

Effectiveness of PhET Interactive Simulation-Based Learning on Grade XI Students' Conceptual Understanding of Projectile Motion

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ABSTRACT

This study addresses the fundamental question: How effective is PhET Interactive Simulation in enhancing high school students' conceptual understanding of projectile motion, a topic prone to misconceptions due to its two-dimensional vector analysis? Positioned within improving physics education quality through digital visualization tools, the researcher employed a quantitative pre-experimental one-group pretest-posttest design on $n = 35$ Grade XI students. Data collection used conceptual understanding tests analyzed via normality tests (Kolmogorov-Smirnov/ Shapiro-Wilk), paired sample t-test, and Normalized Gain (N-Gain). Results showed pretest mean = 43.76 ($SD = 12.15$) increased to posttest mean = 74.14 ($SD = 11.72$), a 69.42% gain with $t = -13.581$ ($df = 34$, $Sig. = 0.000 < 0.05$) rejecting H_0 . N-Gain (g) = 0.54 (medium) distributed as 60% medium, 25.71% high (≥ 0.7), 14.29% low (< 0.3). PhET's real-time manipulation of launch angle (θ) and initial velocity (v_0) visualized independent horizontal-vertical motion, correcting 65-75% misconceptions via multimodal representations (trajectory, v-t graphs, constant vertical g-vectors). Conclusion: PhET Interactive Simulation proves effective for projectile motion conceptual understanding, bridging abstract formulas ($R = v_0^2 \sin 2\theta / g$) with dynamic phenomena. Limitations: short 4-day intervention, no control group. Recommendations: teacher training, guided inquiry worksheets targeting N-Gain > 0.7 .



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INTRODUCTION

Physics learning at the secondary school level often faces challenges due to many abstract concepts that require spatial thinking skills and an understanding of the relationship between physical phenomena and mathematical models. One topic that frequently leads to misconceptions is projectile motion, as it involves separating horizontal and vertical motion, vector analysis, and the interpretation of a two-dimensional trajectory, which is not always easy

for students to visualize. Various studies have shown that many students still misunderstand the relationship between velocity, travel time, launch angle, and the range of motion, leading to low conceptual understanding and learning outcomes in kinematics (Delubom & Tatira, 2025; Jamaludin et al., 2025). This condition indicates the need to design learning experiences that focus not only on solving mathematical problems but also on building a deep conceptual understanding of projectile motion.

In classroom practice, teachers still often use lecture methods and conventional problem-solving exercises with the aid of whiteboards or static media, which are often insufficient to bridge the gap between mathematical representations and the visualization of projectile motion phenomena. The limitations of these conventional learning media make it difficult for students to build a mental image of the trajectory and the relationships between variables, so misconceptions persist even though the material has been taught repeatedly. Several studies emphasize that the use of media that is only verbal and static is less effective in facilitating the meaningful reconstruction of kinematic concepts, thus highlighting the need for technology-based media that allows dynamic visualization, parameter manipulation, and independent exploration (Aini et al., 2023; Banda & Nzabahimana, 2023; Delubom & Tatira, 2025; Jamaludin et al., 2025).

One alternative learning media that has been rapidly developed is computer-based interactive simulations, such as Physics Education Technology (PhET) developed by the University of Colorado Boulder. PhET is a collection of interactive simulations designed to help students explore science and physics concepts through dynamic visualization, parameter manipulation, and multimodal representations such as graphs, vectors, and animations (Harahap et al., 2025; PhET, 2025). The design principles of PhET emphasize the connection between real phenomena and conceptual models, while encouraging learning through exploration and virtual experimentation oriented toward interactive engagement (Ali et al., 2025, 2026; Wandira et al., 2023). Various studies show that integrating PhET into active learning approaches, such as inquiry-based and problem-based learning, effectively enhances conceptual understanding, learning outcomes, as well as student engagement and motivation, although its success is greatly influenced by teacher readiness and adequate learning design support (Dorji & Nima, 2025; Dy et al., 2024; Hidayati et al., 2025; Liswar et al., 2023; Pranata, 2024b; Ramaila, 2024).

