Lensa: Jurnal Kependidikan Fisika
Penerbit: Universitas Pendidikan Mandalika
https://e-journal.undikma.ac.id/index.php/Lensa/index

June 2026, Vol. 14, No. 1
e-ISSN: 2686-0937
pp. 137–156

The Effect of PhET-Assisted Problem-Based Learning on Students' Problem-Solving Ability in Momentum and Impulse

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Abstract

This study examined the effect of PhET-assisted problem-based learning on students' problem-solving ability in momentum and impulse. A quasi-experimental method with a pretest-posttest control group design was used. The participants were 57 eleventh-grade students at SMAN 1 Lembar, consisting of 29 students in the experimental class and 28 students in the control class. The experimental class learned through problem-based learning assisted by PhET simulations, whereas the control class received conventional instruction. Data were collected using six validated and reliable essay items measuring four indicators of problem-solving ability: recognizing the problem, planning a strategy, applying the strategy, and evaluating the solution. The results showed that the experimental class achieved a higher posttest mean score (86.11) than the control class (78.17). The independent-samples t-test indicated a significant difference between groups, $t_{(55)} = 2.13$, $p = .038$, confirming the effect of the intervention. The N-Gain score of the experimental class was 0.81, categorized as high, while the control class obtained 0.70, categorized as medium. Indicator-based analysis showed that the highest improvement occurred in planning a strategy, whereas evaluating the solution remained the weakest indicator. These findings suggest that PhET-assisted problem-based learning effectively improves students' problem-solving ability in momentum and impulse.

Keywords: PhET simulation; Problem-based learning; Problem-solving ability; Momentum and impulse; Physics education

How to cite: Kurniawati, N. R., Verawati, N. N. S. P., & Harjono, A. (2026). The Effect of PhET-Assisted Problem-Based Learning on Students' Problem-Solving Ability in Momentum and Impulse. *Lensa: Jurnal Kependidikan Fisika*, *14*(1), 137–156. https://doi.org/10.33394/j-lkf.v14i1.20285

INTRODUCTION

Physics learning requires students to develop not only conceptual understanding, but also the ability to apply concepts, principles, and mathematical representations to solve problems related to real physical phenomena. In physics classrooms, students are expected to identify relevant information, select appropriate principles, construct mathematical models, perform calculations, and evaluate whether their solutions are physically meaningful. Therefore, problem-solving ability is widely regarded as one of the central competencies in physics education, particularly because physics problems often require students to integrate conceptual reasoning, procedural knowledge, and representational skills. Without adequate problem-solving ability, students may memorize formulas but fail to understand when and how those formulas should be applied in a specific physical situation.

Momentum and impulse are important topics in senior high school physics because they connect force, time interval, mass, velocity, changes in momentum, collision events, and conservation principles. These concepts are closely related to daily phenomena such as vehicle collisions, ball games, and object impacts, but they are not always easy for students to understand. Students often experience difficulties when they are asked to interpret a physical situation, identify known and unknown variables, choose the correct equation, and evaluate the reasonableness of their answers. International studies have also shown that impulse and momentum are challenging domains in physics learning, especially because students frequently hold misconceptions and struggle to connect conceptual understanding with problem-solving procedures (Fang & Guo, 2022; Rytting et al., 2019). Therefore, the teaching of momentum and impulse should provide learning experiences that help students visualize physical events, investigate relationships among variables, and practice systematic problem-solving processes.

The need to strengthen students' problem-solving ability is also aligned with current educational reforms that emphasize active learning, critical thinking, collaboration, and digital literacy. In the Indonesian context, the Merdeka Curriculum encourages learner-centered instruction, student independence, active participation, and the development of students' potential through meaningful learning experiences (Nursafinah et al., 2024; Salamah et al., 2024). This curriculum orientation requires teachers to select instructional models that allow students to construct knowledge actively rather than merely receive information from the teacher. In physics education, this shift is particularly important because many physics concepts are abstract, dynamic, and difficult to understand through verbal explanation alone. Learning should therefore involve inquiry, exploration, discussion, and reflection so that students can develop deeper conceptual understanding and stronger problem-solving skills.

One instructional model that is consistent with these demands is problem-based learning. Problem-based learning is a student-centered model that uses contextual problems as the starting point for learning. Through problem-based learning, students are encouraged to understand a problem, identify relevant information, formulate possible strategies, conduct investigations, discuss solutions, present findings, and evaluate the problem-solving process (Susilawati & Doyan, 2023). The syntax of problem-based learning, which includes orienting students to problems, organizing students for learning, guiding individual or group investigations, developing and presenting work, and analyzing or evaluating the problem-solving process, is closely related to the stages of physics problem solving. This model gives students opportunities to engage in collaborative reasoning, develop critical thinking, and apply physics concepts in meaningful contexts. Previous studies have reported that problem-based learning can improve students' physics problem-solving ability because it actively involves students in analysis, discussion, collaboration, and communication (Aulia et al., 2022; Firmansyah et al., 2022).

However, problem-based learning may not be optimally implemented if it is not supported by appropriate instructional media. Physics learning often involves phenomena that are difficult to observe directly in the classroom, especially when schools have limited laboratory facilities. In such contexts, students may have limited opportunities to conduct experiments, manipulate variables, and observe the effects of physical interactions. This condition may lead teachers to rely on conventional instruction, such as lectures and question-answer sessions, which may not sufficiently support students' conceptual visualization and problem-solving practice. Ajizah et al. (2022) argued that problem-based learning can become less effective when students are not interested in the problems presented, making the selection of appropriate learning media an important factor in supporting the success of the learning process. Therefore, interactive media are needed to help students visualize abstract physics concepts and engage more actively in problem-solving activities.

