

## PHET VIRTUAL EXPERIMENTS TO ENHANCE NUMERACY SKILLS IN MOMENTUM AND IMPULSE CONCEPTS

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### Abstract :

Limited laboratory facilities pose a challenge in physics learning, particularly in developing students' numeracy skills in quantitative topics such as momentum and impulse. This study aims to investigate the effectiveness of virtual experiment-based learning using PhET Colorado simulations in enhancing students' numeracy skills. A quasi-experimental design with a pretest-posttest control group was employed involving two eleventh-grade classes at SMA Negeri 1 Purwanegara. Data were analyzed using paired sample t-tests and effect size calculations (Cohen's  $d$ ). The experimental group showed an increase in scores, as indicated by  $t(34) = -20.5$ ,  $p < 0.001$ , with a very large effect size ( $d = 2.31$ ). The control group also showed an increase,  $t(35) = -2.65$ ,  $p = 0.012$ , with a moderate effect size ( $d = 0.48$ ). The larger effect size in the experimental group indicates a stronger impact of the treatment compared to conventional learning.

These results provide empirical evidence that virtual experiment-based learning using PhET simulations is more effective in enhancing students' numeracy skills.

Keywords: Virtual Experiment, Numeracy Skills, Momentum and Impulse

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## INTRODUCTION

Despite the well-documented advantages of PhET Interactive Simulations in fostering conceptual understanding, there is still limited attention to how such tools can explicitly support the development of students' numeracy skills within physics learning (Obeng 2024; Rianti et al., 2024; Makofani et al., 2025). Numeracy in this context goes beyond basic calculation; it involves the ability to interpret graphs, analyze proportional relationships, and apply mathematical reasoning to explain physical phenomena (Nanda & Rani, 2025; Siswandari et al., 2025; Warniasih et al., 2026). In topics such as momentum and impulse, students are required to connect abstract formulas with observable events, such as collisions and changes in motion. Virtual experiments provide a dynamic environment where variables such as mass and velocity can be manipulated in real time, enabling students to observe how numerical changes directly affect physical outcomes (Rodrigues & Carvalho, 2022; Kade, 2024; Vilada et al., 2025). This interactive feature has strong potential to bridge the gap between mathematical representation and conceptual understanding.

Moreover, the integration of numeracy skills into physics learning is closely aligned with the demands of 21st-century education, which emphasize higher-order thinking and problem-solving

abilities (Gradini et al., 2025; Kusumawardani, 2025; Sihombing, 2025). International frameworks like OECD through the Programme for International Student Assessment (PISA) highlight numeracy as a fundamental competency that students must master to function effectively in modern society. However, many students still struggle to interpret equations such as momentum ( $p = mv$ ) and impulse ( $I = F\Delta t$ ) as meaningful representations of real phenomena. This indicates that traditional instructional approaches may not sufficiently support the development of integrated conceptual and numerical understanding (Dairo et al., 2024; Ncube & Luneta, 2025). Therefore, the use of virtual simulations offers a promising alternative by allowing students to visualize and quantify relationships simultaneously.

In addition, virtual experiments using PhET can support inquiry-based learning approaches, where students actively construct knowledge through exploration and data analysis (Drastisianti et al., 2024; Warneri, 2024; Fitriani & First, 2026). By engaging with simulation-based activities, students are encouraged to collect numerical data, identify patterns, and draw conclusions based on quantitative evidence. This process directly contributes to the enhancement of numeracy skills, particularly in interpreting data tables, graphs, and mathematical models. In the context of momentum and impulse, students can investigate how varying force and time intervals influence the resulting impulse, thereby strengthening their ability to apply mathematical reasoning in scientific contexts. Such experiences are essential for developing students' confidence in handling numerical information and making evidence-based decisions.

Finally, this study also contributes methodologically by combining the use of virtual experiments with rigorous quantitative analysis to measure learning outcomes. Unlike previous studies that primarily rely on descriptive improvements, this research incorporates effect size analysis to determine the strength of the intervention's impact on students' numeracy skills. This approach provides deeper insight into not only whether the use of PhET simulations is effective, but also how substantial the improvement is in measurable terms. Consequently, the findings of this study are expected to offer valuable implications for physics educators, curriculum developers, and policymakers in designing more effective learning strategies that integrate conceptual understanding with strong numeracy competencies.