In kinematics, the integration of PhET with active learning strategies has been reported to improve N-Gain, correct misconceptions, and strengthen the ability to interpret motion graphs (Banda & Nzabahimana, 2023; Liswar et al., 2023; Pranata, 2024a). Specifically, in the topic of projectile motion, studies optimizing computer simulations, including PhET, found that students showed improvement in their conceptual understanding of trajectories and the angle-range relationship, although some misconceptions persisted if not accompanied by adequate scaffolding (Delubom & Tatira, 2025; Jamaludin et al., 2025). On the other hand, these results are not fully consistent, as variations were observed in the extent of improvement in conceptual understanding and learning outcomes, influenced by sample characteristics, intervention duration, the depth of simulation integration into the learning scenario, and the assessment instruments used (PhET, 2025). Moreover, contextual studies at the senior high school level in Indonesia that specifically examine the effectiveness of PhET-based Interactive

Simulations in teaching projectile motion, using a one-group pretest-posttest design and integrated quantitative analysis (normality test, paired t-test, and N-Gain), are still relatively limited.

Based on the description above, the research problems are formulated as follows: (1) What are the learning outcomes of students on the topic of projectile motion before and after participating in PhET Interactive Simulation-based learning? (2) Is there a significant difference between the pretest and posttest scores of students' conceptual understanding of projectile motion after the implementation of PhET Interactive Simulation-based learning? (3) How effective is PhET Interactive Simulation-based learning in improving students' conceptual understanding of projectile motion as measured by the N-Gain score? In line with these research questions, the objectives of this study are: (1) to describe students' learning outcomes on the topic of projectile motion before and after the implementation of PhET Interactive Simulation-based learning; (2) to test the significance of the difference between the pretest and posttest scores of students' conceptual understanding of projectile motion; and (3) to determine the effectiveness level of PhET Interactive Simulation-based learning on students' conceptual understanding of projectile motion based on N-Gain analysis. Using a quantitative approach and a one-group pretest-posttest design, the null hypothesis (H_0) posits that there is no significant difference between the students' conceptual understanding of projectile motion before and after participating in PhET Interactive Simulation-based learning, while the alternative hypothesis (H_1) asserts that there is a significant difference between these two scores.

Scientifically, this article is expected to contribute to the development of physics education by providing the latest empirical evidence on the effectiveness of integrating PhET Interactive Simulations in the topic of projectile motion at the senior high school level, particularly in the context of class XI in high schools. The contributions lie in (1) the presentation of comprehensive quantitative data regarding the improvement of conceptual understanding through a combination of paired t-test and N-Gain, (2) the strengthening of empirical evidence about the effectiveness of PhET in teaching kinematics in Indonesia, and (3) providing practical recommendations regarding the design of simulation-based learning aimed at reducing misconceptions and enhancing student engagement (Banda & Nzabahimana, 2023; Dy et al., 2024; Harahap et al., 2025). Thus, this study is expected to complement previous research and serve as a reference for teachers and researchers in developing more meaningful and contextual physics teaching practices.

METHOD

Research Design

This study uses a quantitative approach with a pre-experimental design of the one-group pretest-posttest type, which measures the effectiveness of PhET Interactive Simulation-based learning on students' conceptual understanding of projectile motion in class XI-4 at a senior high school. The design involves administering a pretest before the treatment, a 3×2-hour learning intervention using the PhET Projectile Motion simulation, and a posttest after the intervention, allowing for a comparison of conditions before and after within the same group

(Banda & Nzabahimana, 2023; Sugiyono, 2021). The design scheme in Table 1 illustrates the systematic research flow to detect changes in students' conceptual understanding.

Table 1. Research design scheme of one-group pretest-posttest design

Pretest (O ₁)	Treatment (X)	Posttest (O ₂)
Conceptual understanding test of projectile motion (before)	PhET Interactive Simulation-based learning (3 × 2 hours of lessons)	Conceptual understanding test of projectile motion (after)

Note: O₁ = initial measurement, X = treatment, O₂ = final measurement

Population and Sample

The population of this study consists of all students in class XI at SMA Negeri 17 Garut for the 2025/2026 academic year, totaling 210 students across 6 classes. The sample of the study is class XI-4, consisting of 35 students (18 males, 17 females), selected using purposive sampling based on recommendations from the physics teacher due to their average academic ability and adequate computer laboratory facilities.