Physics Education Technology, commonly known as PhET, is one of the interactive media that can support physics learning. PhET simulations provide virtual environments where students can manipulate variables, observe outcomes, and connect mathematical representations with visual phenomena. These simulations are accessible and useful for helping students understand abstract concepts through interactive exploration. Verawati et al. (2022) stated that PhET can be used as an alternative to laboratory experiments because it allows students to conduct virtual simulations. Segening et al. (2022) also explained that PhET can provide concrete representations of scientific phenomena and make complex concepts easier to understand. In international literature, PhET simulations have been recognized as interactive learning tools that support visualization, experimentation, and conceptual clarification in physics learning (Dap-og & Orongan, 2022; Fang & Guo, 2022; Rytting et al., 2019). These features are particularly relevant to momentum and impulse because students can observe collision events, changes in velocity, and the relationship between mass, velocity, and momentum through dynamic visual representations.

The integration of problem-based learning and PhET simulations is theoretically and pedagogically relevant. Problem-based learning provides the instructional structure for engaging students in solving contextual problems, while PhET provides visual and interactive support for investigating physical phenomena. Through this integration, students can explore a problem, conduct virtual investigations, collect and analyze data, discuss possible solutions, and evaluate their answers. This combination can help bridge conceptual understanding and procedural problem solving because students are not only asked to apply formulas, but also to observe how physical variables interact in a simulated environment. Gunawan et al. (2021) indicated that PBL assisted by PhET simulations can support higher-order thinking, while Liana et al. (2023) found that PhET-assisted problem-based learning improved students' problem-solving ability and mastery of physics concepts. Similarly, Julia et al. (2025) reported that the implementation of PBL with PhET simulations can support students' interest and collaboration, showing that this integration is consistent with contemporary science education priorities.

Empirical evidence from various educational contexts has shown positive effects of simulation-assisted and inquiry-oriented learning on physics outcomes. Fang and Guo (2022) found that computer simulation and animation can improve students' learning of impulse and momentum in particle dynamics. Rytting et al. (2019) reported that simulation-based laboratories can be effective in helping high school students learn physics concepts, although they also noted that students may still prefer hands-on laboratory experiences in some cases. Hidayatullah et al. (2021) showed that a conceptual change model assisted by PhET simulations can enhance students' critical thinking related to momentum and impulse concepts. Other studies also suggest that PhET-based interventions, when combined with inquiry or problem-based frameworks, tend to produce better outcomes than traditional instruction in terms of conceptual understanding, higher-order thinking, and problem-solving performance (Dap-og & Orongan, 2022; Gunawan et al., 2021; Liana et al., 2023; Syafriyanti, 2023). These findings provide strong support for the use of PhET-assisted problem-based learning in physics classrooms.

Nevertheless, the effectiveness of PhET-assisted learning should not be viewed simplistically. Some studies suggest that PhET simulations are not always superior to hands-on laboratories or conventional approaches for every learning outcome. Rytting et al. (2019), for example, found that PhET laboratories can be as effective as hands-on laboratories for learning physics concepts, while students' preferences may vary depending on the learning experience. This indicates that the impact of PhET-assisted learning depends on several factors, including the instructional model used, teacher guidance, the quality of scaffolding, students' prior knowledge, and the alignment between simulation activities and learning objectives. Therefore, research on PhET-assisted problem-based learning should not only examine whether students' scores increase, but also how different aspects of problem-solving ability develop during the learning process.

Many previous studies have examined the effect of problem-based learning, PhET simulations, or their integration on students' physics learning outcomes. However, most studies tend to report students' problem-solving ability as a general score. Such an approach is useful, but it may not fully explain students' performance across different stages of problem solving. In physics, problem solving involves several interrelated processes, including recognizing the problem, planning a strategy, applying the strategy, and evaluating the solution (Young & Freedman, 2012). Students may be able to identify known variables and apply equations correctly, but still fail to evaluate whether their final answer is conceptually reasonable or whether the unit is appropriate. This issue is important because successful physics problem solving does not end with obtaining a numerical answer; it also requires students to reflect on the meaning and validity of the solution.

The evaluating-solution stage deserves particular attention because it reflects students' conceptual and metacognitive awareness. In many physics classrooms, students tend to stop working once they obtain an answer, without checking the consistency of the result with the physical concept or the correctness of the unit. This weakness suggests that students' problem-solving ability may remain incomplete even when their calculation skills improve. Therefore, analyzing problem-solving ability by indicator can provide a more detailed understanding of the strengths and limitations of an instructional intervention. In the context of PhET-assisted problem-based learning, this analysis can reveal whether the intervention supports all stages of problem solving equally or whether some indicators, such as evaluating solutions, require more explicit instructional emphasis.

Preliminary observations at SMAN 1 Lembar showed that physics learning was still dominated by conventional instruction, while laboratory activities were rarely conducted due to limited practical equipment. The use of virtual laboratory media had also not been implemented in the learning process. As a result, students had limited opportunities to investigate physical phenomena through experiments or simulations. This situation may contribute to students' difficulties in understanding abstract physics concepts and solving problems systematically. Similar concerns have been raised in previous studies, which reported that students' low problem-solving ability can be related to difficulties in understanding concepts, interpreting word problems, identifying relevant information, and selecting appropriate equations (Hidayatulloh et al., 2020; Putri et al., 2024; Surur et al., 2022).

