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Peer Instruction Using PhET Integrated with Inquiry-based Learning in Kinematics Physics Learning

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ABSTRACT

This study investigates the impact of integrating peer instruction with PhET simulations and inquiry-based learning on physics education. Given the constraints of having only one class of 40 students, a one-group quantitative design was employed, complemented by a qualitative approach to create a mixed-method design. Quantitative analysis of pre-test and post-test results was performed using N-Gain, effect size, and paired samples t-test. Furthermore, qualitative analysis provided insights into students' learning experiences. The average N-Gain score initially showed a low increase (0.26), but excluding cases with negative gains revealed a moderate increase (0.38). The paired samples t-test confirmed a significant improvement in post-test scores compared to pre-test scores, with a large effect size ($d = 0.83$), demonstrating the effectiveness of the intervention. However, further analysis is needed to explore the distribution of student answers and underlying misconceptions. Some misconceptions were corrected, such as those related to distance, displacement, and velocity equations. However, kinematics graphs and vertical motion persisted. This finding underscores the urgency of refining teaching methods to address these persistent issues. The findings highlight the potential of this integrated approach to improve physics instruction and suggest that educators can use these insights to better support students' understanding of kinematics and graphical analysis.

INTRODUCTION

The concept of motion is a fundamental part of physics, starting with understanding position, velocity, and acceleration. This understanding helps students observe how objects move and their velocity changes over time. Mastering these basics opens the door to exploring more complex topics such as forces, energy, and momentum, which are central to dynamics and other branches of physics. Learning typically begins with one-dimensional motion to facilitate understanding, such as horizontal motion or free fall, which are relatively simple. Once students grasp the basics, they move on to two-dimensional motion, including parabolic, circular, and inclined plane motion. These stages gradually introduce the relationship between forces and motion, helping students understand dynamics more deeply. A strong foundation in motion is essential for tackling more advanced concepts like rotational dynamics, electromagnetism, and fluid mechanics.

However, many misconceptions persist regarding the basic concepts of motion, particularly within kinematics. For example, students often incorrectly believe that velocity and acceleration are always in the same direction or that an object's velocity

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must be zero when its acceleration is zero (Sutopo & Waldrip, 2013). Additionally, students may struggle with the idea that an object moving upward in free fall has a downward acceleration due to gravity (Winter & Hardman, 2020), which contradicts their intuitive notion that acceleration should point in the same direction as motion. Misunderstandings extend to creating and interpreting motion graphs, crucial tools for visualizing and analyzing motion in physics. One common issue is that students interpret kinematics graphs as showing the path of motion rather than understanding that these graphs depict how position changes with time (Sutopo et al., 2020).

These misconceptions are persistent and widespread (Beichner, 1994; Berryhill et al., 2016; Guidugli et al., 2005; Laverty & Kortemeyer, 2012; McDermott et al., 1987). Despite these challenges, motion graphs are essential for analyzing phenomena and gaining insights into a system's characteristics (Sokolowski, 2017). Therefore, mastering the skills of understanding and interpreting graphs is crucial for students in physics and across other scientific disciplines.

Kinematics graphs should be taught qualitative and quantitative (Bollen et al., 2016). Students often encounter challenges when linking graphs to physics concepts and connecting graphs to real-world phenomena (McDermott et al., 1987). They may also struggle to relate the slope or shape of graphs to the underlying physics principles (Beichner, 1994). Moreover, constructing and interpreting graphs, especially as functions, presents difficulties for students (Laverty & Kortemeyer, 2012). Furthermore, once students become proficient in interpreting one type of motion graph, they may still make errors when confronted with new types of motion graphs. Distinguishing between graphical shapes and actual motion trajectories remains a common issue for students (Berryhill et al., 2016). As a result, special attention is necessary to ensure students develop a correct understanding of these fundamental movement concepts.

Active learning has been shown to enhance students' understanding of motion concepts and their graphical representations (Sokoloff et al., 2011). One form of active learning is inquiry-based learning, which prioritizes processes that empower students to construct their understanding through active activities, such as observation and experimentation (Wenning, 2011). This approach emphasises the content and the processes taking place in the classroom. Aligning content and processes can enhance students' experiences and comprehension of these concepts. One way to facilitate this integration of content and processes is through technology, making inquiry more effective (Haleem et al., 2022).

Technological advancements have been widely leveraged in the physics learning process, offering various supportive features, including learning resources and the ability to model and simulate complex natural phenomena (Testoni & Brockington, 2016). One of the most popular technology-based simulations in physics is the Physics Education Technology (PhET) simulation, developed by experts at the University of Colorado and offered as open access. PhET simulations are seamlessly integrated into the inquiry learning process and provide numerous features to support inquiry learning (Haleem et al., 2022). Most notably, PhET simulations enable students to engage in investigative activities, collect data, and make reasoned conclusions based on these inquiry activities.

The success of inquiry-based learning with PhET simulations hinges on instructor involvement (Wieman et al., 2010). Studies have shown that guided inquiry, where students construct knowledge with limited instructor direction, effectively enhances their understanding of concepts and scientific process skills (Bunterm et al., 2014). Therefore, instructors need to strike the right balance in their involvement in the learning process. Several studies demonstrate that students can build their knowledge effectively with PhET when the instructor's guidance is not overbearing or implicit (Wieman & Perkins, 2006). This approach grants students greater opportunities to explore simulations (Chamberlain et al., 2014) and engage in productive discussions with their peers.

Discussions about discoveries made while using the simulation can be highly beneficial. When findings differ, students can discuss the reasons for these discrepancies. When findings align, they can use this concurrence to confirm their results. PhET simulations inherently offer features for testing and confirming students' answers or predictions (Pranata, 2023). Yet, comparing and confirming findings with peers is also a vital part of the knowledge acquisition process through peer confirmation. Therefore, to support student discussions, inquiry-based learning and PhET simulations are complemented by steps in peer instruction.

Peer instruction also falls under the umbrella of active learning, facilitating student interaction and discussion in the classroom while focusing on fundamental concepts during the learning process (Knight & Brame, 2018; Mazur, 1997, 2014). Peer instruction has been widely adopted in learning environments as it can uncover student misconceptions and encourage active participation (Crouch & Mazur, 2001; Fagen et al., 2002; Mazur, 1997, 2014). These aspects make it well-suited for addressing conceptual challenges and supporting kinematic learning. However, implementing peer instruction also poses certain challenges.