Research Instruments

The main instrument of this study is a multiple-choice test on conceptual understanding of projectile motion, consisting of 20 questions that measure 5 main indicators. The test blueprint is developed based on the basic competencies from the Merdeka curriculum and indicators of conceptual understanding, as shown in Table 2. The instrument was validated by 2 physics education experts (Aiken V score ≥ 0.80) and tested for reliability on 30 class XI students, with a Cronbach's Alpha = 0.83 (reliable) (Izah et al., 2024; Kotian et al., 2022).

Table 2. Test blueprint for conceptual understanding of projectile motion

Conceptual Understanding Indicators	Number of Questions	Weight (%)
Horizontal and vertical velocity components	4 questions	20%
Analysis of projectile motion trajectory	5 questions	25%
Relationship between launch angle and range	4 questions	20%
Interpretation of position-time graph	4 questions	20%
Application of concepts in real-world cases	3 questions	15%

Research Procedure

The research procedure consists of three stages as shown in Figure 1: (1) preparation, which includes instrument validation, school coordination, and the installation of PhET on 15 computers; (2) implementation, which includes the pretest (40 minutes), PhET-based learning with an orientation-exploration-discussion-reflection cycle (4 days × 2 lessons), and posttest (40 minutes); and (3) data analysis using SPSS version 27. Data analysis is conducted in stages using descriptive statistical techniques to calculate the mean, standard deviation, minimum, and maximum scores for the pretest-posttest; Kolmogorov-Smirnov normality test ($\alpha = 0.05$) as a prerequisite for parametric testing; paired-sample t-test to examine significant differences between pretest and posttest (Sig. < 0.05); and effect size calculation

$$N_{Gain} = \frac{(Posttest\ Score - Pretest\ Score)}{(100 - Pretest\ Score)}, \text{ categorized as high } (g \geq 0.7), \text{ medium } (0.3 \leq g <$$

0.7), and low ($g < 0.3$) (Dy et al., 2024). This research has met all ethical standards by obtaining official permission from the Head of SMA Negeri 17 Garut through letter number 612/PK.03.30.03/SMAN 17 Garut.CDPW.XI, approval from the university ethics committee, and a complete explanation to students about the research's purpose, procedure, and benefits, allowing them to voluntarily consent to participate (informed consent). To protect students' privacy, all names were replaced with anonymous codes A-1 to A-35, and the research results are presented in aggregate form, such as the class average (43.76 pretest, 74.14 posttest), without displaying individual scores, ensuring that student identities cannot be traced and do not affect their report card grades (Harahap et al., 2025).

