JURNAL EDUSCIENCE (JES)
p-ISSN : 2303 - 355X | e-ISSN : 2685 - 2217
PUBLISHED BY : LPPM of UNIVERSITAS LABUHANBATU

# The Effect of PBL Integrated with PhET Virtual Laboratory and Self-Efficacy on Students' Science Problem-Solving Skills

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**ARTICLE INFO**

*Keywords:*
Problem-Based Learning (PBL)
PhET Virtual Laboratory
Self-Efficacy
Problem-Solving Skills

**ABSTRACT**

**Purpose –** Mastering critical thinking and problem-solving skills is the primary demand in 21st-century education. However, the evaluation results at SMPN 2 Rangkasbitung showed that students still experienced difficulties in these aspects, which were exacerbated by using conventional learning models. For this reason, this study aims to examine the effectiveness of the Problem-Based Learning (PBL) model integrated with the PhET virtual laboratory and the role of self-efficacy in improving students' problem-solving skills on energy material.

**Methodology –** This study used mixed methods with an explanatory sequential design. In the first stage, a quantitative approach was used to analyze the effect of PBL-PhET and self-efficacy on problem-solving ability, followed by a qualitative approach to explore the quantitative findings further. The sample consisted of 61 randomly selected grade VIII students. Data were collected through problem-solving tests, self-efficacy questionnaires, and lesson observations and analyzed using inferential statistical tests.

**Findings –** The results showed that applying PBL integrated with PhET significantly improved students' problem-solving ability ($\rho$ = 0.044). Self-efficacy also significantly influences students' problem-solving success ($\rho < 0.001$). However, the interaction between the learning model and self-efficacy did not show a significant effect ($\rho$ = 0.159). The qualitative findings supported the quantitative results by showing that students with high self-efficacy were more active and confident and demonstrated more effective problem-solving strategies during problem-based learning.

**Significance**—This research confirms the importance of integrating innovative approaches and psychological factors in science learning. Teachers and curriculum developers need to consider implementing PBL-PhET and strengthening self-efficacy as effective learning strategies relevant to the demands of the times.

Received 14 January 2025; Received in revised form 22 January 2025; Accepted 12 June 2025
Jurnal Eduscience (JES) Volume 12 No. 3 (2025)
Available online xx June 2025

## INTRODUCTION

The 21st century has brought significant changes in human life, including education (Kay & Greenhill, 2011; Voogt & Pareja, 2012; Nulhakim et al., 2019). The rapid development of information and communication technology demands a transformation in the teaching-learning process, where education no longer merely emphasizes content mastery but also critical thinking skills, problem-solving, creativity, and collaboration (González et al., 2020; Trilling & Fadel, 2009; Mariano & Chiappe, 2021). However, the evaluation results at SMPN 2 Rangkasbitung and the Minimum Competency Assessment (AKM) data in 2024 showed that students still struggled with critical thinking and solving complex problems. This is in line with the PISA report, which ranks Indonesia in the bottom 12 in maths and science globally (OECD, 2023), reinforcing the urgency of the need for improved learning. One of the contributing factors is the dominance of conventional learning that is teacher-centered, lacks practice, and does not encourage active student participation, thus inhibiting the development of problem-solving skills as well as student motivation and confidence (Djamarah, 2016; Serin, 2018; Gozali et al., 2022).

In this context, innovative approaches such as Problem-Based Learning (PBL) combined with PhET virtual labs are important to explore (Maulana et al., 2022). The PBL model allows students to actively solve meaningful contextual problems, while PhET helps visualize abstract science concepts realistically (Harun et al., 2012; Aziza, 2020; Bogar et al., 2023). In addition, self-efficacy or student confidence in completing tasks significantly supports learning success, including problem-solving (Bandura et al., 1999; Cassidy, 2015). Problem-solving skills associated with creativity, risk-taking, and exploration of new ideas are in high demand in today's workforce, where 85% of employers seek individuals with these skills (NACE, 2023; Sari, 2016; Suparyati & Habsya, 2024). Therefore, the development of these abilities should be prioritized in 21st-century education, taking into account aspects of creativity (Amran et al., 2019), social-emotional learning (Maksum et al., 2021), and metacognition (Utami et al., 2023).