Instructors can implement peer instruction according to their preferences and learning objectives, significantly influencing students' perceptions of the learning process. A certain amount of flexibility is necessary to respond to the sometimes unexpected results of the concept test (Mazur, 2014). The most significant challenge from an instructor's perspective in implementing peer instruction is the time required to create concept tests aligned with learning objectives (Fagen et al., 2002). Moreover, class interactions and discussions may sometimes fall short of the instructor's expectations, with some failing to address the prescribed topics, concepts, and questions (Knight & Brame, 2018). Additionally, some students may hesitate to participate actively in discussions and feel uncomfortable doing so (Fagen et al., 2002). To overcome these challenges, teachers can utilize available online test collections or question sets in user manuals developed by Mazur (Mazur, 1997, 2014). Furthermore, teachers are critical in providing feedback to guide and motivate students in peer instruction activities.

Considering the challenges associated with understanding basic motion concepts and the existing research on active learning approaches, this study contributes a novel approach by integrating peer instruction with PhET simulations to enhance students' understanding of kinematics. While previous studies have explored the individual benefits of peer instruction and PhET simulations, few have examined their combined impact within an inquiry-based framework, particularly in the context of kinematics. This research investigates how this integrated approach influences students' conceptual understanding and delves into the specific mechanisms through which it addresses persistent misconceptions about motion. By focusing on how peer instruction and simulations complement each other in fostering deeper learning, this study offers fresh insights into the effectiveness of active learning strategies in physics education.

METHODS

The study was based on experimental methods designed to test the effect or impact of a treatment on learning. However, only one class of students (40 students enrolled in the Basic Physics Course) was available as subjects, which limited the experiment to using a one-group (commonly referred to as a one-group pre-test-post-test design). This design was considered weak because no control group was available to ensure that the observed effects were not influenced by factors other than the treatment (Cohen et al., 2018). Therefore, a qualitative approach was also integrated to complement the experimental method during the learning process. As a result, a mixed-method intervention (or experimental) design (as illustrated in Figure 1) was employed. This approach was chosen because there was only one class of students in the basic physics course, and the researcher aimed to assess the quantitative impact of the treatment and understand why and how the treatment influenced students' conceptual understanding (Creswell & Clark, 2017).

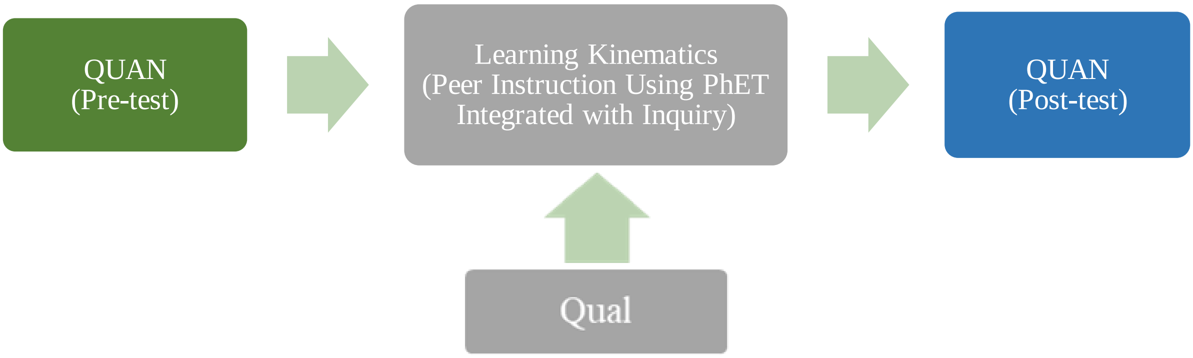

Figure 1. Research Design

Figure 2. PhET Simulation: The Moving Man

Before the learning process, students answered pre-test questions, which were then repeated as post-test questions after the learning process. These questions were adapted from peer-instruction questions developed by Eric Mazur, focusing on motion materials, especially kinematics (Mazur, 1997, 2014). There were eight multiple-choice questions included in both the pre-test and post-test. The pre-test and post-test followed the same procedure. Questions were presented to students, taking into consideration the allotted time and number of questions. Students had 30 minutes to answer the questions, followed by an additional 30 minutes for discussion with classmates to convince them of their answers and make any necessary revisions. Afterwards, the question responses were collected. Following the pre-test, students engaged in the learning process, and the post-test followed the same structure, concluding with feedback from the teacher regarding the answers and an explanation of the test.

The inquiry-based learning process was implemented through integration with peer instruction using PhET (The Moving Man) simulation, as shown in Figure 2. The simulation is accessible via the website link: https://phet.colorado.edu/en/simulations/moving-man. This simulation focuses on fundamental motion topics, including position, velocity, and acceleration, as well as their graphical representations over time. The learning process also utilized modules and worksheets prepared by the teacher to support the inquiry-based learning approach. Modules and worksheets were designed to facilitate the learning process, with QR codes providing links for easy student access. Subsequently, students were directed to practice creating position, velocity, and acceleration graphs against time for various motion scenarios. Additionally, students were required to provide explanations and reasoning related to the graphs they produced. Qualitative data was collected during the learning process (discussion).

Data analysis took various forms. First, a descriptive analysis was based on correct answers and total scores. Each correct answer received a score of 1, while incorrect or unanswered questions received a 0. The total score and N-Gain analysis were presented with references to individual questions and students. N-Gain calculations involved the difference between post-test and pre-test scores, as defined by equation (1) (Hake, 1998).

$$N - Gain = \frac{Post\ test\ score - Pre\ test\ score}{Max\ score - Pre\ test\ score} \quad (1)$$

A positive N-Gain value was obtained in the first category, where there were more correct answers in the post-test compared to the pre-test. In the second category, the N-Gain was zero when the number of correct answers remained the same in both the pre-test and post-test. Finally, a negative N-Gain value was obtained in the third category, where there were more correct answers in the pre-test compared to the post-test.

Second, statistical analysis was conducted to compare pre-test and post-test scores. The paired samples t-test or Wilcoxon signed-ranks test was applied using SPSS software. The choice between the two tests depended on the normality of the data distribution. The paired samples t-test was used for normally distributed data, while the Wilcoxon signed-ranks test was used for non-normally distributed data (Morgan et al., 2004).

