	82%	Very Good
Total	449	89.8%	Very Good	419	83.8%	Very Good

Based on Table 8, the percentage test results show that the average percentage of collaborative skills in the experimental class was 89.8%, while the control class achieved 83.8%. Although both classes were categorized as very good based on the established assessment criteria, the experimental class showed higher achievement in every indicator. This indicates that the Problem-Based Learning model was more effective in improving students' collaborative skills than the Discovery Learning. This finding is consistent with Hartina et al. (2022), who found that PBL successfully improved collaboration skills. Mardawati et al. (2022) also reported that collaboration skills were more effectively developed through PBL than through Discovery Learning, although both remained in the high category.

The indicator of *working productively with group members* was higher in the experimental class. PBL encourages students to divide tasks fairly, contribute actively, and complete assignments together. Structured responsibility sharing in PBL has been shown to improve group productivity (Risandy et al., 2023). In contrast, Discovery Learning often emphasizes individual exploration, so structured cooperation is less developed (Nainggolan, 2024).

The indicator of *maintaining balance between listening and speaking* also improved more in the experimental class. Since discussion is central in PBL, students practice reciprocal communication by listening to peers and expressing ideas proportionally. This finding is supported by Zhang & Hwang (2023) and Nurwidodo et al. (2023), who reported that PBL discussions significantly improve interpersonal communication skills.

The indicator of *demonstrating adaptability and compromise* showed better results in the experimental class. During PBL activities, students face differing opinions and must negotiate to reach agreement. This process trains flexibility, tolerance, and consensus-building skills (Dewi et al., 2022; Oktaviani & Hermawan, 2023). Meanwhile, Discovery Learning provides fewer opportunities for intensive negotiation (Ramadhani & Sari, 2021; Assidik, 2026).

The indicator of *respecting others' ideas* was also higher in the experimental class. PBL requires students to consider multiple perspectives before making group decisions, creating a more open and respectful learning environment (Rohaniyah et al., 2025; Pertiwi & Wahyuningsih, 2022).

The indicator of *solving problems together and generating new ideas* achieved strong results in the experimental class. PBL places students in authentic problem situations that require idea sharing, collective reasoning, and creative solution development. Previous studies found that PBL supports participatory problem solving and collaborative creativity (Hidayah et al., 2021; Lestari et al., 2019). Discovery Learning may be less optimal for collaborative innovation because students often focus on individual exploration (Putra, 2020; Kusumawati et al., 2024). Overall, these findings show that PBL not only improves academic learning outcomes but also strengthens collaborative skills needed in 21st-century learning, especially communication, teamwork, and shared problem solving in physics topics such as heat.

The higher collaboration score in the PBL group may be attributed to the interdependent nature of problem-solving tasks, which required students to distribute roles, exchange ideas, and coordinate efforts to develop solutions. In contrast, collaboration in the DL group was primarily focused on sharing observations and discussing findings, resulting in less intensive interaction among group members.

Critical Thinking Skills Results

Students' critical thinking skills in this study were measured through pretests and posttests consisting of five essay questions. The responses were analyzed using Microsoft Excel to determine the average scores obtained by students in both the experimental and control classes. Based on the findings, the pretest and posttest scores in the experimental class were higher than those in the control class. A summary of the pretest and posttest results is presented in Table 9.

Table 9. Average Score of Critical Thinking

	Average Score of Critical Thinking	
	Pretest	Posttest
Experiment	24.09	83.63
Control	23.25	77.00

Based on Table 9, the average critical thinking skills scores of students in the experimental and control classes during the pretest were relatively similar and categorized as very low, with an average of 24.09 for the experimental class and 23.25 for the control class. This indicates that before the treatment, students in both classes had similar initial critical thinking skills and understanding of heat material. However, after the implementation of the learning models, the posttest scores in both classes increased. The experimental class achieved an average score of 83.63, which was higher than the control class with an average score of 77.00. Agnafia (2019) similarly noted that low critical thinking skills are influenced by students' tendency to memorize rather than reason, limited conceptual mastery, insufficient practice in higher-order thinking, and restricted learning time.

In addition, instructional strategies also contribute to weak critical thinking development. Conventional learning models centered on one-way knowledge transfer often reduce student participation and opportunities for analysis, evaluation, and reflection. As reported by Kusumawati et al. (2022), teacher-centered instruction tends to hinder students from reaching expected learning outcomes because critical thinking is not explicitly trained. This argument is reinforced by recent international evidence showing that passive instruction produces significantly lower gains in reasoning than inquiry-based or problem-centered approaches in science education.