One of the challenges in science learning is teaching the concept of energy, which is abstract and fundamental but important in understanding natural phenomena (Bussotti, 2023; Darman et al., 2019). Many students have difficulty understanding this concept, especially the principle of energy transfer (Kaniawati & Suhendi, 2014), so an approach that links concepts to real life and makes use of instructional tools such as PhET to visualize them effectively is needed (Linn et al., 2010; Apriani et al., 2021). However, conventional learning, still dominant in SMPN 2 Rangkasbitung, often does not accommodate this approach due to the limited laboratory facilities and the lack of variety in teaching methods (Indrasvari et al., 2021). The results of observations and interviews with students show that learning is still monotonous and teacher-centered and makes students passive and less motivated (Bawamenewi et al., 2024; Gozali et al., 2022; Chan et al., 2023).

PBL is a solution where students are grouped into small teams and faced with contextual problems from the beginning of learning to trigger active participation (Arends, 2012; Mufidah et al., 2020). With this approach, students are invited to undergo the stages of the scientific method, such as problem identification, information gathering, hypothesis testing, and solution presentation, which trains critical thinking skills and mindset restructuring (Setyawan & Koeswanti, 2021; Zubaidah, 2018). The role of technology such as PhET in this process is increasingly important as it allows students to conduct experiments virtually, change variables, observe results, and gain better conceptual understanding without the limitations of physical facilities (Khoiriyah et al., 2015; Cahyadi, 2019).

Based on this background, this study aimed to analyze the effect of the Problem-Based Learning (PBL) learning model combined with the PhET virtual laboratory and self-efficacy on the problem-solving ability of SMPN 2 Rangkasbitung students. This research is important because there are still limited studies that specifically explore the integration between PBL models, learning technologies such as PhET, and psychological factors such as self-efficacy in science education at the junior high school level. The results of this study are expected to provide theoretical contributions in developing 21st-century learning literature and practical advice for teachers and curriculum developers in designing effective learning strategies oriented toward 21st-century skills.

## METHODOLOGY

### Research Design

This study used a pretest-posttest control group design, which belongs to the quasi-experimental approach. This design involves experimental and control groups, each given a pretest before treatment and a posttest afterward. The experimental group received learning with the Problem-Based Learning (PBL) model integrated with Virtual Laboratory (PhET), while the control group only used the PBL model. This design was chosen because it can objectively identify cause-and-effect relationships by comparing pretest and posttest scores. This selection refers to the principle of Campbell and Stanley (1963), which emphasizes the importance of control and experimental groups in evaluating the effectiveness of treatment. The placement of students in groups was not done randomly due to the limitations of the pre-formed classroom context. Therefore, pre-existing groups were used, as is standard practice in quasi-experiments in school settings. To maintain internal validity, initial equivalence between the groups was tested through pretest results before the intervention was applied.

### Participants

The population in this study included all grade VIII students at SMP Negeri 2 Rangkasbitung in the even semester of the 2024/2025 academic year, with a total of 320 students. This population was relatively homogeneous regarding academic grades because all students were at the same grade level and followed a uniform curriculum and evaluation system. The research sample comprised 61 students selected through the Simple Random Sampling technique, part of the Probability Sampling approach. This method provides an equal opportunity for each member of the population to be selected as the research sample. Sample selection is based on calculations with a 5% margin of error and a 95% confidence level so that the number of samples obtained can optimally represent the population. The samples were then divided into two groups, namely the experimental group that received the Problem-Based Learning (PBL) learning model integrated with Virtual Laboratory (PhET) and the control group that received the Problem-Based Learning (PBL) learning model. This research will be conducted in the even semester of the 2024/2025 academic year, from February to March 2025.

### Data Collection

This study collected data through various techniques to measure students' problem-solving skills and self-efficacy in Problem-Based Learning (PBL) based learning integrated with Virtual Laboratory (PhET). The main instruments used include tests, questionnaires, observations, and interviews. Tests were used to evaluate students' problem-solving skills before and after the learning intervention, beginning with a pretest in both groups to measure the initial level and ending with a posttest to assess the changes that occurred. The researcher designed the test based on the indicators of problem-solving skills, validated by two expert validators (lecturer and teacher), and empirically tested on another class. The validity test results showed that the calculated r value was greater than the r table (0.349) and Cronbach's alpha value of 0.804, which showed very high reliability. To measure self-efficacy, a questionnaire based on the General Self-Efficacy (GSE) scale consisting of 35 statement items was used, for example, 'I am not sure I can solve different science problems', with four answer options: SS (strongly agree), S (agree), TS (disagree), and STS (strongly disagree). This questionnaire was adapted from previous research, validated by two experts, and empirically tested with the results of r count > r table (0.349) and Cronbach's alpha of 0.904, which indicates very high reliability. In addition, observations were made during the learning process to identify class dynamics, student responses, and the effectiveness of PhET-assisted PBL implementation. Semi-structured interviews were also conducted to explore students' experiences and understand the impact of learning on their problem-solving skills and self-efficacy. Combining these instruments, the study captured the quantitative and qualitative dimensions of the learning intervention outcomes.