Another important aspect that strengthens the relevance of this study is the alignment between virtual experiments and the characteristics of abstract physics concepts such as momentum and impulse. These concepts often involve instantaneous events, such as collisions, which are difficult to observe directly in real classroom settings. Through PhET Interactive Simulations, students are able to repeatedly simulate these events with controlled variables, allowing them to generate consistent numerical data for analysis. This repetition not only supports conceptual clarity but also reinforces students' ability to perform quantitative comparisons, identify trends, and validate mathematical relationships. As a result, students can develop a deeper understanding of how formulas are derived and applied, rather than merely memorizing them without context (Hagos, 2026).

Furthermore, the use of virtual experiments also addresses practical limitations commonly faced in traditional laboratory activities, such as limited equipment, time constraints, and safety concerns. By utilizing simulation-based learning, teachers can create a more inclusive and flexible learning environment where all students have equal opportunities to engage in experimental activities. This is particularly important in supporting numeracy development, as students need sufficient time and practice to interpret data and perform calculations accurately. In line with the growing emphasis on digital learning innovations, integrating PhET simulations into classroom instruction represents a strategic effort to enhance both technological literacy and numeracy skills simultaneously, preparing students to meet the challenges of modern science education.

## **RESEARCH METHOD**

### **Type of research**

This study employed a quantitative approach using a quasi-experimental design. The design applied in this research was the pretest-posttest control group design. This design was used to examine the effectiveness of virtual experiment-based learning in improving students' numeracy skills on the topic of Momentum and Impulse.

### **Research Design**

This study employed a quantitative approach using a *quasi-experimental design*. Specifically, the research applied a *pretest–posttest control group design* to examine the effectiveness of virtual experiment-based learning in improving students' numeracy thinking skills on the topic of Momentum and Impulse. The research design is presented as follows:

Table 1. The research design

Group	Pretest	Treatment	Posttest
Experiment	$O_1$	Virtual Experiment (PhET Simulation)	$O_2$
Control	$O_1$	Conventional Learning	$O_2$

In this design, both groups were given a pretest ( $O_1$ ) to measure their initial ability before the treatment. The experimental group received instruction through virtual experiments using PhET simulations, while the control group was taught using conventional learning methods. After the treatment, both groups were administered a posttest ( $O_2$ ) to assess the improvement in students' numeracy thinking skills. The use of this design allows the researcher to compare the learning outcomes between the experimental and control groups, as well as to measure the effect of the treatment by analyzing the differences between pretest and posttest scores.

### **Research Target/Subject**

The target population of this study comprised all eleventh-grade students of SMA Negeri 1 Purwanegara in the second semester of the 2024/2025 academic year. The sample of the study was selected using a *purposive sampling* technique. This technique involves selecting participants intentionally based on specific criteria that are relevant to the research objectives. In this study, two classes were chosen as the sample based on several considerations: (1) they belong to the same academic track, (2) they have relatively similar average physics scores from the previous semester, and (3) they have adequate readiness to participate in digital-based learning, including access to devices and internet connectivity. The use of purposive sampling aimed to ensure that both the experimental and control groups had comparable initial characteristics (Obilor, 2023; Magnone & Yeziarski, 2024). This condition is important to reduce potential bias and to ensure that any differences in learning outcomes can be attributed primarily to the treatment given. To support this assumption, preliminary data on students' initial abilities were obtained from pretest results and academic records, which were analyzed descriptively to confirm baseline equivalence between the groups.

### **Research Procedure**

To ensure a systematic and comprehensive understanding of the research procedure, the entire process of this study is presented in the form of a flowchart. This diagram illustrates the sequential stages undertaken, encompassing the preparation, implementation, and data collection and analysis phases, thereby providing a clear depiction of how the research was conducted.