Study Purpose and Research Questions

Based on the theoretical and empirical considerations described above, this study aimed to examine the effect of PhET-assisted problem-based learning on students' problem-solving ability in the topic of momentum and impulse. The study focused on senior high school students and used four indicators of problem-solving ability adapted from Young and Freedman (2012): recognizing the problem, planning a strategy, applying the strategy, and evaluating the solution. By examining these indicators, this study sought to determine not only whether PhET-assisted problem-based learning improves students' overall problem-solving ability, but also how students' performance differs across specific stages of the problem-solving process.

The research questions addressed in this study are as follows:

1. Does PhET-assisted problem-based learning have a significant effect on students' problem-solving ability in momentum and impulse?
2. How does students' problem-solving ability differ between the experimental class taught using PhET-assisted problem-based learning and the control class taught using conventional instruction?
3. How does students' improvement differ across the four indicators of problem-solving ability, namely recognizing the problem, planning a strategy, applying the strategy, and evaluating the solution?

Novelty of the Study

The novelty of this study lies in its indicator-based analysis of students' physics problem-solving ability in the context of PhET-assisted problem-based learning. Previous studies have provided evidence that problem-based learning, PhET simulations, or their combination can improve students' conceptual understanding, learning outcomes, critical thinking, higher-order thinking, and general problem-solving ability in physics (Dap-og & Orongan, 2022; Fang & Guo, 2022; Gunawan et al., 2021; Hidayatullah et al., 2021; Liana et al., 2023; Rytting et al., 2019; Syafriyanti, 2023). However, many of these studies have primarily emphasized overall achievement or total problem-solving scores. Such findings are useful, but they do not provide sufficient information about which stages of students' problem solving are most affected by the intervention.

This study addresses that limitation by analyzing students' problem-solving ability through four specific indicators: recognizing the problem, planning a strategy, applying the strategy, and evaluating the solution. This approach allows a more detailed examination of the contribution of PhET-assisted problem-based learning to each stage of physics problem solving. The focus on momentum and impulse also strengthens the relevance of the study because this topic is conceptually demanding, mathematically structured, and closely related to physical phenomena that can be explored through simulation. Furthermore, the study highlights the evaluating-solution indicator as an important but often underdeveloped component of physics problem solving. In this way, the study contributes not only to evidence on the effectiveness of PhET-assisted problem-based learning, but also to a more diagnostic understanding of students' strengths and weaknesses in solving physics problems.

METHODS

Research Design

This study employed a quasi-experimental method with a pretest-posttest control group design. This design was used because the study involved two existing classroom groups, namely an experimental class and a control class. The experimental class was taught using PhET-assisted problem-based learning, while the control class was taught using conventional instruction. Before the treatment, both classes were given a pretest to determine their initial problem-solving ability in momentum and impulse. After the treatment, both classes were given a posttest to measure their problem-solving ability after the learning process. The research design is presented in Table 1.

Table 1. Research Design

Group	Pretest	Treatment	Posttest
Experimental	O_1	X	O_2
Control	O_3	C	O_4

Note. O_1 = pretest of the experimental class; O_2 = posttest of the experimental class; O_3 = pretest of the control class; O_4 = posttest of the control class; X = PhET-assisted problem-based learning; C = conventional instruction

As shown in Table 1, both the experimental and control classes were given a pretest before the learning treatment to identify their initial problem-solving ability in momentum and impulse. The experimental class then received instruction using PhET-assisted problem-based learning, while the control class received conventional instruction. After the treatment, both classes were given a posttest to measure their problem-solving ability after the learning process. The comparison between pretest and posttest scores was used to determine students' improvement, while the comparison between the experimental and control classes was used to examine the effect of PhET-assisted problem-based learning.

Participants and Research Setting

The study was conducted at SMAN 1 Lembar during the second semester of the 2024/2025 academic year. The population consisted of all Grade XI students at SMAN 1 Lembar, totaling 132 students distributed across four classes: XI-1, XI-2, XI-3, and XI-4. The sample was selected using cluster random sampling because the population was organized into intact classroom groups.

Based on the sampling process, class XI-4 was assigned as the experimental class, while class XI-3 was assigned as the control class. The final data analyzed in this study consisted of 57 students who completed both the pretest and posttest. The experimental class consisted of 29 students, while the control class consisted of 28 students.

Learning Treatment

The learning material used in this study was momentum and impulse. The topic included momentum, impulse, the relationship between impulse and change in momentum, the law of conservation of momentum, and collisions. Both the experimental and control classes studied the same topic within the same learning period.

In the experimental class, the learning process was carried out using PhET-assisted problem-based learning. The learning activities followed the syntax of problem-based learning, consisting of orienting students to the problem, organizing students for learning, guiding individual or group investigations, developing and presenting the results, and analyzing or evaluating the problem-solving process. PhET simulations were used during the investigation stage to help students visualize collision phenomena, manipulate variables, observe changes in motion, and connect the simulation results with the concepts of momentum and impulse.

In the control class, the same topic was taught using conventional instruction. The learning process was more teacher-centered and relied mainly on explanation, question-and-answer activities, and problem exercises. Unlike the experimental class, the control class did not use PhET simulations as part of the learning activities. The learning treatment in both classes is summarized in Table 2.

Table 2. Summary of Learning Treatment

Aspect	Experimental	Control
Instructional model	Problem-based learning assisted by PhET.	Conventional instruction.
Learning media	PhET simulation, worksheet, laptop, projector, and teaching materials.	Worksheet, textbook, projector, whiteboard, and teaching materials.
Main learning activity	Contextual problem orientation, group investigation using PhET, discussion, presentation, and evaluation.	Teacher explanation, question-and-answer activity, and problem exercises.
Student role	Actively investigated problems, explored simulations, discussed findings, and evaluated solutions.	Listened to explanations, answered questions, and completed exercises.
Teacher role	Facilitator and guide during problem investigation and solution evaluation.	Main source of explanation and learning direction.