## Data Analysis

The quantitative data analysis of the pretest and posttest results was carried out using descriptive analysis to obtain an overview of the collected data. The data obtained was tabulated based on the measured variables, arranged in a frequency distribution table, and analyzed by calculating each group's mean, median, and standard deviation of the cognitive learning scores. Furthermore, a hypothesis test was carried out to determine whether the hypothesis in this study was accepted or rejected. A variance difference test (two-way ANOVA) was used, and a post hoc test was continued to analyze significant differences between groups. Effectiveness analysis was conducted using ANOVA and post hoc tests with the help of SPSS (Statistical Package for the Social Sciences) software.

For qualitative data analysis, the results of learning process activities in the experimental class were analyzed using the student activity assessment interval formula:

$$K = \frac{\textit{highest overall score} - \textit{number of observation items}}{\textit{the highest score for each observation item}}$$

Based on the calculation results, a frequency distribution graph was created to illustrate the predicate of student learning activities. In addition, data from student interviews in the experimental class were compiled in transcript form and analyzed using NVivo 12 software. Features in NVivo, such as Word Frequency Query and Project Map, were used to identify patterns in the text and evaluate various aspects of learning. This evaluation includes analyzing student learning outcomes, their attitudes toward questions asked, and strategies used to overcome difficulties during the learning process.

## FINDINGS

### Analysis of Science Problem-Solving Skill Test Data

The hypothesis test was carried out by comparing the posttest results between two groups of eighth-grade students: the control group that participated in Problem-Based Learning (PBL) and the experimental group that participated in PBL integrated with the Virtual Laboratory (PhET).

**Table 1.** Description of Posttest Data on Problem-Solving Skills in Science Based on Learning Gro

| Class | N | Min | Max | Mean | Std. Dev | Variance |
|---|---|---|---|---|---|---|
| Experiments | 31 | 60 | 88 | 72,74 | 6,787 | 46,065 |
| Control | 30 | 60 | 80 | 69,90 | 4,773 | 22,783 |

Based on Table 1, the average posttest score of the experimental group was 72.74, while that of the control group was 69.90. This indicates a significant difference in the two groups' ability to solve science problems.

**Table 2.** Posttest Data Description of Problem-Solving Ability in Science Based on Learning Group and Self-Efficacy Level

| Model Pembelajaran | Level of Self-Efficacy | N | Min | Max | Mean | Std. Dev | Variance |
|---|---|---|---|---|---|---|---|
| Integrated PBL Virtual Laboratory (Experiments) | high | 5 | 70 | 88 | 83,60 | 3,507 | 65,700 |
| | medium | 22 | 60 | 78 | 71,64 | 4,776 | 20,874 |
| | low | 4 | 63 | 68 | 65,25 | 2,062 | 4,250 |
| PBL (Control) | high | 4 | 73 | 80 | 76,50 | 3,109 | 12,667 |
| | medium | 22 | 60 | 78 | 69,45 | 4,126 | 19,846 |
| | low | 4 | 63 | 70 | 65,75 | 2,986 | 8,917 |

Based on Table 2, in the high self-efficacy category, the experimental group had a higher average score (83.60) than the control group (76.50). This shows that learning with the Problem-Based Learning (PBL) model integrated with a virtual laboratory (PhET) provides greater opportunities for improved learning outcomes for students with high self-efficacy. In the moderate self-efficacy category, the experimental group also showed a higher average score (71.64) than the control group (69.45). However, the difference was less significant than in the high self-efficacy category. This indicates that although the PhET-assisted PBL model still positively impacts learning outcomes, its effect is more limited for students with moderate self-efficacy. Meanwhile, in the low self-efficacy category, the average scores of the experimental group (65.25) and the control group (65.75) are almost the same, which shows that this learning model does not significantly impact students with low self-efficacy.