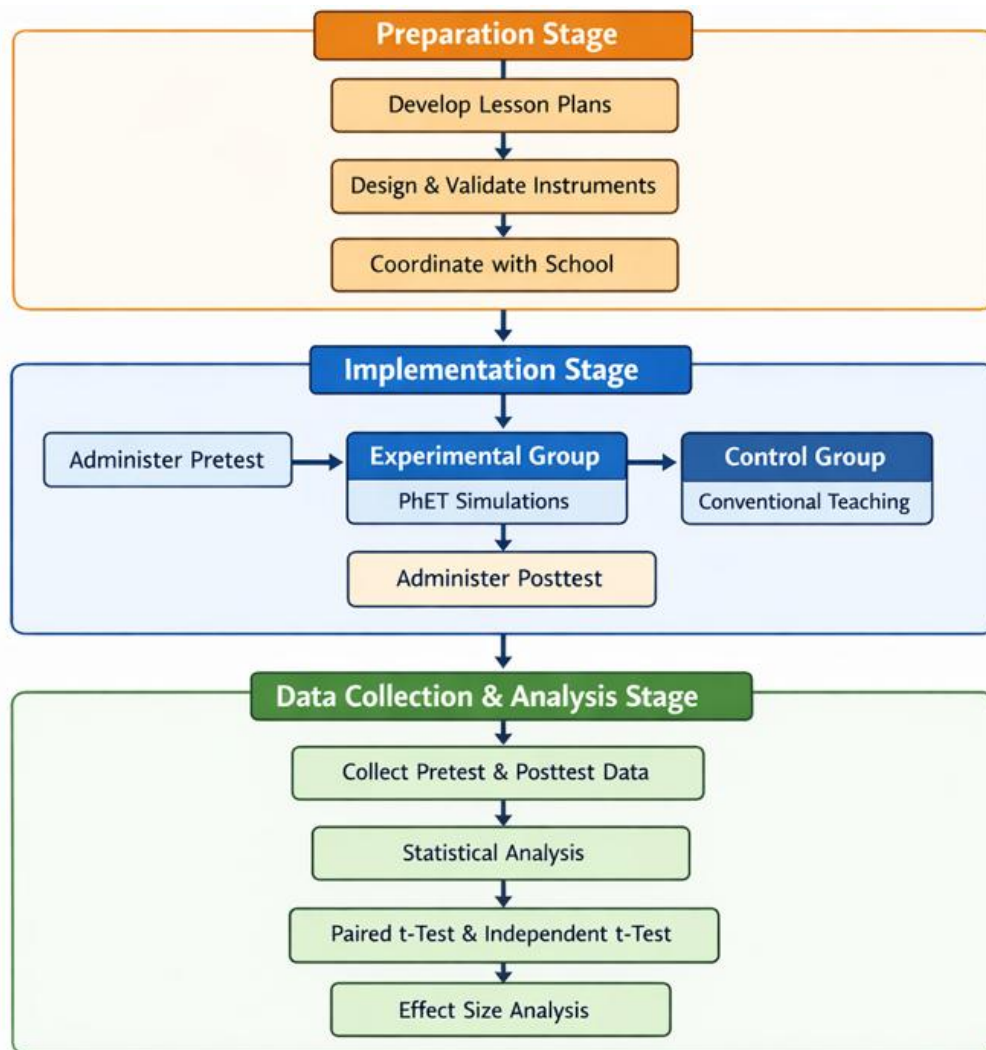


Figure 1. Research Procedure

As depicted in the flowchart, the research procedure was systematically structured into interconnected stages comprising preparation, implementation, and data collection and analysis. The sequential organization of these stages reflects a coherent methodological framework, ensuring procedural rigor and enabling a comprehensive evaluation of the treatment effects on students' numeracy thinking skills.

#### **Data analysis technique**

The data were analyzed quantitatively using parametric statistical methods. Prior to hypothesis testing, prerequisite analyses were conducted to ensure that the data met the assumptions required for parametric tests, including tests of normality and homogeneity of variance.

The normality test was conducted to determine whether the data were normally distributed. In this study, the Shapiro–Wilk test was used due to its suitability for small to moderate sample sizes. The decision criterion was based on the significance value ( $p$ -value). If the  $p$ -value is greater than 0.05, the data are considered to be normally distributed. Conversely, if the  $p$ -value is less than or equal to 0.05, the data are not normally distributed.