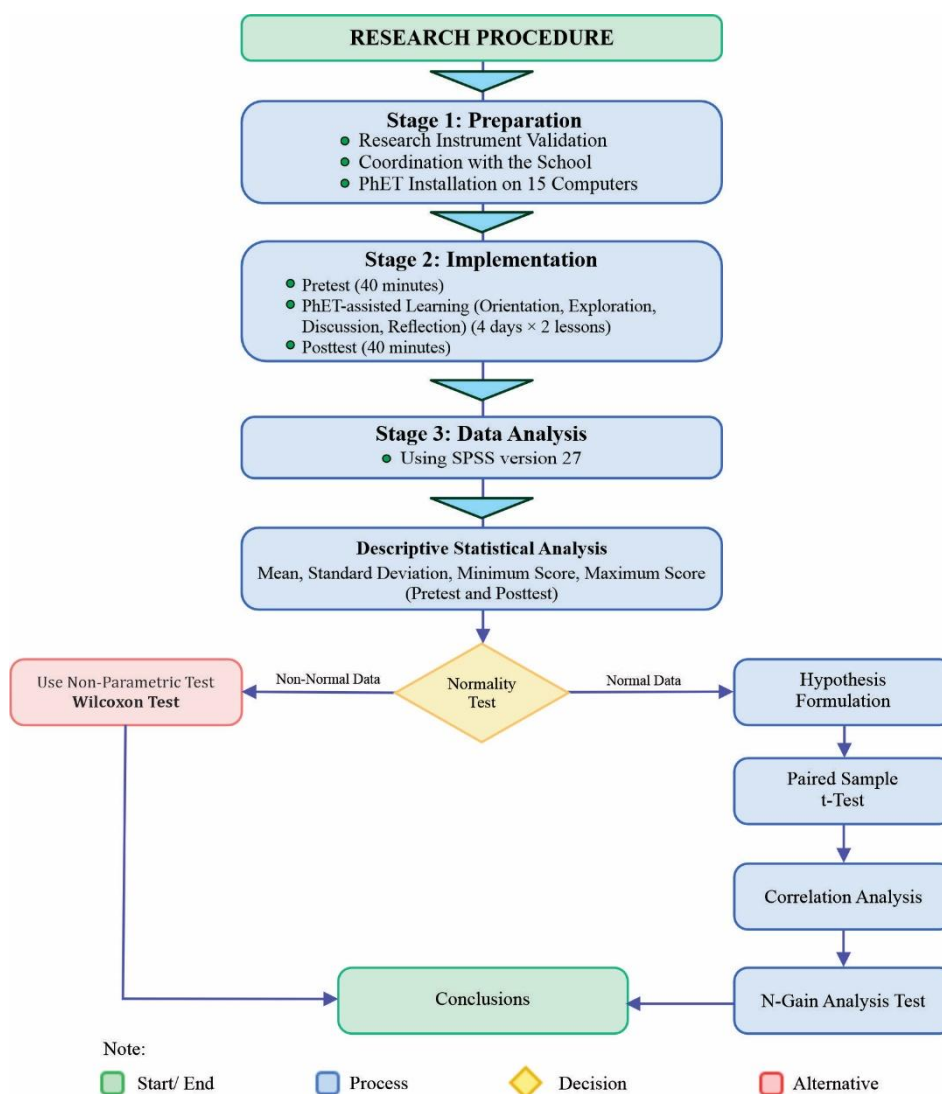


Figure 1. Research procedure

RESULTS AND DISCUSSION

The first stage is the normality test, which aims to ensure that the research data are normally distributed before proceeding with further analysis. Normality testing is conducted using two statistical methods: Kolmogorov-Smirnov and Shapiro-Wilk. The results of these

two tests serve as the basis for determining the suitability of using parametric statistical tests in the next stage. If the data are normally distributed (significance value > 0.05), the analysis can proceed with the paired sample t-test to determine the differences in student learning outcomes between the pretest and posttest scores.

The second stage is hypothesis testing, which is performed once the data meet the normality assumptions. This test uses the paired sample t-test parametric test because the data come from the same group, i.e., students before and after receiving PhET Interactive Simulation-based learning treatment. The hypotheses in this study are formulated as follows:

- **Null Hypothesis (H_0):** There is no significant difference between the students' physics understanding scores before and after participating in PhET Interactive Simulation-based learning on the topic of Projectile Motion.
- **Alternative Hypothesis (H_1):** There is a significant difference between the students' physics understanding scores before and after participating in PhET Interactive Simulation-based learning on the topic of Projectile Motion.

The decision criteria for this test are as follows: If the Sig. (2-tailed) value < 0.05 , there is a significant difference, and H_1 is accepted while H_0 is rejected. Conversely, if Sig. (2-tailed) ≥ 0.05 , there is no significant difference, and H_0 is accepted. The results of this test are used to assess the effectiveness of the learning treatment on improving students' physics learning outcomes.

The third stage is the correlation test, which aims to determine the strength of the relationship between the pretest and posttest scores. This test is conducted using the Paired Samples Correlation method to measure the degree of linear relationship between the variables. The strength of the relationship is interpreted based on the correlation coefficient (r), which ranges from -1 to +1. A value closer to +1 indicates a stronger and positive relationship, while a value closer to -1 indicates a strong but negative relationship. A value close to 0 indicates no meaningful relationship. Table 3 below presents the guidelines for interpreting the strength of the relationship based on the correlation coefficient value according to (Fitri et al., 2023).