**Table 3.** Two-Way Anova Test Results

| Source | Type III Sum of Squares | df | Mean Square | F | Sig |
|---|---|---|---|---|---|
| Class | 74,089 | 1 | 74,089 | 4,270 | 0,044 |
| Self_Efficacy | 974,672 | 2 | 487,336 | 28,089 | <0,001 |
| Class*Self_Efficacy | 66,102 | 2 | 33,051 | 1,905 | 0,159 |

Based on Table 3, the results of the two-way ANOVA test show that the significance value in the Class column is 0.044, which means ($Sig.$) < 0.05 so that $H0$ is rejected. This indicates a significant difference in the average posttest scores of students based on learning factors. Thus, there is a difference in science problem-solving ability between students who take Problem-Based Learning (PBL) integrated with a virtual laboratory (PhET) and students who take the PBL learning model without PhET integration.

**Analysis of Science Problem Solving Skill Test Data Given Self-Efficacy**

**Table 4.** Scheffe Test Results

| *Self-Efficacy* | | Mean Difference | Std. Error | Sig. | 95% Confidence Interval | |
|---|---|---|---|---|---|---|
| | | | | | Lower Bound | Upper Bound |
| High | Medium | 9,90 | 1,524 | <0,001 | 6,07 | 13,73 |
| | Low | 14,94 | 2,024 | <0.001 | 9,85 | 20,04 |
| Medium | High | -9,90 | 1,524 | <0,001 | -13,73 | -6,07 |
| | Low | 5,05 | 1,601 | 0,010 | 1,02 | 9,07 |
| Low | High | -14,94 | 2,024 | <0,001 | -20,04 | -9,85 |
| | Medium | -5,05 | 1,601 | 0,010 | -9,07 | -1,02 |

Based on Table 3, the results of the two-way ANOVA test show that the significance value for the self-efficacy category is $Sig$ < 0.001, which means $Sig.$ < 0.05 so that $H0$ is rejected. This shows a significant difference in the average between the self-efficacy categories and students' problem-solving abilities. The results were further analyzed with the Scheffe test in Table 4, which shows that A significant difference was found between students with high and medium self-efficacy ($Sig$ < 0.001). The average posttest score of students with high self-efficacy (83.60) was higher than that of students with medium self-efficacy (71.64), indicating that the higher the self-efficacy, the better the ability to solve science and mathematics problems. Students with medium and low self-efficacy also showed a significant difference ($Sig$ = 0.010). The average posttest of students with medium self-efficacy (71.64) was higher than that of low self-efficacy (65.25), indicating that higher self-efficacy contributes to improved problem-solving ability. A significant difference also occurred between low and high self-efficacy ($Sig$ < 0.001). The average posttest score of students with high self-efficacy (83.60) was much higher than that of students with low self-efficacy (65.25), confirming that students with high self-efficacy have better science problem-solving abilities. Overall, these results confirm that self-efficacy significantly affects science problem-solving abilities, where the higher the students' self-efficacy, the better their learning outcomes.