The homogeneity of variance test was performed to examine whether the variances of the groups being compared were equal. This assumption is important for the validity of the independent sample  $t$ -test. Levene's test was used in this study. The decision criterion is based on the  $p$ -value: if the  $p$ -value is greater than 0.05, the variances are considered homogeneous; otherwise, they are not homogeneous.

After the assumptions of normality and homogeneity were met, hypothesis testing was conducted using the *t*-test to examine differences in mean scores. Two types of *t*-tests were applied in this study. The paired sample *t*-test was used to compare the pretest and posttest scores within the same group, in order to determine whether there was a statistically significant difference before and after the treatment. The independent sample *t*-test was used to compare the posttest scores between the experimental group and the control group, provided that the data were homogeneous, in order to determine whether there was a statistically significant difference between the two groups. A significance level of 0.05 was used, where a *p*-value less than 0.05 indicates a statistically significant difference.

Hypothesis testing was carried out using the following statistical tests:

1. Paired Sample T-Test was used to determine whether there was a significant difference between pretest and posttest scores within each group.
2. Independent Sample T-Test was used to determine whether there was a significant difference between the experimental and control groups.

The magnitude of the treatment effect was measured using effect size (Cohen's *d*), calculated as follows:

$$d = \frac{M_{post} - M_{pre}}{SD_{pooled}}$$

- d* = effect size (Cohen's *d*)  
*M<sub>post</sub>* = mean score of the posttest  
*M<sub>pre</sub>* = mean score of the pretest  
*SD<sub>pooled</sub>* = pooled standard deviation

The pooled standard deviation was calculated using:

$$SD_{pooled} = \sqrt{\frac{(n_1 - 1)SD_1^2 + (n_2 - 1)SD_2^2}{2n - 2}}$$

Where:

- SD<sub>pooled</sub>* = pooled standard deviation  
*n<sub>1</sub>* = sample size of the first group  
*n<sub>2</sub>* = sample size of the second group  
*s<sub>1</sub><sup>2</sup>* = variance of the first group  
*s<sub>2</sub><sup>2</sup>* = variance of the second group

For small sample sizes, a correction was applied using Hedges' *g*, calculated as:

$$g = d \times \left[ 1 - \frac{3}{4N - 9} \right]$$

Where:

- g* = corrected effect size (Hedges' *g*)  
*d* = Cohen's *d* effect size  
*N* = total sample size

The interpretation of effect size followed Cohen's (1988) criteria:

- 0.20 = small effect  
 0.50 = medium effect  
 ≥ 0.80 = large effect

All statistical analyses were conducted using Jamovi software with a significance level of 0.05. A p-value less than 0.05 indicates a statistically significant result.

## RESULTS AND DISCUSSION

This study aimed to determine the effect of virtual experiment-based learning using PhET Colorado simulations on improving students' numeracy thinking skills in the topic of Momentum and Impulse. The measurement was conducted using pretest and posttest in both the experimental and control groups.

Table 2. Descriptive Statistics

Experimental	Pretest	Posttest	Improvement
Control Group	46.8	74.1	+27.3
Experimental Group	43.3	51.7	+8.4

Table 1 shows that both groups experienced improved learning outcomes, but the improvement in the experimental group was significantly higher than in the control group. The experimental group experienced an improvement of 27.3 points, while the control group only achieved 8.4 points. This difference indicates that virtual experiment-based learning using PhET is more effective in improving students' numeracy skills on momentum and impulse. This finding aligns with recent research showing that the use of interactive simulations significantly improves students' quantitative understanding and numeracy skills compared to conventional methods (Srisawasdi & Panjaburee, 2020; Ndzi & Naidoo, 2021).

Pedagogically, the significant improvement in the experimental group can be explained by the superiority of PhET in presenting multimodal representations that simultaneously integrate visual, numerical, and symbolic representations. These representations enable students to connect abstract concepts with real-world phenomena, facilitating the internalization of mathematical concepts and relationships. Research by Chen et al. (2022) shows that digital simulation-based learning can improve the ability to translate between representations, a crucial component of scientific numeracy. In this context, students not only perform calculations but also understand the meaning behind the quantitative relationships they learn.