Research Instrument

The main instrument used in this study was a problem-solving ability test in the form of six essay questions on momentum and impulse. Essay questions were used because they allowed students to show their reasoning and solution processes rather than merely selecting answers. The test was designed to measure four indicators of problem-solving ability adapted from Young and Freedman (2012): recognizing the problem, planning a strategy, applying the strategy, and evaluating the solution.

The first indicator, recognizing the problem, assessed students' ability to identify relevant information, list known quantities, and determine what was being asked in the problem. The second indicator, planning a strategy, assessed students' ability to select appropriate concepts, principles, or equations. The third indicator, applying the strategy, assessed students' ability to substitute known values into the selected equation and perform calculations correctly. The fourth indicator, evaluating the solution, assessed students' ability to check the conceptual appropriateness of the answer and the correctness of the unit.

Before being used in the main study, the instrument was tried out with students who had previously learned the topic of momentum and impulse. The tryout was conducted to examine item validity, reliability, item difficulty, and item discrimination. Item validity was analyzed using the product-moment correlation, while reliability was analyzed using Cronbach's alpha. The validity and reliability results are presented in Table 3.

Table 3. Validity and Reliability Results of the Problem-Solving Ability Test

Item	Validity Coefficient (r)	r_{table}	Interpretation
1	0.43	0.36	Valid
2	0.82	0.36	Valid
3	0.43	0.36	Valid
4	0.79	0.36	Valid
5	0.40	0.36	Valid
6	0.56	0.36	Valid
Instrument reliability	0.98	0.36	Reliable

Note: Item validity was examined using the product-moment correlation, while instrument reliability was examined using Cronbach's alpha

As shown in Table 3, all six items met the validity criterion because each validity coefficient was higher than the r-table value. The reliability coefficient of the instrument was 0.98, indicating high internal consistency. Therefore, the instrument was considered appropriate for measuring students' problem-solving ability in the pretest and posttest. Item difficulty and item discrimination analyses were also conducted to support the feasibility of the instrument.

Data Collection Procedure

The data collection procedure consisted of three stages: preparation, implementation, and final data processing. In the preparation stage, the researcher conducted a literature review, prepared the teaching modules, developed student worksheets, prepared the PhET-assisted learning activities, and constructed the problem-solving ability test. The researcher also conducted preliminary observation at the school to identify the learning conditions and problems in physics instruction.

In the implementation stage, both the experimental and control classes were given a pretest before the treatment. The pretest was administered to measure students' initial problem-solving ability in momentum and impulse. After that, the experimental class was taught using PhET-assisted problem-based learning, while the control class was taught using conventional instruction. After the learning process was completed, both classes were given a posttest using the same problem-solving indicators.

In the final stage, students' answers were scored using the problem-solving rubric. The scores were tabulated and analyzed to determine students' problem-solving ability before and after the treatment. The analysis included descriptive statistics, prerequisite tests, hypothesis testing, and N-Gain calculation.

Data Analysis

The data were analyzed using descriptive and inferential statistics. Descriptive statistics were used to determine the minimum score, maximum score, mean score, and category of students' problem-solving ability. The analysis was conducted for both the overall problem-solving ability score and each problem-solving indicator.

Before conducting the hypothesis test, prerequisite tests were performed. The normality test was used to determine whether the pretest and posttest data were normally distributed. The normality test was conducted using the Chi-square test. The homogeneity test was used to determine whether the experimental and control classes had homogeneous variances. The homogeneity test was conducted using the F-test.

After the data met the prerequisite assumptions, an independent-samples t-test was used to examine whether there was a significant difference in problem-solving ability between the experimental and control classes. The hypothesis was tested at a significance level of 0.05. The alternative hypothesis was accepted when the calculated t-value was greater than the t-table value.

The improvement in students' problem-solving ability was analyzed using the normalized gain or N-Gain. The N-Gain score was calculated using the following formula:

$$g = \frac{\text{Posttest score} - \text{Pretest score}}{\text{Maximum score} - \text{Pretest score}}$$

The N-Gain results were interpreted using the following categories: high, medium, low, no improvement, and decrease. The N-Gain analysis was conducted for both overall problem-solving ability and each indicator of problem-solving ability. All statistical analyses were conducted using IBM SPSS Statistics version 32.

RESULTS AND DISCUSSION

Students' Problem-Solving Ability Before and After Treatment

The students' problem-solving ability in momentum and impulse was measured using a pretest and posttest administered to both the experimental and control classes. The pretest was conducted before the learning treatment to identify students' initial problem-solving ability, while the posttest was conducted after the treatment to determine the development of students' problem-solving ability after the learning process. The descriptive statistics of students' problem-solving ability are presented in Table 4.

Table 4. Descriptive Statistics of Students' Problem-Solving Ability

Group	N	Pretest			Category	Posttest			Category
		Min	Max	Mean		Min	Max	Mean	
Experimental	29	11	46	22.17	Very low	67	100	86.11	High
Control	28	8	43	21.38	Very low	65	100	78.17	High

As shown in Table 4, the pretest mean score of the experimental class was 22.17, while the control class obtained a mean score of 21.38. Both scores were categorized as very low. This indicates that students in both classes had relatively similar initial problem-solving ability before the learning treatment. The low pretest scores also suggest that students initially had difficulties in solving momentum and impulse problems. These difficulties may include identifying relevant quantities, determining what is being asked, selecting appropriate physics principles, applying equations, and evaluating the final solution.