One promising effort to improve conceptual understanding and critical thinking is the implementation of student-centered learning models. Previous studies by Nurbaya (2021), Sundari & Sartiky (2021) found that PBL can improve conceptual understanding and thinking ability. Likewise, Haryanti & Febrianto (2017) and Hamimi et al. (2024) reported that PBL strengthens critical thinking because it emphasizes reasoning processes and meaningful learning experiences. A summary of students' critical thinking skills results for each indicator is presented in Table 10.

Table 10. Students' Critical Thinking Skills Results by Indicator

Indicator	**Experiment class**		**Control class**	
	Pretest	**Posttest**	**Pretest**	**Posttest**
Providing Simple Explanation	44	95	38	88
Building Basic Skills	6	56	4	34
Drawing Conclusions	18	86	30	86
Giving Further Explanation	20	88	18	82
Managing Strategies and Tactics	33	95	28	91

Based on Table 10, all indicators of critical thinking skills showed improvement in both classes. However, the improvement in the experimental class was generally higher than in the control class. For the indicator of providing simple explanations, the increase in the experimental class was 51 points, while the control class increased by 50 points. The indicator of building basic skills increased by 50 points in the experimental class and 30 points in the control class. The inference indicator showed an increase of 68 points in the experimental class and 56 points in the control class. Furthermore, the indicator of providing further explanations increased by 68 points in the experimental class and 64 points in the control class. Finally, for the indicator of setting strategies and tactics, the increase was 62 points in the experimental class and 63 points in the control class. Although the differences in improvement for some indicators were not very large, overall, the experimental class demonstrated more consistent and significant improvement than the control class. The improvement in critical thinking skills in the experimental and control class can be seen in Figure 2 and 3.

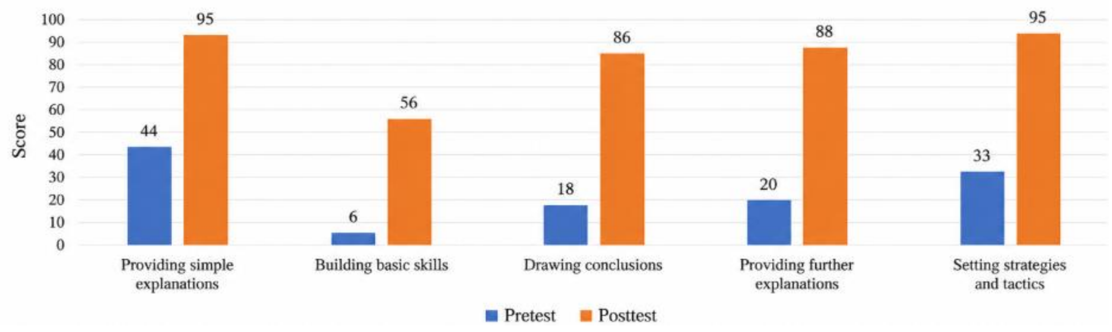

Fig.2. Pretest and posttest score of the experimental class

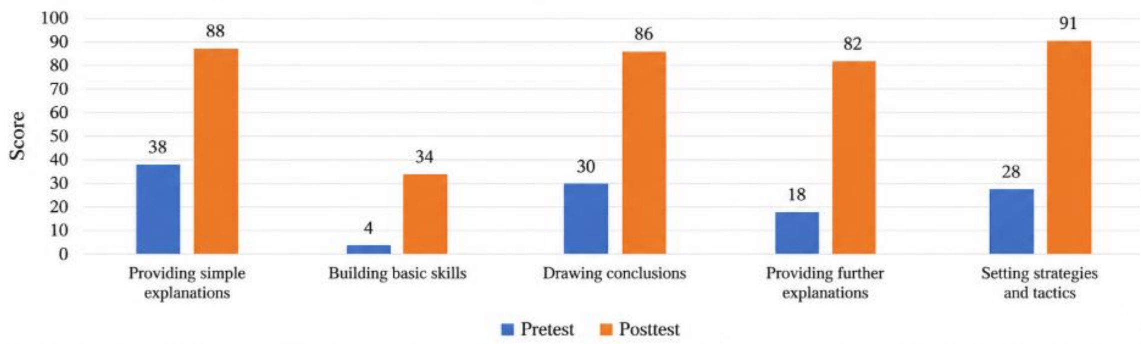

Fig.3. Pretest and posttest score of the control class

Based on the results presented in the graph, each indicator of critical thinking skills increased after the learning intervention in both classes. However, the improvement in the experimental class was generally higher than that in the control class. This indicates that the learning model used contributed differently to the development of each aspect of students' critical thinking skills.

