SPEKTRA: Jurnal Kajian Pendidikan Sains
Vol. 10, No. 2, 2024, pp. 244-258
ISSN: 2548-642X, DOI: 10.32699/spektra.v10i2.7740

THE IMPACT OF UTILIZING INTERACTIVE CONCEPTUAL INSTRUCTION ASSISTED BY PHET SIMULATIONS ON STUDENTS' UNDERSTANDING ABILITY IN PHYSICS

M. Furqon[1]
[1]Department of Physics Education, Faculty of Teaching Training and Education, Universitas Jambi, Muaro Jambi, Indonesia

Article Info

Article history:
Received 26/07/2024
Accepted 30/09/2024
Published 07/10/2024

Keywords:
Impact;
Interactive conceptual instruction
PhET simulations;
Understanding;
Physics;

ABSTRACT

Recent research in physics education highlights the positive effects of PhET simulations on enhancing students' comprehension of physics topics. However, there is still a gap in investigating the combined impact of PhET simulations and Interactive Conceptual Instruction (ICI) in improving student understanding. This study seeks to assess the effect of integrating ICI with PhET simulations on students' conceptual grasp of physics. A quasi-experimental design was used, employing a pretest-posttest control group setup. The sample consisted of 62 high school students in Indonesia, with 32 in the experimental group and 30 in the control group. Data analysis, conducted using the t-test and N-Gain calculations, revealed a significant difference between the groups. The experimental group, which utilized PhET simulations, achieved a higher N-Gain score (0.61) compared to the control group (0.41), reflecting greater improvement in conceptual understanding. These results suggest that the combination of ICI with PhET simulations has the potential to significantly enhance physics learning outcomes.

Corresponding Author:
M. Furqon
[1]Department of Physics Education, Faculty of Teaching Education, Universitas Jambi, Muaro Jambi, Indonesia
Email: mfurqon@unja.ac.id

1. INTRODUCTION

Integrating physics education is essential for strengthening students' scientific understanding and their knowledge of the natural world. Nevertheless, many students encounter difficulties when grasping complex physics theories and concepts (Wieman & Perkins, 2005). Conventional teaching methods often emphasize passive learning techniques, which may reduce student involvement and impede their understanding of various topics (Freeman et al., 2014). To tackle this issue, educators are increasingly turning to technology-enhanced teaching strategies, such as interactive simulations. One notable platform is physics education technology (PhET), which offers virtual, interactive environments where students can visualize and experiment with physics concepts. PhET simulations, created by the University of Colorado Boulder, serve as dynamic digital tools that emulate real-world phenomena. A wealth of studies has confirmed their effectiveness in enriching students' learning experiences in science and mathematics (Adams et al., 2010; Moore et al., 2014; Perkins et al., 2012). Research by Lancaster et al. (2013) and

McKagan et al. (2008) further supports PhET's role in enhancing students' understanding of scientific subjects. These virtual environments enable learners to adjust variables, witness visual representations, and carry out virtual experiments, thereby boosting engagement and immersion in the learning process.

In recent times, PhET simulations have gained considerable prominence in physics education, as highlighted by numerous studies that emphasize their advantages. Adams et al. (2010) explored challenges and potential solutions in developing online science learning materials, focusing on the global accessibility of PhET simulations. As open educational resources, PhET simulations play a vital role in making high-quality science education more accessible. Moreover, these simulations offer a platform that enhances student engagement and understanding of intricate scientific ideas. As technology becomes more integral to teaching methods, PhET remains a pivotal resource in merging traditional education with innovative digital tools. Several studies have delved into the impact of PhET simulations on specific physics topics such as momentum and impulse (Adimayuda et al., 2021), optical materials (Aminah et al., 2020), the photoelectric effect (Aminoto et al., 2021), and Newton's law of gravitation (Aryani et al., 2019). Additionally, Admoko et al., (2019) used virtual laboratory simulations combined with guided discovery learning to correct students' misconceptions about mechanical waves. PhET simulations have consistently proven effective in improving student understanding and reducing misunderstandings. Ardiyati et al. (2019) also demonstrated that using scaffolding strategies with PhET simulations enhanced science process skills in physics, underscoring the effectiveness of PhET in helping students grasp both basic and advanced physics concepts.

Furthermore, PhET simulations have been shown to improve students' critical thinking skills. Agustina & Dwikoranto (2021) developed STEM-focused worksheets that incorporated PhET simulations of Hooke's law to enhance critical thinking. Positive outcomes from using PhET simulations in physics education include improvements in scientific literacy (Bahtiar & Maimun, 2022), creativity (Astutik & Prahani, 2018), and visual representation skills (Luliyarti et al., 2020). These results underscore the positive impact of PhET simulations on various aspects of physics education. While the benefits of PhET simulations are well-recognized, exploring the advantages of combining PhET simulations with interactive conceptual instruction (ICI) in physics education is equally important. ICI promotes active student participation, deeper conceptual understanding, and practical application of knowledge. This approach incorporates interactive activities, discussions, and hands-on experiments to enhance the understanding of scientific topics (Haryadi & Pujiastuti, 2020; Johan, 2018). Hasyim et al. (2020) and Maulidina et al., (2019) suggest that merging ICI with PhET simulations fosters active student engagement, interaction with virtual models, and improved understanding of physics subjects.