After the treatment, both classes showed improvement in their problem-solving ability. The experimental class obtained a posttest mean score of 86.11, while the control class obtained a posttest mean score of 78.17. Although both classes reached the high category, the posttest mean score of the experimental class was higher than that of the control class. This result indicates that students who learned through PhET-assisted problem-based learning achieved better problem-solving performance than students who learned through conventional instruction.

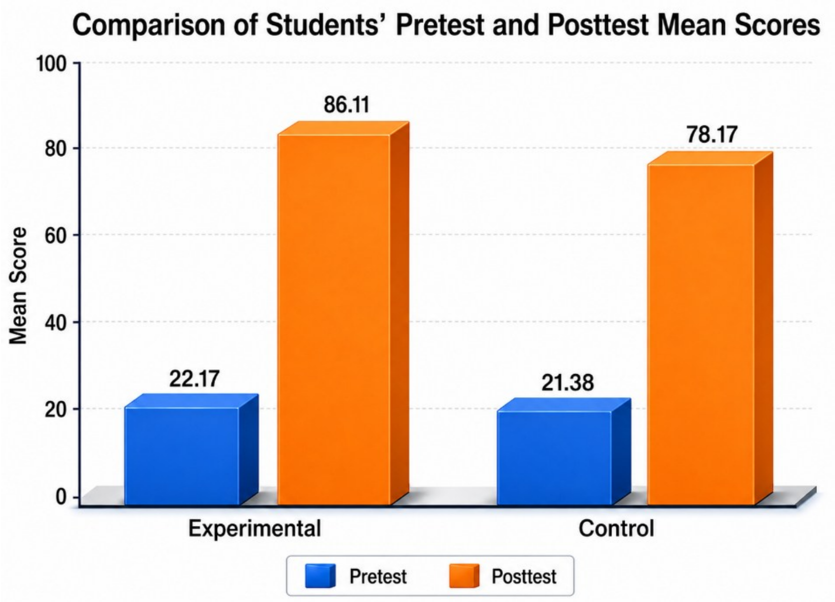

Figure 1. Comparison of students' pretest and posttest mean scores in problem-solving ability between the experimental and control classes

Figure 1 visually shows that both groups experienced improvement from pretest to posttest, but the improvement in the experimental class was greater. The pretest scores of the two classes were almost equal, indicating comparable initial ability. However, after the intervention, the experimental class showed a higher posttest score. This pattern supports the view that PhET-assisted problem-based learning provided additional learning support that was not obtained in the conventional class.

The stronger performance of the experimental class can be explained by the characteristics of the learning treatment. In the experimental class, students were not only asked to solve physics problems mathematically, but were also guided to investigate the physical meaning of momentum and impulse through PhET simulations. This is important because momentum and impulse involve dynamic phenomena, such as collisions, changes in velocity, force interactions, and conservation of momentum. These phenomena are difficult to understand if students only receive verbal explanations or formula-based exercises. Computer simulations and animations have been reported to improve students' learning of impulse and momentum because they provide dynamic visual representations of physical processes that are difficult to observe through static instruction (Fang & Guo, 2022). In this study, PhET simulations helped students observe collision phenomena and connect them with the concepts of momentum and impulse.

The finding is also consistent with studies reporting that simulation-assisted and inquiry-oriented learning can improve conceptual understanding and problem-solving fluency in physics. Dap-og and Orongan (2022) found that computer-assisted instruction supported students' academic achievement and engagement in science. Liana et al. (2023) reported that problem-based learning assisted by PhET simulations improved students' problem-solving ability and mastery of physics concepts. Similarly, Syafriyanti (2023) showed that guided inquiry learning using PhET simulations improved students' learning outcomes. These studies support the present finding that PhET-assisted learning can help students develop better physics problem-solving ability when it is integrated into an active learning framework.

Assumption Testing and Hypothesis Testing

Before conducting the hypothesis test, normality and homogeneity tests were performed to ensure that the data met the assumptions for parametric statistical analysis. The homogeneity test was conducted using the F-test, while the normality test was conducted using the Chi-square test. The results are presented in Table 5.

Table 5. Results of Normality and Homogeneity Tests

Test	Data	Group	Cal. Value	Crit. Value	Interpretation
Homogeneity	Pretest	Experimental & control	$F = 1.01$	$F_{table} = 1.90$	Homogeneous
Homogeneity	Posttest	Experimental & control	$F = 1.17$	$F_{table} = 1.90$	Homogeneous
Normality	Pretest	Experimental	$\chi^2 = 9.02$	$\chi^2_{table} = 11.07$	Normally distributed
Normality	Pretest	Control	$\chi^2 = 3.51$	$\chi^2_{table} = 11.07$	Normally distributed
Normality	Posttest	Experimental	$\chi^2 = 2.75$	$\chi^2_{table} = 11.07$	Normally distributed
Normality	Posttest	Control	$\chi^2 = 3.86$	$\chi^2_{table} = 11.07$	Normally distributed

Table 5 shows that the calculated F values for both pretest and posttest data were lower than the Ftable value. Therefore, the variances of the experimental and control classes were homogeneous. The normality test also showed that all calculated Chi-square values were lower than the Chi-square table value, indicating that the pretest and posttest data in both classes were normally distributed. These results indicate that the data met the assumptions required for conducting an independent-samples t-test.