Third, changes in students' answers between the pre-test and post-test were analyzed. This analysis is important for understanding how peer influence plays a role in the learning and testing process (Mazur, 1997, 2014). Additionally, qualitative analysis, which complemented the quantitative analysis, was conducted. Qualitative analysis was employed to observe and understand participants' experiences (including barriers and facilitators), identify potential mediating and moderating factors, ensure procedure fidelity, and identify resources that may impact treatment implementation (Creswell & Clark, 2017).

RESULTS AND DISCUSSION

I. Descriptive Analysis

Figure 3 displays the analysis results of the total pre-test and post-test scores for each question, while Figure 4 shows the scores for each student.

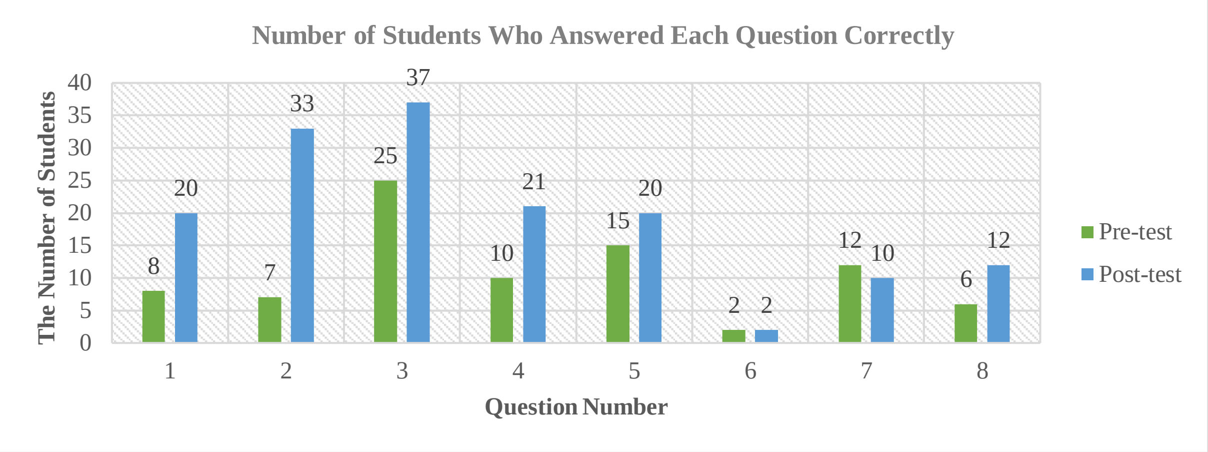

Figure 3. Number of Students Who Answered Each Question Correctly

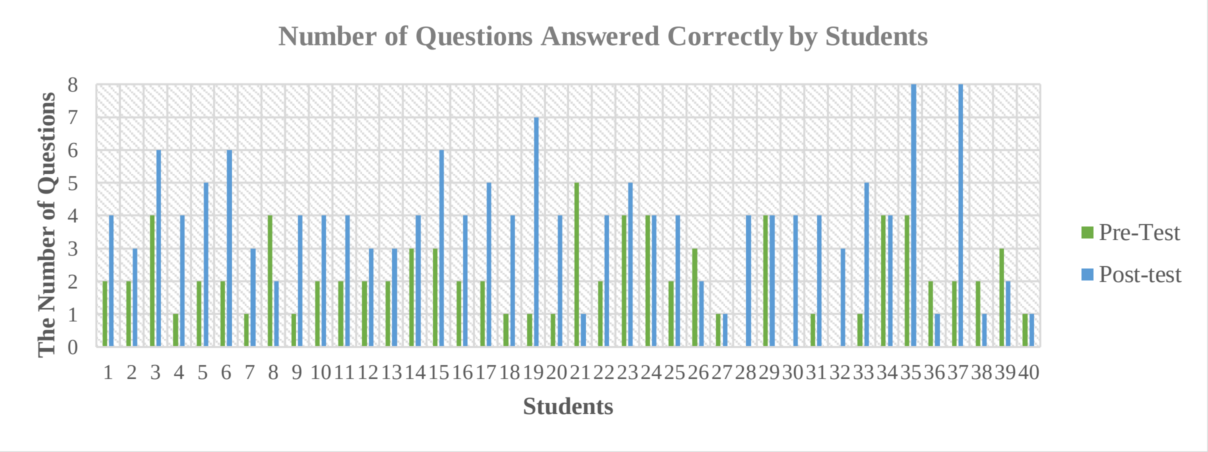

Figure 4. Individual Student Scores

Figure 3 illustrates changes in correct answers for questions from the pre-test to the post-test. Most questions showed increased correct answers in the post-test, except for questions 6 and 7. Question 6, about position versus time graphs for constantly accelerated motion, had consistently low correct responses, with 5% (2 out of 40) correct in both tests. Question 7, comparing motion graphs, had more correct responses in the pre-test (12 students) than in the post-test (10 students). We will further explore these results in the third analysis, focusing on student answer distribution and explanations.

Looking at individual student data in Figure 4, we can categorize students based on their pre-test and post-test performance. The majority (72.5% or 29 out of 40) improved in the post-test, while five students showed no change, and six had lower scores. These categories align with the N-Gain distribution, where positive N-Gain indicates improvement, zero indicates no change, and negative N-Gain signifies a decrease.

The N-Gain values reflect the extent of improvement, with values below 0.3 considered low, 0.3 to less than 0.7 as moderate, and equal to or greater than 0.7 as high. Of the 29 students with positive N-Gain scores, 6 had low scores, 20 had moderate increases, and 3 had high increases (2 with a maximum N-Gain of 1). Five students had zero N-Gain, and six students had negative N-Gains. You can see the N-Gain values for each student in Figure 5, and Figure 6 shows the distribution of student categories based on N-Gain groups.