Although previous studies have examined the effectiveness of PhET simulations in fostering critical thinking, scientific literacy, and creativity, research combining PhET simulations with ICI remains limited. Most studies have focused on PhET or ICI as standalone teaching methods, with little attention to their potential combined impact. Despite suggestions that the integration of ICI with PhET simulations could increase student engagement and conceptual understanding (Hasyim et al., 2020; Maulidina et al., 2019), there is insufficient empirical evidence to confirm this. Further research is necessary to evaluate the synergistic effects of different instructional strategies on students' learning outcomes in physics. Future research should investigate the combined effects of PhET simulations and ICI on students' understanding and retention of physics concepts. Such studies can reveal whether the integration of these methods offers a synergistic advantage over using each one independently, particularly in enhancing conceptual understanding and student engagement in physics education.

While there is substantial research supporting the benefits of PhET simulations, certain gaps remain. Many studies have focused on PhET's effectiveness in improving students' understanding of specific physics concepts, such as momentum, optical materials, the photoelectric effect, and Newton's law of gravitation (Adimayuda et al., 2021; Aminah et al., 2020; Aminoto et al., 2021; Aryani et al., 2019). Additionally, researchers have explored how PhET helps correct misconceptions (Admoko et al., 2019), improve scientific process skills (Ardiyati et al., 2019), and foster critical thinking and scientific literacy (Agustina & Dwikoranto, 2021; Astutik & Prahani, 2018; Bahtiar & Maimun, 2022; Luliyarti et al., 2020). However, limited studies have examined the combined use of PhET and ICI to boost students' conceptual understanding in physics. Therefore, it is essential to explore the combined influence of PhET simulations and ICI on students' understanding and retention of physics concepts in a broader educational framework. Filling this research gap could offer valuable insights for educators seeking to enhance student learning outcomes through innovative instructional approaches. This study aims to assess the impact of integrating PhET simulations and ICI on students' engagement and understanding in physics education.

2. METHOD

2.1. Design and Partipants

The study employed a quantitative research approach, utilizing a quasi-experimental design known as the pretest-posttest group format, as outlined by (Creswell & Guetterman, 2019). This design enables the comparison of control and experimental groups to identify potential causal relationships. The primary aim of the research was to assess the effectiveness of interactive conceptual instruction through PhET simulations in enhancing students' understanding of physics. A pretest was administered to evaluate the students' baseline knowledge, followed by a posttest after the intervention to assess knowledge gains, allowing for a comparison between the two groups. A total of 62 high school students from a public school in Indonesia participated in the study. They were divided into two groups: 30 students in the control group and 32 in the experimental group. Purposive sampling was used to select participants based on specific criteria that aligned with the study's objectives. Only students at the same grade level who had not previously experienced interactive conceptual instruction with PhET simulations were included in the sample. Figure 1 provides a visual overview of the experimental design.

Time →

Select control group	Pretest	No treatment	Posttest
Select experimental group	Pretest	Experimental treatment	Posttest

Figure 1. Pre- and post-test group design

2.2. Research Procedure

The research process is divided into three critical phases: preparation, implementation, and finalization. In the preparation phase, the researcher undertakes a comprehensive literature review, conducts a field study, selects participants, assigns them to groups, and prepares the necessary instruments. During the implementation phase, pretest and posttest are administered using the developed assessment tools. In this phase, the experimental group undergoes an intervention, which includes interactive conceptual instruction using PhET simulations. Lastly, in the Finalization phase, the researcher collects and analyzes the data from the pre-tests and post-tests, subsequently presenting the results. Figure 2 present outlines the entire research process.

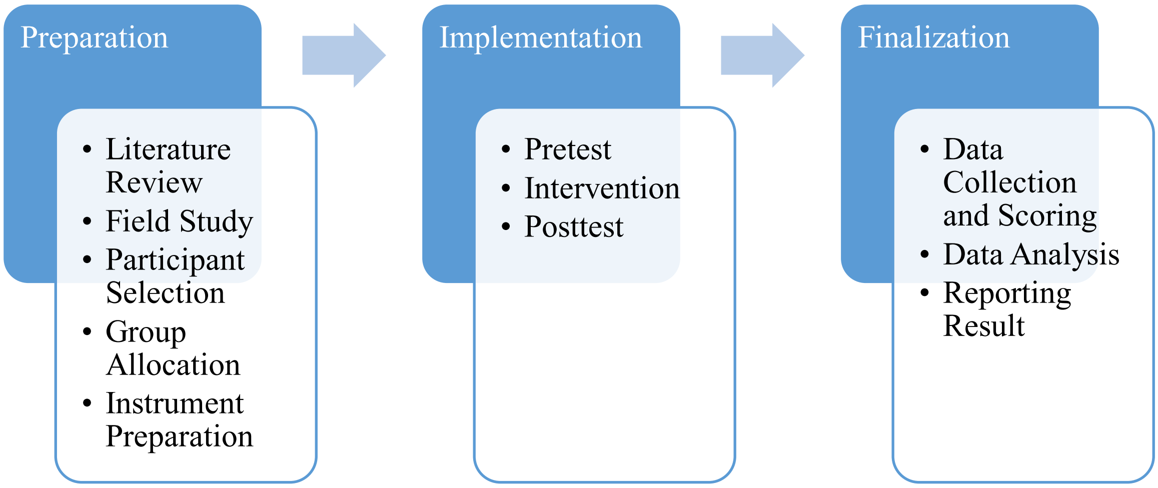

Figure 2. Research procedure

2.3. Data Collection and Instruments

Data was obtained through pretest and posttest forms to assess students' understanding. The instrument utilized for this purpose was a understanding evaluation, constructed in alignment with (Anderson & Krathwohl, 2001) Revised Bloom's Taxonomy. The evaluation has 20 multiple-choice questions centered on Newton's Law, each designed to measure one of five specific cognitive indicators: interpreting, exemplifying, inferring, comparing, and explaining. The distribution of these questions is illustrated in Table 1.