The independent-samples t-test was then conducted to examine whether there was a significant difference in problem-solving ability between the experimental and control classes after the learning treatment. The results are presented in Table 6.

Table 6. Independent-Samples t-Test Result

Group	N	Posttest Mean	df	t_{count}	t_{table}	p-value	Decision
Experimental	29	86.11	55	2.13	2.00	.038	Significant
Control	28	78.17	55				

The result of the independent-samples t-test showed that the tcount value was higher than the ttable value (2.13 > 2.00), with $p < .05$. Therefore, the null hypothesis was rejected and the alternative hypothesis was accepted. This result indicates that there was a significant difference in students' problem-solving ability between the experimental class and the control class. In other words, PhET-assisted problem-based learning had a significant effect on students' problem-solving ability in momentum and impulse.

This finding supports the assumption that the integration of problem-based learning and PhET simulations provides a more effective learning environment for physics problem solving than conventional instruction. Through problem-based learning, students were guided to understand contextual problems, conduct investigations, discuss possible solutions, present findings, and evaluate the problem-solving process. At the same time, PhET simulations helped students visualize collision phenomena and observe the relationships among mass, velocity, momentum, and impulse. This combination likely helped students connect conceptual understanding with mathematical procedures.

The finding is in line with Gunawan et al. (2021), who reported that PBL assisted by PhET simulations can support students' higher-order thinking. It also supports the study by Liana et al. (2023), which found that PhET-assisted problem-based learning improved students' problem-solving ability and mastery of physics concepts. The present study extends those findings by showing that the effect of PhET-assisted PBL is evident in the specific topic of momentum and impulse and can be observed through students' performance on problem-solving indicators.

However, the result should not be interpreted as evidence that PhET simulations alone caused the improvement. The effectiveness of simulation-based learning depends on how the simulation is used in the learning process. Rytting et al. (2019) noted that simulation-based laboratories can be as effective as hands-on laboratories for learning physics concepts, but the relative benefit of simulation depends on learning context, student engagement, and instructional design. Therefore, the significant difference found in this study is better understood as the effect of an integrated instructional design in which PhET simulations were embedded within the syntax of problem-based learning.

Improvement in Students' Problem-Solving Ability Based on N-Gain

The improvement in students' problem-solving ability was further analyzed using the normalized gain or N-Gain. This analysis was conducted to determine the extent to which students' scores improved from pretest to posttest in both classes. The results are presented in Table 7.

Table 7. N-Gain Results of Students' Problem-Solving Ability

Group	Pretest Mean	Posttest Mean	N-Gain	Category
Experimental	22.17	86.11	0.81	High
Control	21.38	78.17	0.70	Medium

Table 7 shows that the experimental class obtained an N-Gain score of 0.81, which was categorized as high. Meanwhile, the control class obtained an N-Gain score of 0.70, which was categorized as medium. These results indicate that both classes experienced improvement after the learning process, but the improvement in the experimental class was higher than that in the control class. This finding strengthens the hypothesis test result, showing that PhET-assisted problem-based learning was more effective in improving students' problem-solving ability than conventional instruction.

The higher N-Gain score in the experimental class can be attributed to the learning process that required students to actively engage with problems and explore physical phenomena through simulation. In the experimental class, students did not only receive explanations from the teacher, but also investigated momentum and impulse concepts through PhET-based activities. They manipulated variables, observed outcomes, discussed findings with peers, and related the simulation results to the problem-solving steps. Such activities are consistent with inquiry-based and problem-based learning, both of which emphasize active exploration, evidence-based reasoning, and conceptual construction.

This result is consistent with previous studies showing that PhET-assisted inquiry or problem-based learning can improve students' learning outcomes in physics. Fang and Guo (2022) showed that simulation and animation improved students' learning of impulse and momentum. Hidayatullah et al. (2021) found that a conceptual change model assisted by PhET simulation enhanced students' critical thinking related to momentum and impulse. Syafriyanti (2023) reported that guided inquiry learning using PhET simulation improved students' learning outcomes. These findings suggest that PhET can support students' conceptual development when it is used within a learning framework that requires active investigation and reasoning.

The medium N-Gain score in the control class should also be interpreted carefully. It indicates that conventional instruction, when accompanied by explanation and problem exercises, can still improve students' problem-solving performance. However, the higher N-Gain in the experimental class suggests that PhET-assisted problem-based learning provides additional support for conceptual visualization, active inquiry, and systematic problem-solving practice. This interpretation is consistent with broader findings that student-centered and inquiry-oriented learning approaches can improve physics learning outcomes across different educational contexts (Dap-og & Orongan, 2022; Ningsih et al., 2024).

Improvement Across Problem-Solving Indicators

In addition to the overall N-Gain analysis, this study examined students' improvement across the four indicators of problem-solving ability: recognizing the problem, planning a strategy, applying the strategy, and evaluating the solution. The results are presented in Table 8.

Table 8. N-Gain Results for Each Problem-Solving Indicator

Problem-Solving Indicator	Exp. N-Gain	Category	Con. N-Gain	Category
Recognizing the problem	0.86	High	0.79	High
Planning a strategy	0.98	High	0.84	High
Applying the strategy	0.92	High	0.84	High
Evaluating the solution	0.51	Medium	0.23	Low

As shown in Table 8, the experimental class obtained higher N-Gain scores than the control class across all four indicators. The highest improvement in the experimental class occurred in planning a strategy, with an N-Gain score of 0.98. This was followed by applying the strategy with an N-Gain score of 0.92, recognizing the problem with an N-Gain score of 0.86, and evaluating the solution with an N-Gain score of 0.51. These results show that PhET-assisted problem-based learning was particularly effective in helping students identify relevant information, select appropriate strategies, and apply physics equations in solving momentum and impulse problems.