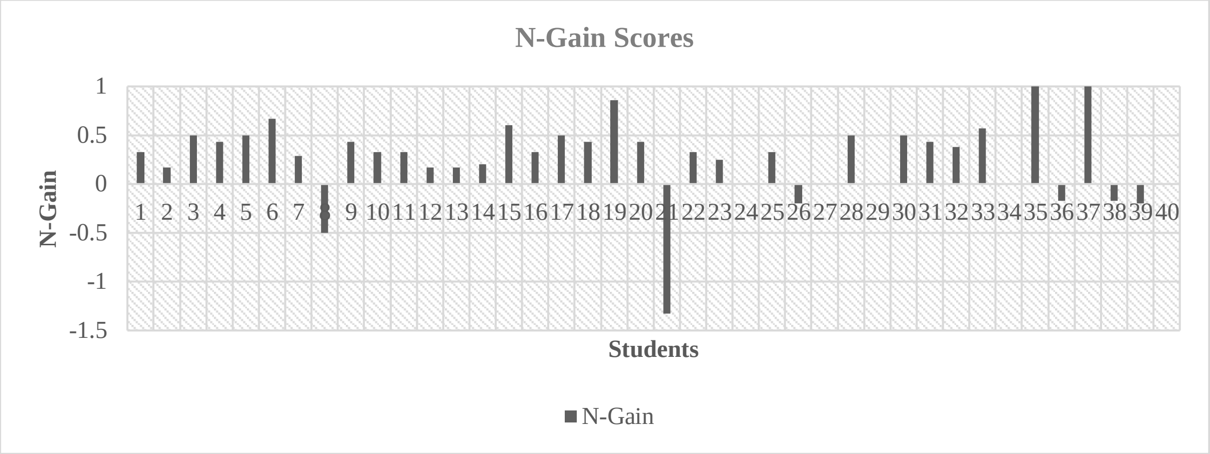

Figure 5. N-Gain Scores for Each Student

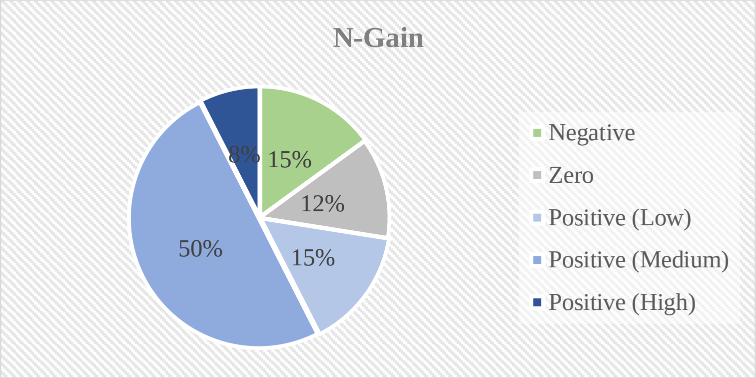

Figure 6. Student Distribution Based on N-Gain Categories

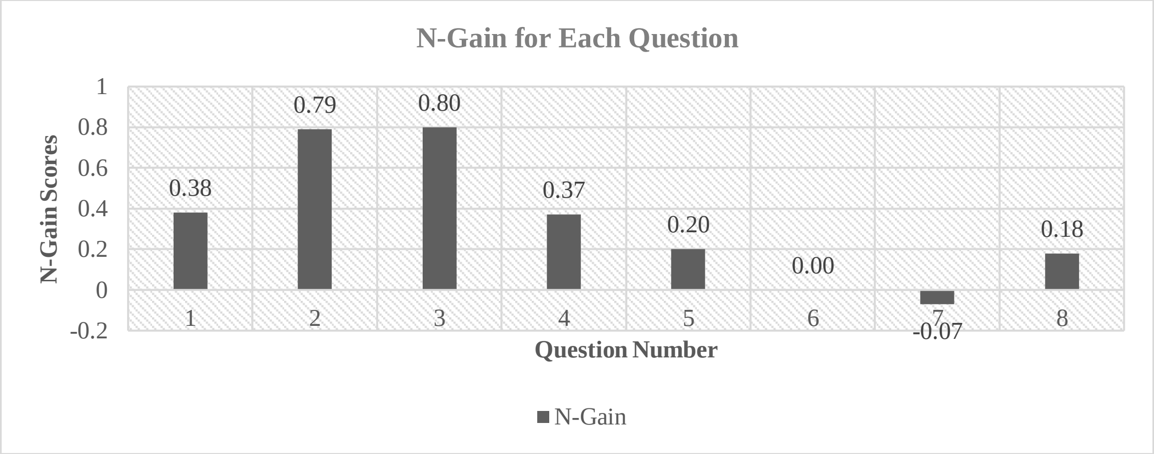

Figure 7. N-Gain Scores for Each Question

On average, the N-Gain score for students indicates a low increase, with an average of 0.26. However, when cases with negative N-Gain values—representing a decline in student performance—are excluded, the average N-Gain rises to 0.38, classified as a moderate increase. The exclusion of negative N-Gain scores is justified because these cases reflect instances where learning did not occur as expected or where students may have misunderstood the material after instruction. By focusing on positive or neutral gains, we can more accurately assess the overall effectiveness of the instructional approach. Figure 7 displays the N-Gain values for each question.

The N-Gain data for each question is noteworthy, showing variations grouped into four categories:

- Questions 6 and 7 exhibit N-Gain values of zero and negative.
- Questions 5 and 8 have relatively low N-Gain.
- Questions 1 and 4 demonstrate moderate N-Gain.
- Questions 2 and 3 show relatively high N-Gain.

Previous studies have consistently demonstrated that Peer Instruction enhances learning processes and outcomes. Active student engagement is a hallmark of this method (Crouch & Mazur, 2001). Improved learning outcomes are seen in students' enhanced understanding of course material and problem-solving abilities (Fagen et al., 2002; Lasry et al., 2008). Remarkably, while Peer Instruction generally promotes better understanding, it can also inadvertently propagate misconceptions (Knight & Brame, 2018), as observed in questions 6 and 7. Misconceptions often stem from overconfident students influencing their peers. Further analysis of student answers will be discussed in the subsequent section.

To address these challenges, teachers should provide accurate feedback to steer students away from misconceptions. Incorporating inquiry-based learning alongside Peer Instruction can be an effective strategy (Bao & Koenig, 2019). Inquiry-based learning with PhET has been proven to enhance students' grasp of concepts (Haleem et al., 2022). The learning process begins with a simulation introduction, followed by students making predictions using the PhET (Moving Man) simulation. Such tools are invaluable in learning, especially inquiry-based approaches (Pranata, 2023). Confirmation through simulation aids student self-evaluation fosters peer discussion and strengthens concepts and confidence (Heydari et al., 2013; Mazur, 2014).

II. Pre-test and Post-test Scores Comparison: The Paired Sample t-test

A paired samples t-test was conducted to compare pre-test and post-test scores, as the data showed a normal distribution with skewness between -1.0 and 1.0 (Morgan et al., 2004), as shown in Table 1.