Table 1. Distribution items of understanding ability test

Indicator	Concept	Item Number(s)
Interpreting	Newton First Law	1
	Newton Second Law	2,3
	Newton Third Law	4
Exemplifying	Newton First Law	5
	Newton Second Law	6,7
	Newton Third Law	8
Inferring	Newton First Law	9
	Newton Second Law	10, 11

Indicator	Concept	Item Number(s)
	Newton Third Law	12
Comparing	Newton First Law	13
	Newton Second Law	14, 15
	Newton Third Law	16
Explaining	Newton First Law	17
	Newton Second Law	18, 19
	Newton Third Law	20

The test was validated by experts and underwent field trials to confirm its effectiveness before being applied in the research. The validation process used the content validity index (CVI) method, which involved five experts in physics content, physics education, and educational evaluation. The CVI assesses the overall content validity of the test items. Based on this technique, the test received a CVI score of 0.77, which, according to Irawan & Wilujeng (2020), indicates a moderate level of validity. Additionally, a field trial was conducted to evaluate the test's reliability using the KR-20 method, which resulted in a reliability index of 0.67. This score, as per Sutrisno (2016), is considered to reflect good reliability, confirming that the test is dependable.

2.4. Data Analysis

The research data consists of quantitative scores obtained from both pretests and posttests. Student scores were calculated using a rights-only scoring method, where correct answers were awarded one point, and incorrect or unanswered items received zero points. The mean score for both the pretest and posttest was calculated using the following formula 1:

$$\bar{X} = \frac{\Sigma\ obtained\ score}{\Sigma\ maximum\ score} \times 100\% \quad (1)$$

This method allowed for the calculation of the average performance of students in both the control and experimental groups, both before and after the intervention. By comparing the pretest and posttest results, the researchers were able to assess the impact of the intervention on the students' understanding and identify any performance differences between the two groups.

A mean difference analysis was conducted to evaluate the impact of Interactive Conceptual Instruction (ICI) with PhET simulations on students' physics comprehension. The Kolmogorov-Smirnov test assessed the normality of the data, and if $D_{max} \leq D_{table}$, the data were considered normally distributed. A 95% confidence level was used. For non-normal data, a nonparametric test was applied. Homogeneity was tested using Bartlett's or Levene's test, depending on normality. If ${\chi^2}_{count} \leq {\chi^2}_{table}$, the data were homogeneous. When both conditions were met, a t-test was used; otherwise, the Mann-Whitney test was applied. A significant difference occurred if $t_{count} > t_{table}$. To assess improvement, normalized gain (Hake, 1998) was calculated in formula 2:

$$(g) = \frac{\%\ posttest - \%\ pretest}{100 - \%\ pretest} \quad (2)$$

This examination was performed for both comprehensive understanding and particular facets. The augmentation in each facet was evaluated utilizing the N-gain. The categories of N-gain scores are presented in Table 2:

Table 2. Category of N-gain score

N-Gain Score	Category
0,70 ≤ (g) ≤ 1,00	High
0,30 ≤ (g) < 0,70	Medium
0,00 < (g) < 0,30	Low

3. RESULTS AND DISCUSSION

3.1. Implementations of Interactive Conceptual Instruction Assisted by PhET Simulations

The instructional process employing Interactive Conceptual Instruction Assisted by PhET Simulations encompasses distinct stages:

1. Orientation Stage: This phase underscores the conceptual aspects, initiated by the instructor's use of questioning to elicit prior knowledge and recapitulate previously covered material. Motivation is further nurtured through the presentation of a pertinent video related to the subject of Newton's Laws. Subsequent discussions, grounded in inquiry, prompt students to respond to queries tied to the video content.
2. Conceptualization Stage: In this phase, the instructor delivers a demonstration that centers on the fundamental principles of Newton's Laws. Engaging question techniques are employed to involve students in the demonstration. Following this, students are grouped and guided through experiments employing PhET Simulations, designed to address questions aligned with the previously showcased concepts. The facilitation of these experiments is augmented by the utilization of PhET Simulations-based Worksheets. Collaborative discussions within groups are subsequently encouraged, concentrating on the outcomes of the Newton's Laws experiments. These groups are subsequently tasked with collectively deriving conclusions from the results of the experiments. Representative students are chosen to present their respective group's findings, providing other groups an opportunity to contribute their perspectives.
3. Concept Reinforcement Stage: Here, the instructor deploys various modes of representation verbal, graphical, and mathematical to elucidate the relationships between variables in Newton's Laws. Moreover, the instructor delves into the underlying causes of events portrayed in the video and demonstrated during the lesson, capitalizing on the tenets of Newton's Laws. Collaborative problem-solving tasks, revolving around Active Learning Problem Sheets (ALPS), are assigned to groups. These problems are rooted in the application of Newton's Laws and involve the use of PhET Simulations. Subsequent group discussions strive to tackle these problems, with the instructor guiding discussions and addressing students' inquiries regarding the ALPS questions.
4. Review Stage: In this culminating phase, the instructor guides students in summarizing the day's lesson on Newton's Laws. Students are prompted to document the concepts they have acquired throughout the lesson. Furthermore, formative assessment is encouraged through the attempt of practice questions pertinent to Newton's Laws. Following this, structured assignments are

provided, including the generation of summaries and concept maps linked to Newton's Laws. The lesson concludes with a glimpse into forthcoming subjects to be covered in subsequent sessions.