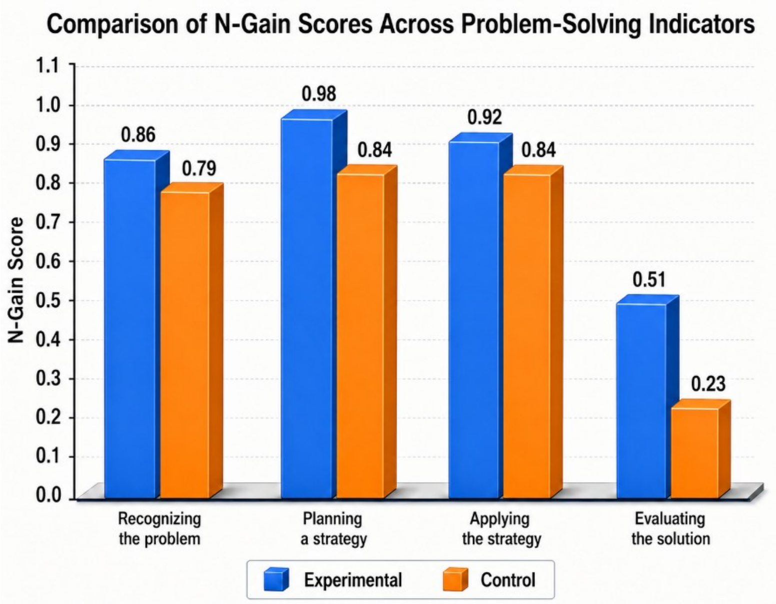

Figure 2. Comparison of N-Gain scores across problem-solving indicators in the experimental and control classes

Figure 2 shows that the experimental class outperformed the control class in all four problem-solving indicators. The most visible gap appeared in the evaluating-solution indicator, where the experimental class obtained a medium N-Gain score, while the control class remained in the low category. This pattern indicates that PhET-assisted problem-based learning supported students' problem-solving development more consistently than conventional instruction, although evaluating the solution remained the most difficult indicator for students.

The high improvement in recognizing the problem can be related to the problem orientation stage in problem-based learning. At this stage, students were exposed to contextual problems related to momentum and impulse. This helped students identify what information was relevant, what quantities were known, and what was being asked in the problem. The use of PhET simulations also gave students visual support for understanding the physical situation. For example, by observing collision events in the simulation, students could more easily connect the problem statement with physical variables such as mass, velocity, and momentum.

The improvement in planning a strategy was the highest among all indicators in the experimental class. This suggests that students benefited from the combination of contextual problems, simulation-based investigation, and group discussion. During the investigation stage, students could manipulate variables in the PhET simulation and observe how changes in mass or velocity affected motion and momentum. This helped students determine which principles or equations were relevant to the problem. The result supports findings by Hidayatullah et al. (2021), who showed that PhET-assisted learning can promote higher-order cognitive processes, and by Handayani et al. (2024), who emphasized the importance of instructional models that support conceptual understanding in momentum and impulse.

The applying-strategy indicator also showed high improvement in both classes, but the experimental class achieved a higher N-Gain score. This indicates that students in the experimental class were better able to substitute known values into equations and carry out calculations. The improvement may have occurred because students had already built a stronger conceptual basis through simulation before solving numerical problems. In other words, PhET helped students understand the physical meaning behind the equation, while problem-based learning provided the structure for applying that understanding to problem-solving tasks.

The improvement in the first three indicators is consistent with the affordances of PhET simulations in physics learning. PhET provides visual feedback and allows students to test the relationships among physical quantities rather than merely memorizing equations. In momentum and impulse, this is especially relevant because students need to understand how mass and velocity influence momentum and how force and time interval relate to impulse. Studies have shown that PhET simulations can facilitate visualization, hypothesis testing, and evidence-based reasoning in physics learning (Hidayatullah et al., 2021; Handayani et al., 2024). PhET-enabled activities have also been reported to support scientific communication and representational reasoning when embedded in instructional models that require discussion and explanation (Hidayat & Subekti, 2022; Patriot & Jannah, 2022).

The control class also showed high improvement in recognizing the problem, planning a strategy, and applying the strategy. This finding indicates that conventional instruction and problem exercises still contributed to students' procedural problem-solving skills. Students in the control class could still learn how to identify information, choose formulas, and complete calculations through teacher explanation and practice. However, the improvement in the experimental class was consistently higher. This suggests that PhET simulations within a problem-based learning framework provided additional support by helping students visualize physical phenomena and connect mathematical procedures with conceptual understanding. Kusaeri et al. (2022) also argued that the combination of PBL and PhET can support critical thinking and problem-solving ability because students engage with problems while receiving visual and interactive support.

The evaluating-solution indicator showed the lowest improvement in both classes. In the experimental class, this indicator reached a medium category, while in the control class it remained in the low category. This finding is important because it shows that students' ability to evaluate solutions was more difficult to develop than their ability to recognize problems, plan strategies, or apply equations. Evaluating a solution requires students to check conceptual consistency, examine the correctness of units, and determine whether the result is reasonable in the given physical context. These skills involve reflective and metacognitive processes that may not develop automatically through calculation-based problem solving.