**Data Analysis of the Interaction of Learning Model and Self-Efficacy on Science Problem Solving Skill**

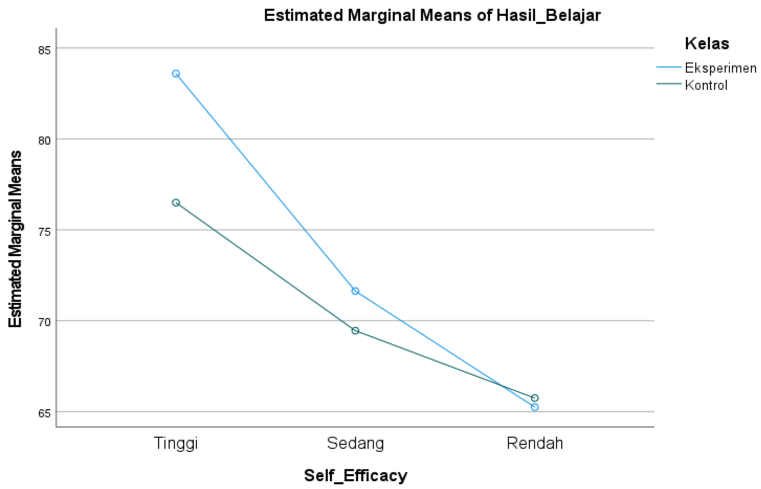


**Figure 1.** Interaction between Learning Model and Self-Efficacy on Science Problem-Solving Skills

Based on Table 3, the results of the two-way ANOVA test show that the significance value in the Class*Self-Efficacy column is 0.159. Since the significance value (Sig.) > 0.05, $H0$ is accepted, there is no significant difference between the learning factors and the level of self-efficacy on the posttest results of science problem-solving skills. However, based on Figure 1, this study shows that the Problem-Based Learning (PBL) method integrated with the Virtual Laboratory (PhET) is more effective for students with high and medium self-efficacy than the control group. On the other hand, this method does not significantly differ from the PBL learning method without virtual laboratory integration for students with low self-efficacy. These findings indicate that the effectiveness of the PBL model integrated with the Virtual Laboratory (PhET) tends to be more optimal for students with higher confidence in solving problems.

**Data Analysis of Student Activity Observation Results**

**Table 5**. Data on Student Activity Observation Results

| Respondent | Total Score of Observation Results | Respondent | Total Score of Observation Results | Respondent | Total Score of Observation Results |
|---|---|---|---|---|---|
| E01 | 21 | E11 | 20 | E21 | 20 |
| E02 | 28 | E12 | 22 | E22 | 13 |
| E03 | 27 | E13 | 27 | E23 | 17 |
| E04 | 20 | E14 | 18 | E24 | 24 |
| E05 | 24 | E15 | 20 | E25 | 13 |
| E06 | 18 | E16 | 22 | E26 | 21 |
| E07 | 19 | E17 | 20 | E27 | 20 |
| E08 | 14 | E18 | 19 | E28 | 14 |
| E09 | 21 | E19 | 26 | E29 | 21 |
| E10 | 17 | E20 | 26 | E30 | 22 |
| | | | | E31 | 21 |

Table 5 shows the results of observations of student activities carried out by the researcher directly as an observer during the learning process using the Problem-Based Learning (PBL) model integrated with a virtual laboratory (PhET). The following intervals were obtained using the interval formula for assessing student activity.

**Table 6**. Student Learning Activity Assessment Intervals

| Interval | Predicate |
|---|---|
| 8 – 13 | Less |
| 14 – 19 | Enough |
| 20 – 25 | Good |
| 26 – 32 | Very Good |

Based on the data in Table 6, a frequency distribution graph of the results of assessing student learning activities according to the predicate was created.

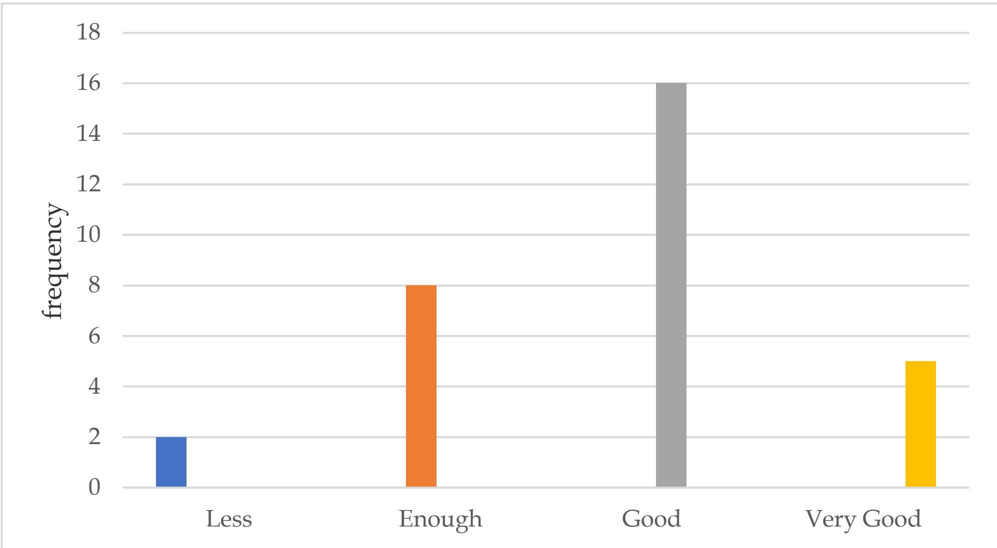


**Figure 2.** Frequency Distribution Graph of Student Learning Activity Assessment Results by Predicate

Based on Figure 2, the frequency distribution of the predicate of the results of student learning activities in solving science problems shows that most students obtained a good predicate, with the highest number being 16 students. This indicates that most students can understand the material well. The Fair category comes in second place with eight students, which indicates that they have sufficient understanding, although it still needs improvement. Meanwhile, only five students were in the Very Good category, indicating that only a few students reached an excellent level of understanding. On the other hand, the Poor category had the least number, only two students, indicating that most students already had an adequate understanding of the material.