3.2. Result of Normality and Homogenity Test

The Kolmogorov-Smirnov test assessed the normality of the student's understanding ability data, with a confidence level of 95%. Table 3 displays the outcomes of the normality test conducted to assess the capacity to comprehend facts.

Table 3. The normality test result of understanding ability data

D value	Experimental Group		Control Group	
	Pretest	Posttest	Pretest	Posttest
D_{max}	0.218	0.161	0.139	0.132
D_{table}	0.234		0.242	

Based on the data in Table 3, the D_{max} values for both the pretest and posttest comprehension ability data in the experimental and control groups are consistently lower than the D_{table} value. This indicates that the data in both groups follow a normal distribution. Consequently, it can be concluded that all four datasets are derived from populations that follow a normal distribution. A homogeneity test was also conducted on the data related to students' understanding abilities using Bartlett's test at a 95% confidence level. The outcomes of this homogeneity test, applied to the understanding ability data, are presented in Table 4.

Table 4. The homogenity test result of understanding ability data

χ^2 value	Experimental Group		Control Group	
	Pretest	Posttest	Pretest	Posttest
${\chi^2}_{count}$	0.048		3.206	
${\chi^2}_{table}$	3.841			

As shown in Table 4, the ${\chi^2}_{count}$ values for both the pretest and posttest comprehension ability data in the experimental group, as well as for the control group's pretest and posttest data, are lower than the corresponding ${\chi^2}_{table}$ values. This suggests that the data for both groups satisfy the homogeneity assumption. Therefore, it can be concluded that the variances in both datasets are homogeneous.

3.3. Result of Mean Difference Test

The normality and homogeneity tests confirmed that the data on students' comprehension abilities in both the experimental and control groups were normally distributed and had homogeneous variances. With these assumptions verified, a mean difference analysis was performed to compare the two groups. The outcomes of this analysis are shown in Table 5.

Table 5. The mean difference test result of understanding ability data

t value	Experimental Group		Control Group	
	Posttest	Pretest	Posttest	Posttest
t_{count}	1.67		3.81	
t_{table}	2.40			

As illustrated in Table 5, the t_{count} value for the pretest of comprehension abilities in both the experimental and control groups is lower than the t_{table} value, indicating no significant difference in the average pretest scores between the groups. However, the t_{count} value for the posttest exceeds the t_{table} value, showing a significant difference in the average posttest scores between the experimental and control groups. this suggests that the use of interactive conceptual instruction (ICI) with PhET simulations positively impacts students' understanding of physics concepts. Similarly, the t_{count} value for pretest comprehension abilities is below the t_{table} value, indicating no statistically significant difference in the pretest scores between the two groups. In contrast, for the posttest, the t_{count} value surpasses the t_{table} value, revealing a statistically significant difference between the groups' posttest scores. This further validates that integrating PhET simulations with Interactive Conceptual Instruction enhances students' grasp of physics concepts.

3.4. Average N-Gain on Understanding Ability in Physics

In the pretest assessing students' understanding skills, the experimental group scored between 30 and 65, while the control group scored between 35 and 60. After the intervention, the posttest results showed that the experimental group's scores ranged from 65 to 90, while the control group scored between 55 and 85. The experimental group recorded an average pretest score of 46.88, compared to 51.67 in the control group, showing a difference of 4.79 points. In the posttest, the experimental group achieved an average score of 79.06, while the control group averaged 71.33, indicating a significant difference of 7.73 points between the two groups. Figure 3 presents a comparison of the average N-Gain, which measures the improvement in students' understanding skills, between the experimental and control groups.

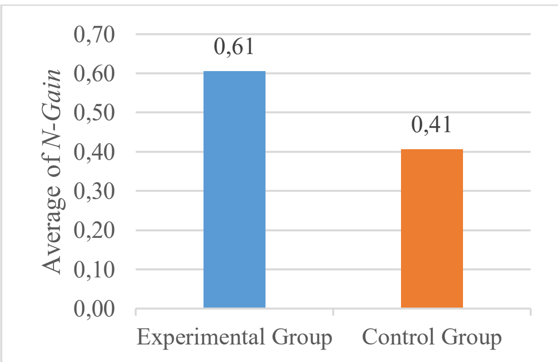

Figure 3. Comparison of Average N-Gain of Understanding Ability

The researchers assessed both the overall growth of students' understanding skills and their progress in specific aspects of understanding. The evaluation focused on five key dimensions:

interpreting, exemplifying, inferring, comparing, and explaining. These dimensions were used to gauge students' understanding abilities. Figure 4 illustrates the mean N-Gain for each of these dimensions, comparing the results between the experimental and control classes, highlighting how students in each group improved across the various aspects of understanding.