Table 1. Statistical Analysis Score

Data	N	Range	Min	Max	Mean	Std. Deviation	Variance	Skewness Statistic	Skewness Std. Error
Post-test	40	7.00	1.00	8.00	3.88	1.74	3.04	0.32	0.37
Pre-test	40	5.00	0.00	5.00	2.13	1.26	1.60	0.39	0.37

The paired samples t-test was conducted using the SPSS software. Tables 2 and 3 present the comparison results for pre-test and post-test scores.

Table 2. Paired Samples Correlation

	N	Correlation	Sig.
Pair 1. Post-test & Pre-test	40	0.54	0.742

Table 3. Paired Samples Test

	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	95% Confidence Interval of the Difference Upper			
Pair 1. Post-test – Pre-test	1.75	2.10	0.33	1.08	2.42	5.28	39	0.00

Table 2 reveals that the correlation between post-test and pre-test scores is not significant ($\rho > 0.05$). This finding suggests that students with low pre-test scores may not necessarily have low post-test scores and vice versa. Therefore, it's likely that the treatment influenced or changed students' conceptual understanding of kinematics material. Then, the paired samples t-test results (Table 3) indicate that post-test scores were significantly higher on average than pre-test scores, $t\,(39) = 5.28, \rho = 0.05, d = 0.83$. The effect size score was large ($d = 1.75/2.10 = 0.83$) based on Cohen's guidelines (J. Cohen, 1988). The confidence interval showed that the difference in the means could be as small as 1.08 or as large as 2.42 on a scale of 8.

Although Tables 2 and 3 provide valuable insights, they do not fully explain how the treatment (Peer Instruction Using PhET Integrated with Inquiry) impacts student learning. Additional analysis is necessary, specifically a third analysis examining student answers' distribution and their underlying causes (Qual).

III. Distribution of pre-test to post-test answers

The third analysis focuses on changes in student answer choices, beginning with mapping student answer distribution for each question (see Figure 8-15, test questions available in Mazur's *Peer Instruction: A User's Manual* (Mazur, 1997, 2014)). Various colour variations in the distribution display illustrate how answers change from the pre-test to the post-test.

Question 1 relates to creating the graph illustrating changes in position over time for a person moving through several points depicted in two-dimensional coordinates. There are six graphs (A-F) available as answer choices. The distribution of answers from the pre-test to the post-test is shown in Figure 8. The most dominant answer chosen by students (16 students) during the pre-test was F. Furthermore, 4 of the 16 students remained with the same answer during the post-test and 12 students changed their answer during the post-test (4 students changed to B, 5 students to D, and 3 students to E). Another interesting finding related to the distribution of students' answers is the absence of answers A and C during the post-test. In the pre-test, two students chose answer A, and seven chose answer C. However, in the post-test, no students chose either of these options.

The ability to create kinematic graphs is a crucial aspect of studying motion. Producing and presenting more realistic motion graphics is essential for helping students grasp the fundamental concepts and tools they learn in kinematics and related mathematics (Sokolowski, 2017). For question number 1, the correct answer is B, which was the predominant choice during the post-test, with 20 students selecting it, constituting 50% of the responses. 8 students answered correctly in the pre-test and maintained the same answer in the post-test. These students may have influenced other students' responses during their learning process through peer instruction using PhET with inquiry, as an additional 12 students answered correctly. However, half of the other students provided incorrect responses in the post-test.

The most prevalent incorrect response during the post-test was option D. This choice revealed misconceptions regarding the creation of graphs for rapid (running) and slow (walking) changes in position. In the case of running, the graph should exhibit a steep slope, indicating a high gradient, whereas when walking, it should display a gentle slope, representing a low gradient. Option D, however, contradicts this expectation. Another incorrect answer in the post-test reflects misconceptions about a person's initial position before moving.

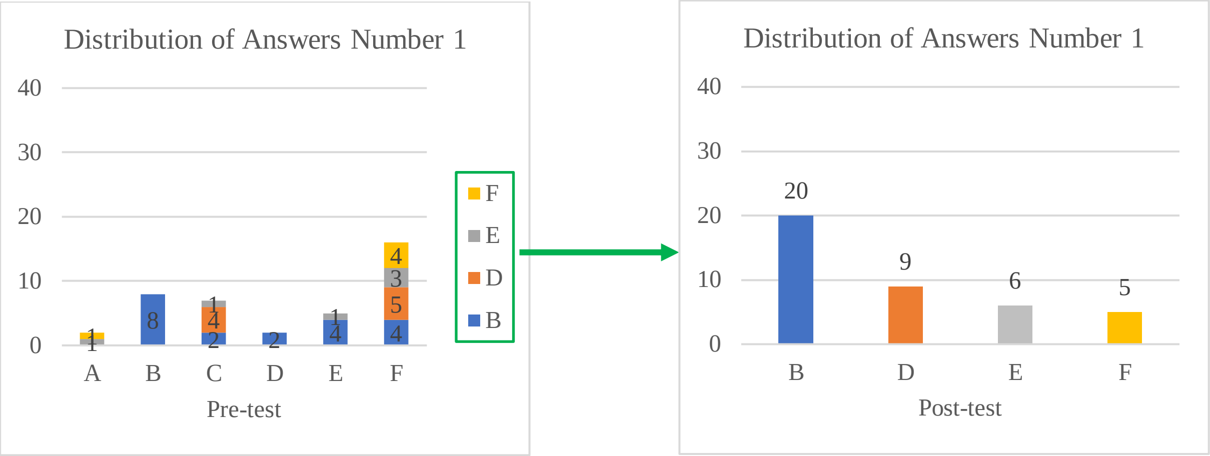

Figure 8. Distribution of Answer Number 1 from Pre-test to Post-test (Correct Answer: **B**)

Moving on to question number 2, it concerns the different concepts of distance and displacement. The distribution of answers, as depicted in Figure 9, shows that students' responses varied during the pre-test, with the most prevalent answers being B (displacement is always greater than distance) and C (displacement is always equal to distance). So, it can be concluded that initially, most students were confused by the difference between the concepts of distance and displacement. Other studies also found the same results: learners confuse distance and displacement and think that displacement is the same as distance, but with a small value or shorter distance (Jufriadi et al., 2021; Motlhabane, 2016). The correct answer is D (displacement is less than or equal to the distance), and only 7 out of 40 (17.5%) students answered correctly during the pre-test.

After engaging in peer instruction using PhET integrated with inquiry, the distribution of answers shifted towards option D, the correct answer. Specifically, 33 out of 40 students chose this option during the post-test. Only five students persisted in selecting the same wrong answer, and two students shifted toward the wrong answer during the post-test. Interestingly, one of the two students who shifted their answer had previously answered correctly during the pre-test, as shown in Figure 9 on the left, with option D coloured in orange. This suggests that misconceptions can persist, even after peer instruction.