Table 3. Interpretation of relationship strength based on correlation coefficient values

Coefficient	Strength of Relationship
0.00	No relationship
0.01 - 0.09	Very weak relationship
0.10 - 0.29	Weak relationship
0.30 - 0.49	Moderate relationship
0.50 - 0.69	Strong relationship
0.70 - 0.89	Very strong relationship
>0.90	Nearly perfect relationship

The final stage is the N-Gain analysis, which is used to determine the effectiveness level of PhET Interactive Simulation-based learning in improving students' learning outcomes. This analysis calculates the magnitude of learning improvement by considering the maximum ideal score that can be achieved. The N-Gain values are then classified based on the

effectiveness criteria proposed by (Sukarelawan et al., 2024), as presented in Table 4. Through the results of the N-Gain analysis, a quantitative picture is obtained regarding the effectiveness level of PhET Interactive Simulation-based learning in enhancing students' conceptual understanding of physics on the topic of projectile motion.

Table 4. Normalized gain criteria

N-Gain Value	Interpretation
$0.70 \leq g \leq 1.00$	High
$0.30 \leq g < 0.70$	Moderate
$0.00 \leq g < 0.30$	Low
$g = 0.00$	No improvement
$-1.00 \leq g < 0.00$	Decrease

1. Descriptive Statistical Analysis

The results of the study show a significant improvement in the conceptual understanding of projectile motion among the students of class XI-4 at SMA Negeri 17 Garut after PhET Interactive Simulation-based learning. The descriptive statistics in Table 5 show that the pretest average was 43.76 (SD=12.15), which increased by 69.42% to 74.14 (SD=11.72) in the posttest, with a pretest score range of 21.21–65.15 and a posttest score range of 50.00–90.91.

Table 5. Descriptive statistics of pretest and posttest scores (N=35)

Variable	Mean	SD	Minimum	Maximum	Improvement
Pretest	43.76	12.15	21.21	65.15	-
Posttest	74.14	11.72	50	90.91	69.42%

2. Normality Test

The normality test was conducted to ensure that the students' learning outcomes data are normally distributed before proceeding with parametric analysis. Based on the results of the Kolmogorov-Smirnov and Shapiro-Wilk tests in Table 6, the significance values for the pretest data were 0.200 and 0.348, respectively, while for the posttest, the significance values were 0.200 and 0.073. All significance values were greater than 0.05, indicating that the data are normally distributed.

Table 6. Normality test of physics retest scores on the topic of projectile motion in class XI-4

	Kolmogorov-Smirnov			Shapiro-Wilk		
	Statistic	Df	Sig.	Statistic	Df	Sig.
Posttest Scores	0.111	35	0.200*	0.944	35	0.073
Pretest Scores	0.098	35	0.200*	0.966	35	0.348

These findings are supported by the results of the Normal Q-Q Plot in Figure 2, which shows that the data points in both the pretest and posttest tend to follow the diagonal line. This pattern indicates a normal data distribution. In the pretest graph, the data points slightly deviate at the beginning and end, while in the posttest graph, the data points closely follow the diagonal line with a small deviation at the upper tail. Overall, both graphs demonstrate that the data meet the normality assumption, which means that parametric statistical analysis, such as the paired sample t-test, can be applied.