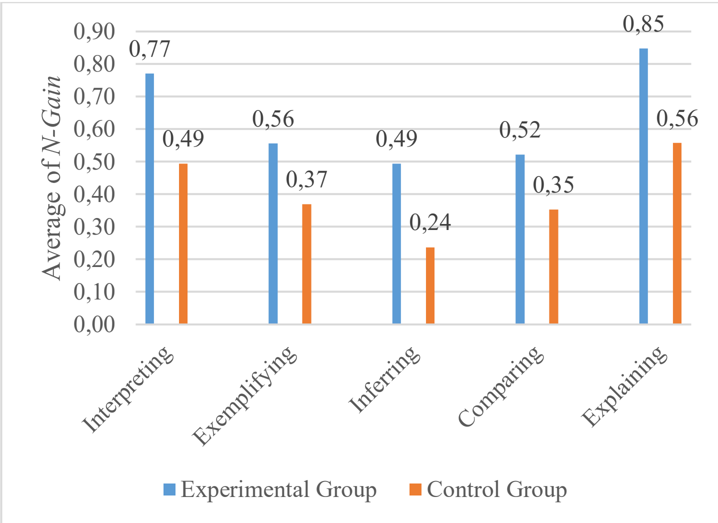

Figure 4. Comparison of Average N-Gain for Each Aspect of Understanding Ability

The analysis of the posttest average scores for each dimension of students' understanding abilities reveals that, in the experimental group, the dimensions are ranked from highest to lowest as follows: interpreting, explaining, comparing, exemplifying, and inferring. The highest average score was achieved in interpreting, with a value of 93.75, while the lowest was in inferring, at 64.84. In the control group, the dimensions are ordered by average scores in the following descending sequence: explaining, comparing, exemplifying, interpreting, and inferring. The highest score in the control group was in the explaining dimension, at 84.17, while the lowest scores were in interpreting and inferring, both at 62.50. The experimental group outperformed the control group in the dimensions of interpretation, exemplification, inference, and explanation. However, in the comparison dimension, the control group's mean score was slightly higher. These results suggest that Interactive Conceptual Learning, combined with PhET simulations, has a positive and significant impact on nearly all aspects of students' understanding abilities, as evidenced by the improvements in the average understanding scores across the different dimensions.

Figure 4 illustrates that the average N-Gain for each dimension of understanding ability in the experimental group consistently surpasses that of the control group. This highlights the notable improvement in understanding skills within the experimental group, confirming the effectiveness of Interactive Conceptual Learning supported by PhET simulations. In the experimental group, two dimensions interpreting and explaining were rated as high, while three dimensions exemplifying, inferring, and comparing were categorized as medium. In contrast, the control group had four dimensions interpreting, exemplifying, comparing, and explaining rated as moderate, with inferring rated as poor. These findings demonstrate that the experimental group, which utilized Interactive Conceptual Learning enhanced by PhET simulations, experienced greater improvements in all aspects of understanding compared to the control group, which engaged in Interactive Conceptual Learning without the use of PhET simulations. This underscores the significant advantage of incorporating PhET simulations in promoting students' understanding abilities.

3.5. Improvement of Student's Understanding Ability in Physics

This study utilizes PhET simulations as an interactive tool to investigate Newton's laws. Three distinct PhET simulations are employed, covering Newton's first, second, and third laws. In the simulation for Newton's first law, students conduct virtual experiments by applying varying forces to objects of different masses until they initiate movement. The motion is then maintained by manipulating controls within the simulation, using the cursor and menu. The goal is for students to grasp Newton's first law, which asserts that an object at rest remains at rest, and an object in motion continues to move at a constant velocity unless acted upon by an external net force. Figure 5 illustrates the PhET simulation corresponding to Newton's first law.

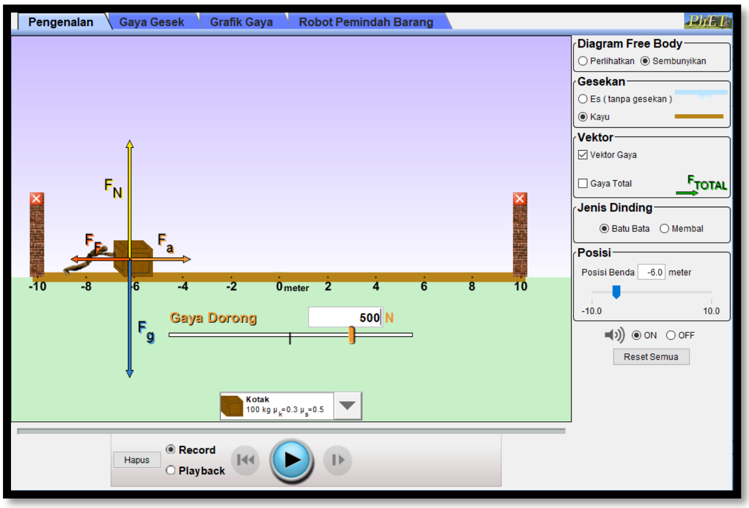

Figure 5. PhET simulation of Newton's first law

In the PhET simulation for Newton's Second Law, students engage in virtual experiments by applying a constant force to objects with different friction coefficients, which leads to uniform motion. This interactive tool allows students to explore and comprehend Newton's Second Law, which states that an object will experience uniform acceleration when the net force acting on it is greater than zero. Figure 6 illustrates a part of the PhET simulation showcasing Newton's Second Law in action.