Sometimes, peer influence can unintentionally lead students toward incorrect answers rather than correcting misconceptions. A small number of students had misconceptions, including beliefs that displacement is greater or equal to distance (7.5% of students), displacement is always greater than distance (7.5% of students), and displacement may be smaller or greater than distance (2.5% of students). Interestingly, one of the dominant misconceptions (displacement is always the same as distance) was no longer found during the post-test.

This problem also yielded a high N-gain of 0.79, slightly smaller than the best for problem number 3 (0.80). The distribution of students' answers predominantly favours the correct answer, and the high N-Gain value indicates that peer instruction using PhET integrated with an inquiry as a teaching method significantly impacts students' understanding of these concepts. This teaching approach enables educators to identify and address misconceptions students hold, particularly those related to distance and displacement. Moreover, this method assists students in acquiring a more accurate understanding of these concepts.

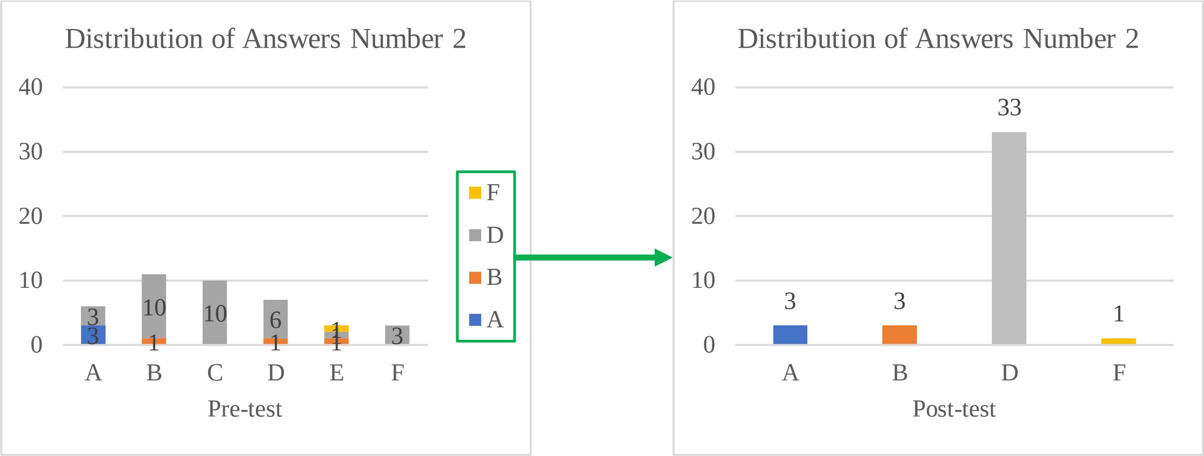

Figure 9. Distribution of Answer Number 2 from Pre-test to Post-test (Correct Answer: **D**)

Moving on to question number 3, which pertains to the concept of velocity based on changes in distance over time, this problem boasts the highest N-Gain value, standing at 0.80. This remarkable result is largely due to the substantial number of correct answers, with 37 students selecting the correct answer during the post-test. Notably, the pre-test results were also quite high, with 25 students choosing the correct answer (B), and all of them maintained this correct response during the post-test. Additionally, 12 students with different answers initially moved to the correct one. In comparison, two students continued with the wrong answer (D), and one shifted from and to the wrong answer (C), as illustrated in Figure 10. The significant improvement can be attributed to the fact that most students had the correct answer. This allowed them to help their peers during the learning process, using the PhET simulation to visually demonstrate and provide evidence for the correct answer.

The problem revolves around using velocity equations and comparing the distances travelled by two objects within the same time interval. Other studies have found that students prefer manipulating equations, regardless of the representational format (Ibrahim & Rebello, 2012). Before implementing peer instruction, many students focused on rote equation manipulation without fully grasping the underlying principles. Learning through peer instruction allows students to discuss the problem, which helps them not only manipulate equations but also understand the concepts at a deeper level. This process allows students to understand motion correctly, particularly distance and velocity.

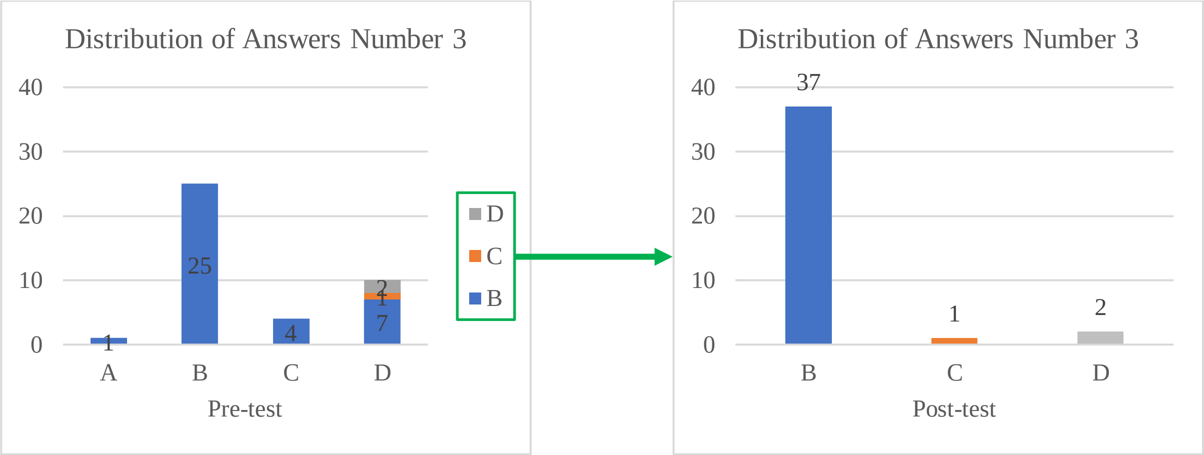

Figure 10. Distribution of Answer Number 3 from Pre-test to Post-test (Correct Answer: **B**)

Questions number 4 and 5 focus on another motion concept, vertical motion. Question number 4 aims to assess students' understanding of gravitational acceleration (g), while question number 5 pertains to speed changes in free fall. One common misconception observed concerning g in free fall (assuming no air resistance) is the belief that its value can change under various conditions, such as during free fall and when upward and downward throws. Many students incorrectly perceive downward motion through a thrown as having an acceleration value greater than the acceleration due to Earth's gravity (g), which is evident in the prevalence of choice C in question number 4 during the pre-test (chosen by 21 students). However, it's crucial to note that the acceleration remains constant despite variations in vertical motion.