The relatively low improvement in evaluating solutions indicates that PhET-assisted problem-based learning, although effective, still requires stronger instructional emphasis on reflection and evaluation. Students may be able to use

PhET simulations to understand physical phenomena and complete calculations, but they still need explicit guidance to evaluate whether their final answers make sense. This finding supports the idea that successful physics problem solving does not end with obtaining a numerical answer. Students must also be trained to interpret the result, check its unit, compare it with physical expectations, and relate it back to the original problem situation.

This result also provides a more nuanced interpretation of simulation-assisted learning. PhET helped students visualize phenomena, plan mathematical strategies, and apply equations, but the evaluation of solutions required deeper reflective reasoning. Rytting et al. (2019) noted that simulation-based laboratories can be effective for learning physics concepts, but their relative advantage depends on the outcome being measured and how the learning activities are implemented. Therefore, the lower gain in evaluating solutions does not weaken the value of PhET-assisted problem-based learning. Instead, it shows that simulation and problem-based activities should be complemented by explicit metacognitive scaffolding.

From a pedagogical perspective, the results indicate that physics teachers can use PhET-assisted problem-based learning to strengthen students' problem-solving ability, especially for topics involving abstract and dynamic phenomena such as momentum and impulse. The approach helps students visualize physical relationships, practice systematic problem solving, and participate more actively in learning. This is in line with studies showing that PhET-supported learning can enhance conceptual understanding, higher-order thinking, critical thinking, and scientific communication when combined with appropriate instructional models (Gunawan et al., 2021; Hidayatullah et al., 2021; Patriot & Jannah, 2022).

However, the findings also suggest that teachers need to give more attention to the evaluation stage of problem solving. Students should be explicitly guided to check units, compare numerical answers with physical expectations, explain the meaning of their results, and justify whether their solutions are reasonable. Such scaffolding can be integrated into worksheets, group discussions, and class reflections. For example, after completing a calculation, students can be asked to answer additional prompts such as: "Does the result make sense physically?", "Is the unit correct?", "How does the result relate to the simulation?", and "What would happen if one variable changed?" These prompts may help students develop stronger reflective and metacognitive habits in physics problem solving.

Thus, the results of this study indicate that PhET-assisted problem-based learning significantly improved students' problem-solving ability in momentum and impulse. The improvement was evident not only in the overall problem-solving score, but also across the four indicators of problem-solving ability. Nevertheless, evaluating the solution remained the most challenging indicator. This finding highlights the need for future implementation of PhET-assisted problem-based learning to strengthen the evaluation stage through explicit reflection, metacognitive prompts, guided solution-checking activities, and stronger alignment between simulation observations and written problem-solving procedures.

CONCLUSION

This study examined the effect of PhET-assisted problem-based learning on students' problem-solving ability in momentum and impulse. The findings showed that students in both the experimental and control classes improved after the learning process, but the improvement in the experimental class was higher. The experimental class obtained a posttest mean score of 86.11, while the control class obtained 78.17. The independent-samples t-test also showed a significant difference between the two classes, with $t_{count} = 2.13 > t_{table} = 2.00$, indicating that PhET-assisted problem-based learning had a significant effect on students' problem-solving ability. The N-Gain result further supported this finding, as the experimental class achieved a high N-Gain score of 0.81, while the control class achieved a medium N-Gain score of 0.70.

The indicator-based analysis showed that PhET-assisted problem-based learning improved all four aspects of students' problem-solving ability: recognizing the problem, planning a strategy, applying the strategy, and evaluating the solution. The highest improvement in the experimental class occurred in planning a strategy and applying the strategy, indicating that the combination of contextual problem orientation, group investigation, worksheets, and PhET simulation helped students select relevant physics principles and apply equations more systematically. These findings support previous studies showing that PhET-assisted inquiry and problem-based learning can strengthen students' conceptual understanding, higher-order thinking, and problem-solving performance in physics, particularly in topics involving dynamic phenomena such as momentum and impulse.

However, the evaluating the solution indicator remained the weakest aspect of students' problem-solving ability. Although the experimental class performed better than the control class on this indicator, its N-Gain score was only in the medium category. This suggests that PhET-assisted problem-based learning was effective in supporting students' conceptual visualization and procedural problem solving, but students still needed stronger guidance to evaluate the reasonableness of their answers, check units, and connect numerical results with physical meaning.

The results imply that PhET-assisted problem-based learning can be used as an effective instructional approach for teaching momentum and impulse, especially in schools with limited laboratory facilities. Nevertheless, future implementation should place greater emphasis on reflective and metacognitive activities, particularly during the evaluation stage of problem solving. Teachers can strengthen this stage by providing explicit prompts that require students to justify their answers, compare results with simulation observations, check units, and explain whether their solutions are physically reasonable. Future studies may also involve larger samples, longer intervention periods, and additional variables such as conceptual understanding, critical thinking, collaboration, or students' attitudes toward physics learning.

RECOMMENDATION

Future studies are recommended to place stronger emphasis on the evaluating the solution indicator, since this aspect remained the weakest part of students' problem-solving ability. Teachers and researchers should provide more explicit scaffolding that guides students to check units, evaluate the reasonableness of numerical answers, relate final results to physical concepts, and compare their solutions with observations from PhET simulations. Further research may also involve larger samples, longer intervention periods, and additional variables such as conceptual understanding, critical thinking, collaboration, scientific communication, or students' attitudes toward physics learning to obtain a broader understanding of the effectiveness of PhET-assisted problem-based learning.

ACKNOWLEDGEMENT

The authors would like to express their gratitude to SMAN 1 Lembar for providing permission, support, and facilities during the research process. Appreciation is also extended to the physics teacher and all Grade XI students who participated in this study.

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