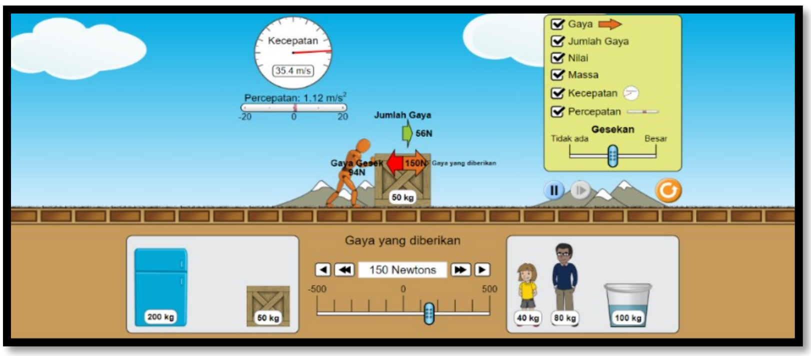

Figure 6. PhET simulation of Newton's second law

In the PhET simulation for Newton's Third Law, students conduct experiments by applying a constant force to different objects with varying friction coefficients. This force maintains the motion of the objects, demonstrating the interaction of forces. Through this simulation, students explore Newton's Third Law, which states that for every action, there is an equal and opposite reaction. Figure 7 provides a visual representation of the PhET simulation, illustrating how forces operate in pairs on different objects.

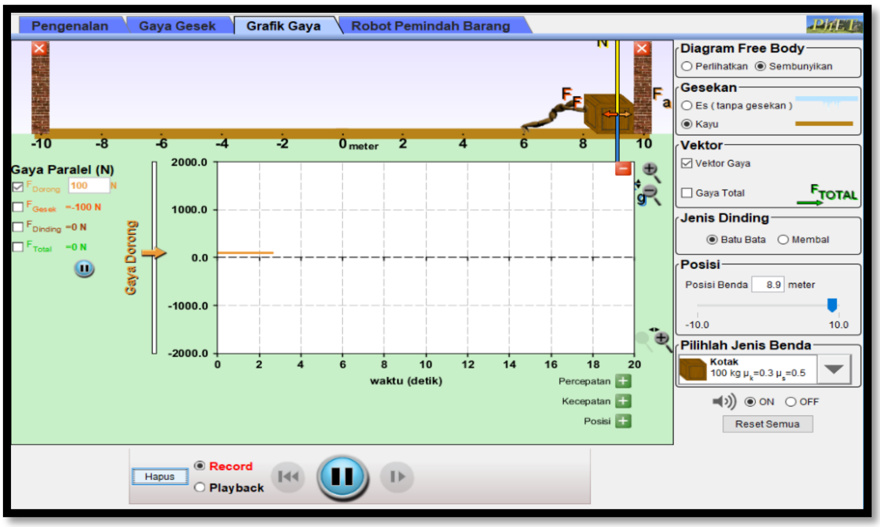

Figure 7. PhET simulation of Newton's third law

The t-test analysis showed a statistically significant difference in the mean scores between the two groups, indicating a substantial performance gap. These findings suggest that the use of interactive conceptual training with PhET simulations enhances students' understanding skills. The PhET simulations include multiple features such as images, vectors, and mathematical formulas that aid in improving students' understanding and representation of physics concepts like Newton's Laws. Furthermore, the interactive nature of PhET allows students to perform virtual experiments, easily manipulate experimental variables, and actively engage in the learning process, facilitating a deeper grasp of the physics topics presented.

This conclusion aligns with previous studies by Johan (2018), Kurnaz & Arslan (2014), Nulhaq & Setiawan (2016), Setyani et al. (2017), and Waldrip et al. (2006), all of which highlight that interactive conceptual learning and multiple representations can significantly enhance students' understanding of physics concepts. According to Dual Coding Theory, the human cognitive system comprises two channels: the verbal subsystem and the nonverbal (visual) subsystem. People process information through either or both subsystems, where the verbal subsystem deals with words or speech, and the nonverbal subsystem handles visual data, such as pictures, diagrams, graphs, and animations. Dual Coding Theory suggests that learning is more effective when instructional materials integrate both verbal and nonverbal elements. The inclusion of multiple representations, like visuals, graphs, tables, and mathematical expressions, enhances memory retention by promoting dual coding (Johan et al., 2018).

Research by Ainsworth (2006) suggests that multirepresentation helps students build deeper conceptual understanding by synthesizing knowledge from different formats, which, in turn, aids in the understanding of scientific concepts. The results in Figure 2 indicate that the experimental group achieved an average N-Gain of 0.61, categorized as moderate, while the control group attained an average N-Gain of 0.41, also moderate. Although both groups demonstrated significant N-Gains, the experimental group surpassed the control group by a margin of 0.20. This demonstrates that the experimental group, which used interactive conceptual instruction through PhET simulations, showed greater improvement in understanding than the control group, which received interactive instruction without PhET simulations.