The indicator of *providing simple explanations* improved more in the experimental class. This may be because PBL encourages students to discuss problems, express opinions, and explain ideas logically in groups. Structured discussion activities have been shown to improve students' ability to communicate explanations clearly (Alfian et al., 2023; Dwijayanti et al., 2025). In contrast, Discovery Learning focuses more on concept discovery, which may be challenging for students who still have difficulty identifying the main concept (Paramita et al., 2023).

The indicator of *building basic skills* showed the lowest improvement in both classes. Many students still experienced difficulty selecting formulas and applying heat equations correctly. Even so, the experimental class achieved better gains than the control class. This suggests that contextual problem solving in PBL helps students connect formulas with real situations, leading to better conceptual understanding than routine procedural exercises.

The indicator of *drawing conclusions* increased substantially, especially in the experimental class. PBL requires students to analyze information, evaluate evidence, and formulate conclusions through discussion and presentation. Previous studies also reported that PBL is more effective than Discovery Learning in strengthening critical thinking and inference skills (Hamij et al., 2020; Awaliyah et al., 2024).

Both classes improved in the indicator of *providing further explanations*, but the experimental class performed better. This may be due to collaborative discussions in PBL, where students exchange arguments, respond to peers' ideas, and refine their explanations (Najaah, 2021; Meulenbroeks, 2021). Such interaction supports deeper understanding and more comprehensive reasoning.

The indicator of *setting strategies and tactics* also showed higher gains in the experimental class. In PBL, students are required to plan solution steps, choose suitable methods, monitor progress, and revise strategies when necessary (Santos-Meneses et al., 2023; Muawanah, 2025). These processes train metacognitive skills, self-regulation, and strategic decision making.

The higher critical thinking performance in the experimental class can be attributed to the unique characteristics of Problem-Based Learning (PBL). In PBL, students are required to analyze authentic and often complex problems, identify relevant information, evaluate alternative solutions, and justify their decisions. These activities directly engage higher-order thinking processes and provide intensive opportunities for critical analysis and reasoning. In contrast, Discovery Learning develops critical thinking through an inductive process in which students observe phenomena, identify patterns, formulate hypotheses, and discover concepts independently. While both models promote active learning, Discovery Learning primarily focuses on concept acquisition, whereas PBL emphasizes problem analysis and solution development. Therefore, the problem-solving orientation of PBL may provide stronger support for the development of critical thinking skills than the concept-discovery orientation of Discovery Learning.

CONCLUSION AND SUGGESTION

Based on the results of the study and discussion, it can be concluded that Problem-Based Learning (PBL) had a significant effect on students' critical thinking skills. The result of the independent t-test showed that $t_{count}(1.800) > t_{table}(1.684)$ at the significance level of $\alpha = 0.05$, indicating that $H_a$was accepted and $H_0$was rejected. This means that students taught using PBL achieved better critical thinking performance than those taught using Discovery Learning. In addition, students' collaborative skills in both classes were categorized as very good, but the experimental class obtained a higher average percentage than the control class. This finding indicates that PBL was more effective in developing teamwork, communication, adaptability, mutual respect, and joint problem-solving skills. Overall, the study demonstrates that PBL provides dual benefits in physics learning by improving both critical thinking and collaborative skills, particularly on the topic of heat. Therefore, teachers are recommended to apply PBL more widely in physics instruction to support 21st-century competencies. Future research may examine the implementation of PBL in other physics topics, different education levels, or through integration with digital learning media.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this paper.

AUTHOR CONTRIBUTIONS STATEMENT

Conceptualization, M.S and Z: methodology, M.S: format analysis, M.S and S: investigation and data curation, Z: writing original draft preparation, M.S: writing review and editing, S: supervision and validation. All authors have read and agreed to the published version of the manuscript.

DECLARATION OF GENERATIVE AI SOURCES

During the preparation of this manuscript, the authors used Gemini AI for language improvement, grammar checking, and structure refinement. All generated content was carefully reviewed, revised, and verified by the authors, who take full responsibility for the final content of the manuscript.

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