In the post-test, there was a shift toward the correct answer (B), with the percentage of students choosing it increasing from 25% to 52.5%, resulting in a moderate gain of 0.37. However, answer C still received many responses, as depicted in Figure 11. Surprisingly, 5 out of 10 students who had answered correctly during the pre-test changed their response to C in the post-test. Simultaneously, the number of students incorrectly believed that acceleration was smaller than 'g' when an object is thrown downwards decreased significantly to 1 out of 9 in the pre-test. This indicates that the concept of acceleration still requires attention in learning. Other studies have also shown that acceleration is a challenging concept in free fall (Jugueta et al., 2012; Wee et al., 2015)

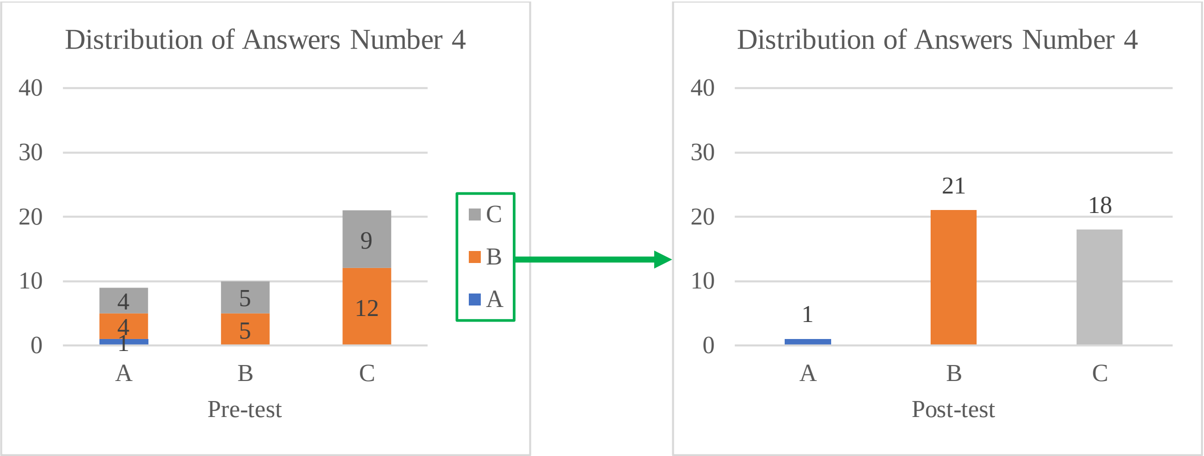

Figure 11. Distribution of Answer Number 4 from Pre-test to Post-test (Correct Answer: **B**)

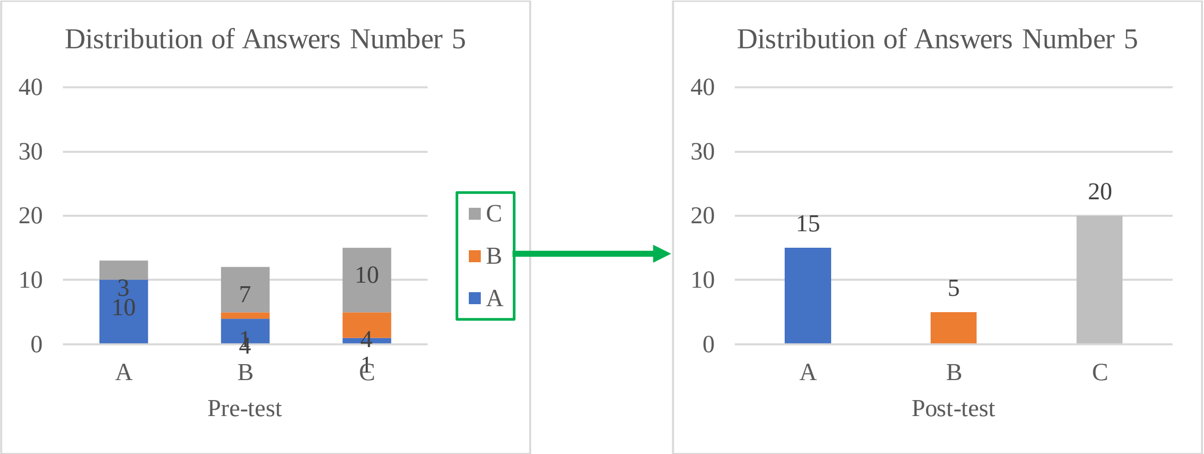

Figure 12. Distribution of Answer Number 5 from Pre-test to Post-test (Correct Answer: **C**)

In addition to misconceptions about the concept of acceleration, there are also misconceptions regarding the concept of speed in vertical motion. When considering an object thrown up and down with the same initial speed, most students erroneously thought that the ball hitting the ground would be greater when the ball was initially thrown upwards. This misconception arises from the notion that the ball fell from a higher position. However, the ball thrown upwards returns to the starting point at the same speed (according to symmetry in parabolic motion). It exhibits an identical motion when thrown downwards. Consequently, both will reach the surface at the same speed (as answer C indicates).

In the pre-test, 15 students answered this question correctly, which increased to 20 students during the post-test, as illustrated in Figure 12. Notably, 10 out of the 15 students who answered correctly during the pre-test maintained the correct answer in the post-test. Other students who answered correctly in the post-test had previously chosen option B (7 students) or option A (3 students) in the pre-test. Based on this answer distribution, only 25% of students consistently gave the correct answer. Another study also reported a low percentage of students being consistent in their answers to questions about speed in vertical motion which was 12% (Lemmer, 2013).

As mentioned earlier, questions 6 and 7 had the lowest percentage of students answering correctly. These questions focus on graphs depicting position versus time. Question number 6 pertains to graphs of position versus time in accelerated motion, specifically when velocity is decreasing. Notably, only 5% of students answered question number 6 correctly, both on the pre-test and post-test, as indicated in Figure 13. This indicates no improvement in the results for question number 6, with an N-Gain value of zero.