**Data Analysis of Student Interview Results**


**Figure 3**. Words that Often Appear at Low, Medium, and High Levels of Self-Efficacy

Based on Figure 3, an analysis of words frequently appearing in the conversations of students with low levels of self-efficacy shows that the word 'connecting' dominates, followed by 'reading,' 'high,' 'sequential,' and 'factor.' The words 'connecting' and 'reading' indicate that students in this category can relate various information and concepts well, understand questions superficially, and try to relate relevant concepts to gain a deeper understanding. Meanwhile, students with moderate self-efficacy use the words 'reading,' 'checking,' 'determining,' 'analyzing,' and 'calculating' more frequently. The dominance of the words 'read' and 'check' indicates that they are more thorough in understanding questions before answering and tend to double-check their answers. In addition, using the words 'calculate,' 'determine,' and 'analyze' indicates that students are beginning to apply more mature strategies in solving problems by systematically connecting information.

Meanwhile, students with high levels of self-efficacy also showed a similar pattern with a predominance of the words 'connecting,' 'reading,' 'high,' 'sequential,' and 'factors.' This shows that they can relate various concepts well and are more critical in solving problems, as reflected in the words 'analyze,' 'examine,' and 'calculate.' Thus, the higher the level of student self-efficacy, the better they are at relating concepts, analyzing problems, and checking the process of solving problems.

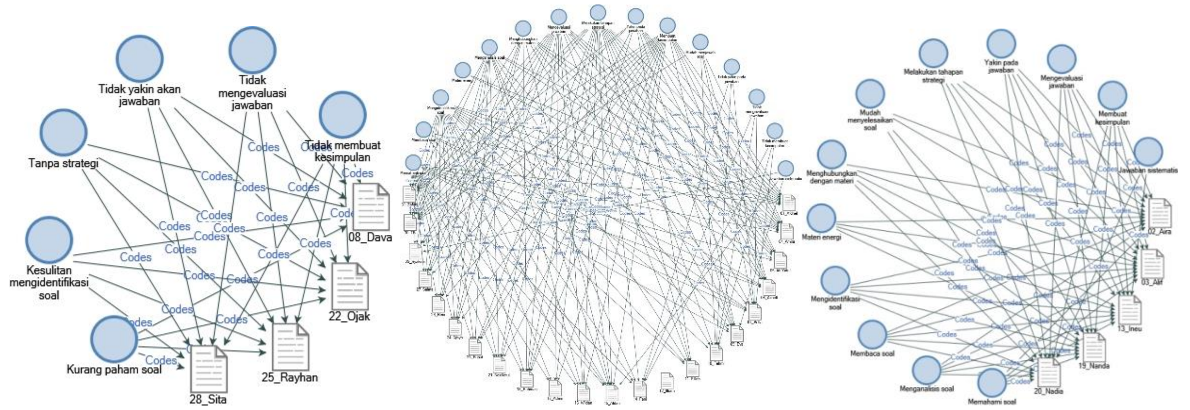


**Figure 4**. Project Map Characteristics of Students in Solving Problems at Low, Medium, and High Levels of Self-Efficacy

Based on Figure 4, the Project Map of Student Characteristics in Solving Problems shows differences in student characteristics based on their level of self-efficacy. Students with low self-efficacy tend to have difficulty identifying and understanding questions, which prevents them from finding the right solution. They also lack a systematic solution strategy, so they often make mistakes in answering. In addition, the uncertainty in their answers reflects a lack of understanding of the concept or a lack of practice in solving problems with the correct approach. They also tend not to evaluate the answers and do not draw conclusions from the solution process.