These findings are consistent with the research by Suryani et al. (2018), which suggests that students engaged in multirepresentation learning exhibit a higher level of understanding compared to those not using this approach. The primary goal of multirepresentation is to enhance understanding, allowing students to develop a deeper, more abstract understanding, establish generalizations, and form connections between various representations. This explanation supports the idea that multirepresentation significantly improves conceptual learning by emphasizing the understanding of key concepts and promoting qualitative reasoning throughout the learning process. When students synthesize knowledge from multiple representations, they achieve a more profound understanding (Ainsworth, 2006). Integrating textual and visual elements is essential for maximizing learning outcomes.

4. CONCLUSION

The research findings, data analysis, and discussion demonstrate a notable difference in students' understanding abilities between those who participated in interactive conceptual training with PhET simulations and those who received similar training without PhET simulation support. The students who engaged with PhET simulations showed a greater improvement in their understanding compared to those who did not use this tool. The use of interactive conceptual learning via PhET simulations significantly enhances students' understanding and should be implemented systematically and continuously across various physics topics to maximize understanding. To further enhance learning outcomes, students should utilize computer-based tools to create accurate representations of images and graphs, ensuring proportionality and minimizing interpretative errors. This approach not only strengthens understanding but also promotes clearer, more precise visualizations of complex physics concepts.

REFERENCES

Adams, W. K., Alhadlaq, H., Malley, C. V., Perkins, K. K., Olson, J., Alshaya, F., Alabdulkareem, S., & Wieman, C. E. (2010). Making on-line science course materials easily translatable and accessible worldwide: Challenges and solutions. *Nuovo Cimento Della Societa Italiana Di Fisica C*, *33*(3), 113–119. Scopus. https://doi.org/10.1393/ncc/i2010-10619-8

Adimayuda, R., Sari, L., Ismail, A., Amalia, I. F., Gumilar, S., & Samsudin, A. (2021). *Assessing two-dimensional collisions second-years students using PhET simulations on momentum and impulse concept*. *1869*(1). Scopus. https://doi.org/10.1088/1742-6596/1869/1/012204

Admoko, S., Yantidewi, M., & Oktafia, R. (2019). *The Implementation of Guided Discovery Learning Using Virtual Lab Simulation to Reduce Students' Misconception on Mechanical Wave*. *1417*(1). Scopus. https://doi.org/10.1088/1742-6596/1417/1/012089

Agustina, F. R. & Dwikoranto. (2021). *Development of STEM model student worksheets with PhET simulation on Hooke's law material to improve the ability students' critical thinking*. *2110*(1). Scopus. https://doi.org/10.1088/1742-6596/2110/1/012023

Ainsworth, S. (2006). DeFT: A conceptual framework for considering learning with multiple representations. *Learning and Instruction*, *16*(3), 183–198. https://doi.org/10.1016/j.learninstruc.2006.03.001

Aminah, S. N., Jumadi, & Astuti, D. P. (2020). *The development of PBL e-handout assisted by PhET simulation of optical material-lenses for high school students*. *1440*(1). Scopus. https://doi.org/10.1088/1742-6596/1440/1/012038

Aminoto, T., Pujaningsih, F. B., Dani, R., & Riantoni, C. (2021). *Assessing pre-service physics teachers' competencies in designing photo-electric effect experiment using PhET simulation*. *1876*(1). Scopus. https://doi.org/10.1088/1742-6596/1876/1/012065

Anderson, L. W., & Krathwohl, D. R. (Eds.). (2001). *A taxonomy for learning, teaching, and assessing: A revision of Bloom's taxonomy of educational objectives* (Complete ed). Longman.

Ardiyati, T. K., Wilujeng, I., Kuswanto, H., & Jumadi. (2019). *The Effect of Scaffolding Approach Assisted by PhET Simulation on the Achievement of Science Process Skills in Physics*. *1233*(1). Scopus. https://doi.org/10.1088/1742-6596/1233/1/012035

Aryani, W. D., Suhendi, E., Suyana, I., Samsudin, A., & Kaniawati, I. (2019). *Effectiveness of implementation interactive conceptual instruction (ICI) with computer simulation to overcome students' misconceptions about newton's law of gravitation*. *1280*(5). Scopus. https://doi.org/10.1088/1742-6596/1280/5/052011

Astutik, S., & Prahani, B. K. (2018). The practicality and effectiveness of Collaborative Creativity Learning (CCL) model by using PhET simulation to increase students' scientific creativity. *International Journal of Instruction*, *11*(4), 409–424. Scopus. https://doi.org/10.12973/iji.2018.11426a

Bahtiar, I. & Maimun. (2022). Analysis of Students' Scientific Literacy Skill in Terms of Gender Using Science Teaching Materials Discovery Model Assisted by PhET Simulation. *Jurnal Pendidikan IPA Indonesia*, *11*(3), 371–386. https://doi.org/10.15294/jpii.v11i3.37279

Creswell, J., & Guetterman, T. (2019). *Educational research: Planning, conducting, and evaluating quantitative and qualitative research* (6th ed.). Pearson.