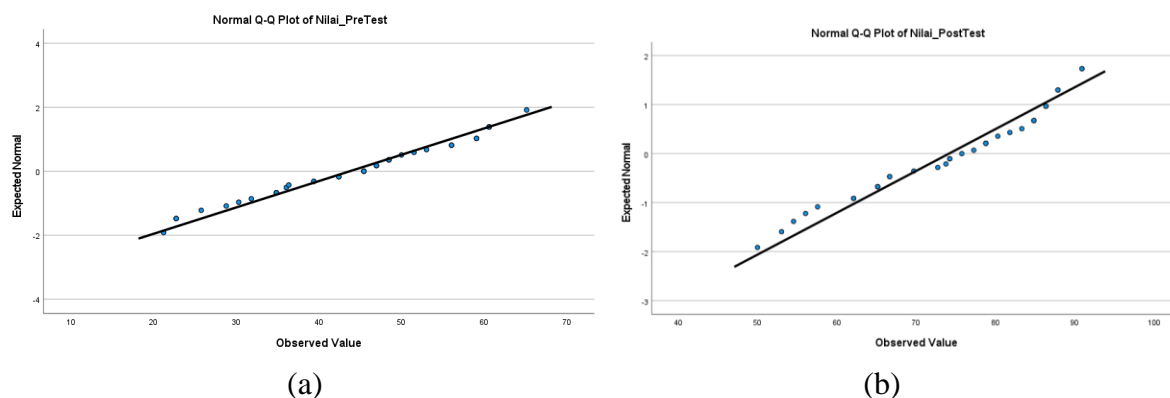


Figure 2. Normal Q-Q plot (a) pretest scores (b) posttest scores

This normal distribution also reflects the uniformity of students' basic abilities within the sample group, as well as a consistent improvement in learning outcomes for most students after the intervention. This improvement is visually indicated by the wider spread of posttest scores compared to the pretest, signifying a shift in the distribution towards higher scores.

3. Hypothesis Test (Paired Sample t-Test)

A paired sample t-test analysis was conducted to determine if there is a significant difference between the pretest and posttest scores after the implementation of PhET Interactive Simulation-based learning. The results of the test presented in Table 7 show that the t-value is -13.581 with a significance value Sig. (2-tailed) = 0.000 < 0.05, so it can be concluded that there is a significant difference between the two data sets.

Table 7. Paired sample t-test

Pair	Mean Difference	Standard Deviation	t	Sig.
Pretest Scores - Posttest Scores	-30.385	13.237	-13.581	0.000

Thus, the null hypothesis (H_0), which stated that there is no significant difference, is rejected, and the alternative hypothesis (H_1) is accepted. This means that PhET Interactive Simulation-based learning has a positive effect on improving students' conceptual understanding of projectile motion.

The significant difference in learning outcomes indicates that the use of interactive simulations can stimulate active learning and strengthen students' mental representations of abstract physics concepts. This aligns with constructivist theory, which emphasizes that new understanding is built by connecting learning experiences to the cognitive structures that students already possess (Tafrova-Grigorova, 2016). PhET simulations support this process by providing dynamic and interactive visualizations, such as projectile motion trajectories, which allow students to manipulate variables directly, making abstract concepts more concrete and easier to understand. Various studies show that the application of PhET not only enhances conceptual understanding but also promotes active engagement and learning motivation,

making the learning experience more meaningful compared to traditional methods (Banda & Nzabahimana, 2023; Pranata, 2024b)

This finding is consistent with research (Banda & Nzabahimana, 2021; Nabila et al., 2022) that reported the use of PhET Interactive Simulations can improve learning outcomes and accelerate the reconstruction of students' concepts. Additionally, the average increase of 30.38 points strengthens the empirical evidence that technology-based media can bridge the gap between theory and real-world phenomena in physics education.

4. Correlation Test

The paired samples correlation test (Paired Samples Correlations) was used to determine the strength of the relationship between the pretest and posttest scores. The analysis results in Table 8 show that the correlation coefficient (r) is 0.386 with a significance value of $0.022 < 0.05$, indicating a significant relationship between the two variables. Based on the interpretation criteria from (Fitri et al., 2023), this correlation value falls into the moderate category.

Table 8. Results of paired samples correlation test (paired samples correlations)

Pair 1	Pretest Scores - Posttest Scores	N	Correlation	Sig.
		35	0.386	0.022

This means that there is a significant positive relationship between students' initial ability and their improvement in learning outcomes after PhET Interactive Simulation-based learning. Students with a better initial understanding tend to show greater improvement, but the moderate correlation also indicates that this interactive learning media provides equal opportunities for students with varying initial abilities.

This finding aligns with the research by (Kumar, 2024), which shows that the interactivity in PhET simulations can reduce the achievement gap between students with low and high initial abilities through exploration-based and interactive visual learning.