Meanwhile, students with moderate self-efficacy can better analyze questions, relate information to the material, evaluate answers, and apply solution strategies. They are more systematic and can conclude, although they still face obstacles such as a lack of confidence in their answers, not always conducting a thorough evaluation, and sometimes having difficulty identifying important information in the question. On the other hand, students with high self-efficacy show more mature abilities in solving questions. They can identify questions well, understand the information, and conduct in-depth analysis. In addition, they can relate questions to relevant material and apply more systematic completion strategies. Another prominent characteristic of this group is their high confidence level in answering questions, with more structured thinking patterns and more systematic answers than other groups. This shows that the higher the student's self-efficacy, the better their ability to understand, analyze, and effectively solve problems.

## DISCUSSION

The results showed that the Problem-Based Learning (PBL) learning model integrated with the PhET virtual laboratory significantly improved students' problem-solving skills in science learning compared to the PBL model without PhET integration. Integrating interactive simulations in PhET helps students understand abstract concepts more concretely, hone analytical skills, and connect theory with practice. The significant increase in students' problem-solving skills in the experimental class compared to the control class is reinforced by the findings of Alfiah and Dwikoranto (2022), Yusra et al. (2025), and Harjono et al. (2024), which showed that problem-based learning supported by virtual laboratories consistently improved concept understanding and higher-order thinking skills. The advantage of this model lies in its ability to motivate students to think critically, analyze, design solutions, and evaluate through virtual experiments. Research by Jamila et al. (2023) also showed that the intuitive PhET interface increased student engagement and strengthened their understanding of science concepts.

Self-efficacy was also found to play an important role in influencing problem-solving ability. Students with high levels of self-efficacy performed better, as they were more confident, persistent, and able to use problem-solving strategies effectively (Nur et al., 2024). This finding is in line with Bandura's motivation theory, which emphasizes the role of self-efficacy in students' self-regulation and goal orientation. Individuals with high self-efficacy are more likely to set challenging goals and persist in facing difficulties, whereas those with low self-efficacy give up easily (Safitri, 2024; Safitri et al., 2022, 2024; Safitri & Ansyari, 2024). During the learning process, students with high self-efficacy were more active in asking questions, discussing, and solving problems, especially in the experimental group. Meanwhile, students with low self-efficacy appeared passive and less confident, especially when facing challenging material, as Walidaina and Hidayat (2024) reported.

The hypothesis testing results showed no significant interaction between the learning model and self-efficacy level on problem-solving ability. This indicates that the two variables contribute independently. One possible cause of not finding an interaction is the strong influence of each variable individually so that they do not strengthen or weaken each other in combination. This finding is in line with the research of Farera et al. (2020), which also showed an independent contribution pattern between the learning model and self-efficacy.

Although the findings show strong effectiveness, this study has some limitations. One of the main limitations is the students' ability to use the virtual laboratory. Some students had difficulty understanding the PhET simulation interface, so exceptional guidance or training is required to ensure optimal utilization. This could affect the effectiveness of the learning process, especially for students who are less familiar with the use of technology. Therefore, the generalization of the results of this study needs to be done with caution, especially in educational environments with limited access or low digital literacy.

The practical implication of this finding is the importance of teacher training in integrating virtual laboratories such as PhET into the curriculum on an ongoing basis. Teachers must be competent in using interactive media and designing in-depth problem-based learning. In addition, strengthening students' self-efficacy through learning strategies that support self-confidence and learning autonomy must be a concern in curriculum development. The results of this study also support the importance of integrating social-cognitive approaches in the design of technology-based learning models, which not only target academic achievement but also motivational and psychological aspects of students.

## CONCLUSION

The results of this study revealed that the Problem-Based Learning (PBL) learning model integrated with a virtual laboratory (PhET) significantly improved students' problem-solving skills in science learning, compared to the PBL model without virtual laboratory integration. In addition, self-efficacy also affects problem-solving ability, where students with high self-efficacy levels perform better than students with moderate or low self-efficacy. However, there was no interaction between the learning model and self-efficacy level on problem-solving ability, indicating that both variables contributed independently.

Integrating PhET into the PBL model improved students' problem-solving skills and self-efficacy. The findings have practical implications for educators, namely that this model can be implemented in regular science classes to encourage students' active participation and strengthen conceptual understanding through interactive simulations that are easily accessible. For optimal implementation, teachers need to receive training in the use of PhET as well as in designing contextualized problem-based learning activities. For future research, it is recommended to test the effectiveness of this model in subjects other than science, as well as explore its effects on students with more diverse characteristics, such as differences in learning styles, initial abilities, or levels of digital literacy, in order to expand the generalisability of the research results.

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