Furthermore, simulation-based learning provides exploratory experiences that allow students to manipulate variables and directly observe changes. This supports an active learning process that has been proven more effective in improving higher-order thinking skills, including numeracy (Fitriani et al., 2021; Putri & Widodo, 2023). Through this exploration, students can build deeper understanding because they are directly involved in the process of discovering concepts, rather than simply passively receiving information.

From a numeracy perspective, this improvement indicates that students are able to develop skills in interpreting data, analyzing relationships between variables, and applying mathematical concepts in a physics context. This is crucial considering that numeracy is a key competency in 21st-century education and is a focus of various global and national education policies (OECD, 2022). Low student numeracy achievement in various international assessments demands learning innovations that effectively integrate concepts and skills.

The urgency of this research is further strengthened by the fact that many physics learning practices still focus on memorizing formulas without in-depth conceptual understanding. This condition makes it difficult for students to apply concepts in real-world situations. Therefore, the use of simulations such as PhET is a strategic solution to address this problem by providing more contextual, interactive, and meaningful learning (Hidayat et al., 2022).

In terms of novelty, this research makes an important contribution by emphasizing the improvement of numeracy skills through the use of virtual experiments. Previous research has tended to focus on conceptual understanding or learning motivation, whereas this study specifically demonstrates that simulations are also effective in developing students' numerical thinking skills. Thus, this research broadens the scope of the benefits of using technology in physics learning, particularly in strengthening numeracy literacy.

Table 3. Paired Sample T-Test Results and Effect Size

Experimental	t	p-value	Effect Size (d)	Category
Control Group	-20.5	<0.001	2.31	Very large
Experimental Group	-2.65	0.012	0.48	Medium

Based on Table 2, the inferential test results show that the improvements in both groups were statistically significant, but with strikingly different strengths. The experimental group had an effect size of 2.31, which is considered very large, while the control group had only 0.48, which is considered medium. This indicates that virtual experiment-based learning is not only effective but also has a very strong impact on improving students' numeracy skills. This finding is supported by recent research indicating that the use of digital simulations in science learning can have a significant impact on improving students' quantitative analysis skills (Suhandi et al., 2020; Nurhayati et al., 2023).

This difference in effect sizes indicates that the learning approach plays a crucial role in determining the quality of learning outcomes. In PhET-based learning, students are actively involved in the process of exploration, variable manipulation, and analysis of results, allowing them to develop a deeper understanding. This aligns with the inquiry-based learning approach, which emphasizes the importance of active student involvement in the learning process to improve critical thinking and numeracy skills (Rahmawati et al., 2022).

Furthermore, simulations also help reduce students' cognitive load by presenting information in an intuitive and easy-to-understand visual format. Research by Kurniawan et al. (2021) shows that the use of simulation-based media can improve students' cognitive efficiency in understanding abstract concepts, allowing them to focus more on the mathematical reasoning process. Thus, students are not simply memorizing formulas but are able to understand the relationships between variables logically and systematically.

In terms of urgency, these results demonstrate that the transformation of learning towards the use of digital technology is an unavoidable necessity in the modern education era. Numeracy skills are one of the main indicators of educational success, so learning strategies that can optimally develop these skills are needed. The use of PhET as a learning medium is one innovation that can address this challenge (OECD, 2022).

The novelty of this research also lies in the use of effect size as the primary indicator in assessing the strength of the learning impact. This approach provides a more comprehensive picture than simply using significance tests, making the research results more practically meaningful. By demonstrating a very large effect size, this study provides strong empirical evidence that virtual experiment-based learning is a highly effective approach in improving students' numeracy skills.

Overall, the results of this study confirm that integrating technology into physics learning not only improves conceptual understanding but also plays a crucial role in developing students' numeracy skills. Therefore, the implementation of simulation-based learning needs to be expanded and systematically integrated into the science education curriculum.

## CONCLUSION

This study demonstrates that virtual experiment-based learning using PhET simulations is more effective than conventional instruction in improving students' numeracy skills in the topic of momentum and impulse. This is supported by a substantially larger effect size in the experimental group compared to the control group, indicating a stronger impact of the treatment. The findings highlight that interactive simulations facilitate students in interpreting mathematical representations, analyzing relationships between variables, and applying quantitative reasoning.

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