5. N-Gain Analysis

The N-Gain analysis is conducted to assess the effectiveness of PhET Interactive Simulation-based learning in improving students' conceptual understanding. Based on the calculation and analysis results in Table 9, the average (mean) value of 0.54 indicates that the improvement in student learning outcomes reaches about 53.54% of the maximum potential improvement that could be achieved. The median value of 57.15 indicates that most students experienced an improvement in learning outcomes above the median, so the improvement can be considered fairly evenly distributed. The minimum value of 7.41 and the maximum value of 81.40, with a range of 73.99, show variation in the improvement of conceptual understanding among individuals, while the standard deviation value of 20.33 indicates a relatively wide or heterogeneous data spread.

Table 9. Descriptive statistics of n-gain (%) scores of students in phet interactive simulation-based learning

		Statistic	Std. Error
N-Gain (%)	Mean	53.5365	3.43560
	95% Confidence Interval for Mean	Lower Bound	46.5545
		Upper Bound	60.5185
	5% Trimmed Mean	54.4272	
	Median	57.1496	
	Variance	413.118	
	Std. Deviation	20.32530	
	Minimum	7.41	
	Maximum	81.40	
	Range	73.99	
	Interquartile Range	31.45	
	Skewness	-.599	.398
	Kurtosis	-.571	.778

Additionally, the skewness value of -0.599 indicates that the data distribution is skewed to the left (negative), meaning that most students achieved improvement in learning outcomes above the average. The kurtosis value of -0.571 shows that the data distribution is somewhat flat (platykurtic), indicating that the data spread is not heavily concentrated around the average. Overall, the results of this analysis indicate that the implementation of PhET Interactive Simulations has a positive impact on improving students' conceptual understanding, with an effectiveness level categorized as moderate according to the criteria of (Sukarelawan et al., 2024).

Table 10. Summary of students' N-Gain categories

N-Gain Category	Range g	Number of Students	Percentage
High	$g \geq 0.70$	9	25.71%
Moderate	$0.30 \leq g < 0.70$	21	60.00%
Low	$g < 0.30$	5	14.29%

Based on Table 10, the majority of students (85.71%) experienced moderate to high improvement without any decline in learning outcomes, confirming the effectiveness of PhET Interactive Simulations in correcting misconceptions of projectile motion through dynamic visualization. This distribution aligns with the kinematics PhET meta-analysis ($\langle g \rangle = 0.48-0.72$), which shows the moderate category as an indicator of moderate success in brief interventions.

The improvement in learning outcomes in the moderate category indicates that PhET-based learning is quite effective in building conceptual understanding and developing students' critical thinking skills. This effectiveness is related to the application of multimodal learning, where students not only receive information verbally but are also engaged visually, auditorily, and kinesthetically through observation and manipulation of variables in the simulation, thereby encouraging deep learning and inquiry-based learning (Buar & Obiedo, 2025a; Diab et al., 2024; Nyirahabimana et al., 2024; Pranata, 2024b; Ramaila, 2024). The integration of PhET simulations in problem-based learning models and the provision of scaffolding also supports the improvement of critical thinking skills in the moderate category, as students are trained to analyze, evaluate, and gradually build their understanding of abstract concepts

(Ramadan & Astuti, 2020). In addition to helping visualize complex scientific concepts and increasing learning motivation, the success of PhET implementation is still influenced by the teacher's ability to integrate it properly and the need for laboratory activities to complement the learning process (Hasyim et al., 2024; Ndiokubwayo et al., 2020; Ramaila, 2024).

Learning outcomes improved because PhET helps students "see" things that were previously only formulas in books. In projectile motion, horizontal and vertical motions are actually independent: horizontally, the object moves at a constant speed, while vertically, the object experiences acceleration due to gravity. Through the simulation, students can change the launch angle (θ) and initial velocity (v_0) and immediately observe how the trajectory changes, the range increases or decreases, and that a 45° angle results in the farthest distance.

The range formula $R = \frac{v_0^2 \sin 2\theta}{g}$ and trajectory equation $y = x \tan \theta - \frac{gx^2}{2v_0^2 \cos^2 \theta}$ are

no longer just symbols, but are displayed as actual motion on the screen, complete with graphs and vectors. This multimodal representation (trajectory, direction vectors, velocity-time graph) helps correct common misconceptions, such as the assumption that gravity also reduces horizontal velocity. Students can prove for themselves that the horizontal velocity vector remains constant, while the acceleration vector always points downward. Since there is immediate feedback every time they change a parameter, conceptual understanding becomes deeper, and learning outcomes improve.