Freeman, S., Eddy, S. L., McDonough, M., Smith, M. K., Okoroafor, N., Jordt, H., & Wenderoth, M. P. (2014). Active learning increases student performance in science, engineering, and mathematics. *Proceedings of the National Academy of Sciences*, *111*(23), 8410–8415. https://doi.org/10.1073/pnas.1319030111

Hake, R. R. (1998). Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses. *American Journal of Physics*, *66*(1), 64–74. https://doi.org/10.1119/1.18809

Haryadi, R., & Pujiastuti, H. (2020). *PhET simulation software-based learning to improve science process skills*. *1521*(2). Scopus. https://doi.org/10.1088/1742-6596/1521/2/022017

Hasyim, F., Prastowo, T., & Jatmiko, B. (2020). The Use of Android-Based PhET Simulation as an Effort to Improve Students' Critical Thinking Skills during the Covid-19 Pandemic. *International Journal of Interactive Mobile Technologies*, *14*(19), 31–41. Scopus. https://doi.org/10.3991/ijim.v14i19.15701

Irawan, E., & Wilujeng, H. (2020). Development of an online mathematical misconception instrument. *Journal of Physics: Conference Series*, *1657*(1), 012080. https://doi.org/10.1088/1742-6596/1657/1/012080

Johan, H. (2018). Pengembangan Phenomena-Based Interactive Conceptual Instruction (PBICI) Pada Perkuliahan IPBA Untuk Meningkatkan Kemampuan Bernalar Dan Sikap …. *DISERTASI UPI*, *Query date: 2024-07-21 15:12:25*. https://repository.upi.edu/34472/1/D_IPA_1302873_Title.pdf

Johan, H., Suhandi, A., Wulan, A. R., & Sipriyadi, S. (2018). Impact of Learning Earth Litosphere using Interactive Conceptual Instruction on Logic Thinking, Conceptual Understanding, and Spiritual Aspect Embedding. *Jurnal Pendidikan Fisika Indonesia*, *14*(1), 7–17. https://doi.org/10.15294/jpfi.v14i1.8259

Kurnaz, M. A., & Arslan, A. S. (2014). Effectiveness of Multiple Representations for Learning Energy Concepts: Case of Turkey. *Procedia - Social and Behavioral Sciences*, *116*, 627–632. https://doi.org/10.1016/j.sbspro.2014.01.269

Lancaster, K., Moore, E. B., Parson, R., & Perkins, K. K. (2013). *Insights from using PhET's design principles for interactive chemistry simulations* (Vol. 1142, p. 126). Scopus. https://doi.org/10.1021/bk-2013-1142.ch005

Luliyarti, D. S., Jumadi, & Astuti, D. P. (2020). *Application of e-handout with Schoology-based PhET simulations to improve students' visual representation ability on optical material*. *1440*(1). Scopus. https://doi.org/10.1088/1742-6596/1440/1/012058

Maulidina, W. N., Samsudin, A., & Kaniawati, I. (2019). *Overcoming students' misconceptions about simple harmonic oscillation through interactive conceptual instruction (ICI) with computer simulation*. *1280*(5). Scopus. https://doi.org/10.1088/1742-6596/1280/5/052007

McKagan, S. B., Perkins, K. K., Dubson, M., Malley, C., Reid, S., Lemaster, R., & Wieman, C. E. (2008). Developing and researching PhET simulations for teaching quantum mechanics. *American Journal of Physics*, *76*(4–5), 406–417. Scopus. https://doi.org/10.1119/1.2885199

Moore, E. B., Chamberlain, J. M., Parson, R., & Perkins, K. K. (2014). PhET interactive simulations: Transformative tools for teaching chemistry. *Journal of Chemical Education*, *91*(8), 1191–1197. Scopus. https://doi.org/10.1021/ed4005084

Nulhaq, S., & Setiawan, A. (2016). Influences of Multiple Representation in Physics Learning to Students in Understanding Physics Material and Scientific Consistency. *Proceedings of the 2015 International Conference on Innovation in Engineering and Vocational Education, Icieve 2015*, 235–238. https://doi.org/10.2991/icieve-15.2016.51

Perkins, K., Moore, E., Podolefsky, N., Lancaster, K., & Denison, C. (2012). *Towards research-based strategies for using PhET simulations in middle school physical science classes*. *1413*, 295–298. Scopus. https://doi.org/10.1063/1.3680053

Setyani, N. D., Cari, C., Suparmi, S., & Handhika, J. (2017). Student's concept ability of Newton's law based on verbal and visual test. *International Journal of Science and Applied Science: Conference Series*, *1*(2), 162. https://doi.org/10.20961/ijsascs.v1i2.5144

Suryani, Y., Distrik, I. W., & Suyatna, A. (2018). The Practicality and Effectiveness of Student Worksheet Based Multiple Representation to Improve Conceptual Understanding and Students' Problem-Solving Ability of Physics. *International Journal of Research - Granthaalayah*, *6*(April), 166–173. https://doi.org/10.5281/zenodo.1243075

Sutrisno, H. (2016). An analysis of the mathematics school examination test quality. *Jurnal Riset Pendidikan Matematika*, *3*(2), 162–177. https://doi.org/10.21831/jrpm.v3i2.11984

Waldrip, B., Prain, V., & Carolan, J. (2006). Learning Junior Secondary Science through Multi-Modal Representations. *Electronic Journal of Science Education*, *11*(1), 87–107. https://doi.org/10.2136/sssaj2009.0437

Wieman, C., & Perkins, K. (2005). Transforming Physics Education. *Physics Today*, *58*(11), 36–41. https://doi.org/10.1063/1.2155756