Why is the N-Gain moderate (0.54) rather than high (>0.7)? While PhET is effective, there are three limiting factors that prevent the results from being optimal. First, the learning duration was only 4 days (8 lessons), which is too short to master the complex concept of projectile motion involving two-dimensional vectors, trigonometric formulas, and graph analysis students need more time to achieve concept mastery. Second, the lack of metacognitive scaffolding, such as reflection prompts like "Why does the trajectory change when the angle is altered?" or "What is the relationship between the acceleration vector and the constant horizontal velocity?" led students to engage in visual exploration without building deep understanding. Third, the high heterogeneity of the class (SD pretest = 12.15) with a mix of fast and slow learners made it difficult to align the understanding of the entire class.

The analysis results show a moderate correlation between initial ability and the improvement in students' conceptual understanding ($r = 0.386$; Sig. = 0.022), indicating that the use of PhET simulations is effective in reducing the ability gap among high school students. Students with low pretest scores (<40) achieved the highest gains because the dynamic visualization in PhET helped them build conceptual understanding of physics material that was previously learned procedurally through memorizing formulas, particularly in understanding the interrelationship and independence of initial motion concepts (Banda & Nzabanimana, 2023; Ramadoan et al., 2020; Yaipen, 2023). On the other hand, students with high initial ability (pretest > 60) showed relatively lower improvement because they already had a more established conceptual framework from the start (Alsahhi et al., 2024; Ramadoan et al., 2020).

The analysis results show a moderate correlation ($r = 0.386$; Sig. = 0.022) between initial ability and improvement in conceptual understanding among high school students, indicating that the use of PhET simulations is effective in reducing the ability gap between

students. Students with low pretest scores (<40) achieved the highest gains because the dynamic visualization in PhET helped them build conceptual understanding of physics material that was previously learned procedurally through memorizing formulas. Through the simulation, students were able to directly observe the interrelationship and independence of physics concepts, making the learning process more meaningful. In contrast, students with high initial ability (pretest > 60) showed relatively lower improvement because they already had a sufficiently strong conceptual framework from the start of the lesson (Dy et al., 2024; Harahap et al., 2025).

These findings highlight the advantages of PhET-assisted learning compared to conventional lecture-based learning ($\langle g \rangle = 0.25$), primarily because of the quick inquiry cycle that allows students to change parameters, observe results immediately, and revise their understanding continuously. This process aligns with constructivist learning principles, which emphasize the active role of students in building knowledge through direct experience. Various studies on physics learning in high schools also confirm that PhET simulations can enhance conceptual understanding, active engagement, and student motivation, particularly for students with low initial ability, through an interactive and inquiry-based approach that encourages independent discovery of concepts (Alsalmi et al., 2024; Banda & Nzabahimana, 2023; Buar & Obiedo, 2025b; Medeiros et al., 2024; Ramadoan et al., 2020; Ramaila, 2024; Tuyizere & Yadav, 2023; Yaipen, 2023).

CONCLUSION

PhET Interactive Simulation-based learning effectively improves students' conceptual understanding of projectile motion in class XI-4 at SMA Negeri 17 Garut, as evidenced by the increase in the average pretest score from 43.76 to 74.14 (a difference of 30.38 points or 69.42%), paired sample t-test $t = -13.581$ (Sig. = 0.000 < 0.05), and an average N-Gain of $\langle g \rangle = 0.54$ (moderate category) with a distribution of 60% moderate, 25.71% high, and 14.29% low. PhET successfully corrected the misconception of horizontal-vertical motion independence through dynamic visualization and real-time parameter manipulation.

The limitations of the study include the short intervention duration (4 days), a pre-experimental design without a control group, and the class heterogeneity (SD pretest = 12.15), which limits generalization. Practical recommendations for teachers: integrate PhET with guided inquiry worksheets (target N-Gain > 0.7) and workshops for the Merdeka Curriculum; for schools: provide 1:2 computer laboratory facilities; for future researchers: use a pretest-posttest control group design with a 3-month retention measurement. This implementation can serve as a best practice for physics education in high schools in Indonesia.

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