Based on the distribution of students' answers, it is evident that the two students who answered correctly during the pre-test and post-test were different. This means that two students who answered correctly during the pre-test (answered B) answered incorrectly during the post-test (answer changed to C). The dominant answer shift occurred towards option C during the post-test, with 29 students selecting it. A similar misconception to question number 1 was identified, which relates to the gradient of the line on the position-versus-time graph. The graph in the problem displays a gradient smaller than one ($m < 1$), suggesting motion in deceleration. However, the majority of students who answered C concluded that the motion graph depicted conditions that accelerated some of the time and slowed down other times.

Slightly better results were observed for question number 7, with 12 students answering correctly during the pre-test. However, this number decreased to 10 students in the post-test, as indicated in Figure 14. Although the percentage of correct answers in question number 7 is higher compared to question number 6, the N-Gain score for question number 7 is lower, specifically negative or less than zero. The primary reason for this is that the number of students who answered correctly was greater during the pre-test compared to the post-test after students received the treatment in the form of learning.

Based on answer distribution, option A dominates both in the pre-test and post-test, with 12 students who answered A in the pre-test continuing to select A in the post-test. This suggests that the same misconceptions persisted even after the learning intervention. The misconception in this problem is related to the concept of velocity, represented by a position graph against time. Answer A reflects students' perception that the intersection of points between two object motion graphs signifies a condition where both objects have the same velocity. Velocity should be represented by the gradient of the line (slope) that forms the graph, not by the points on the graph. The slope error was also found in previous studies about interpretations of speed from kinematics graphs (Bollen et al., 2016; Wemyss & Van Kampen, 2013).

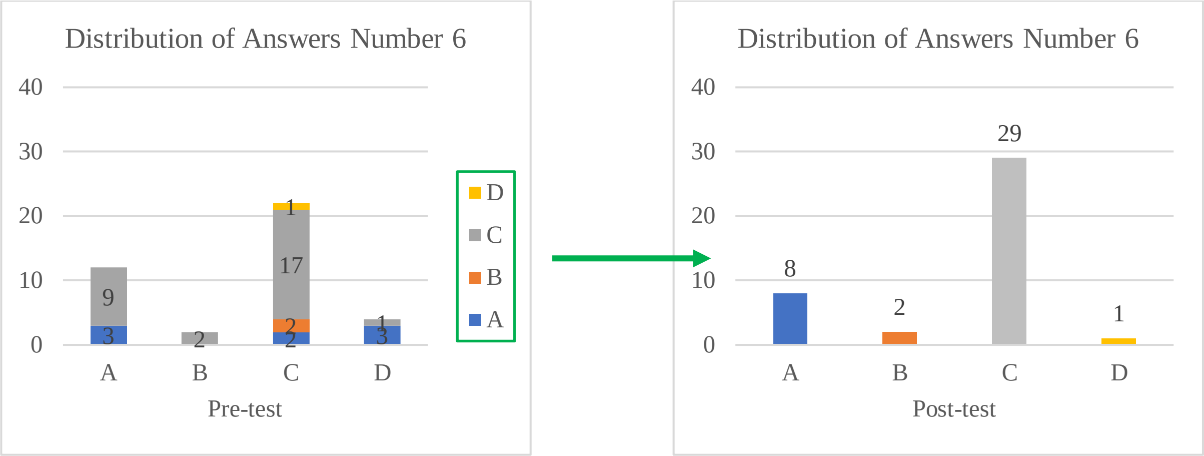

Figure 13. Distribution of Answer Number 6 from Pre-test to Post-test (Correct Answer: **B**)

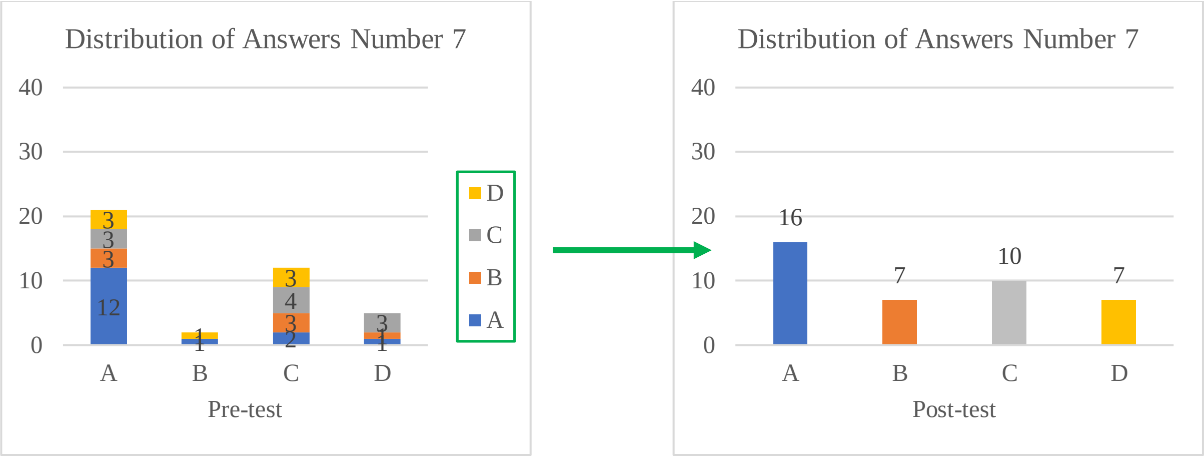

Figure 14. Distribution of Answer Number 7 from Pre-test to Post-test (Correct Answer: **C**)

Question number 8 pertains to understanding the concepts of speed and acceleration in vertical motion when the object is at its highest point. Under these conditions, the object momentarily comes to rest (its speed is zero) while the acceleration remains constant at g. Although there has been an increase in the number of correct answers (from 6 to 12), misconceptions still prevail, as evident in the dominance of answers A (indicating that speed and acceleration are both equal to zero) and B (suggesting that speed is not equal to zero, while acceleration is equal to zero). These misconceptions persist in both the pre-test and post-test, as depicted in Figure 15. This situation highlights that students may not understand the concepts of speed and acceleration in vertical motion.

Based on the distribution of students' answers, it was found that the N-Gain for question number 8 was relatively low (0.18). In line with the results of other studies on learning using a tracker (as a computer-based learning tool), a low N-Gain (0.11) was also observed for the concepts of speed and acceleration in vertical motion when the object is at its highest point (Wee et al., 2015). The same difficulty was observed in students' thinking; they tend to believe that an object at the top of its motion suddenly has zero acceleration. These difficulties persist and indicate that this concept is challenging to understand correctly.

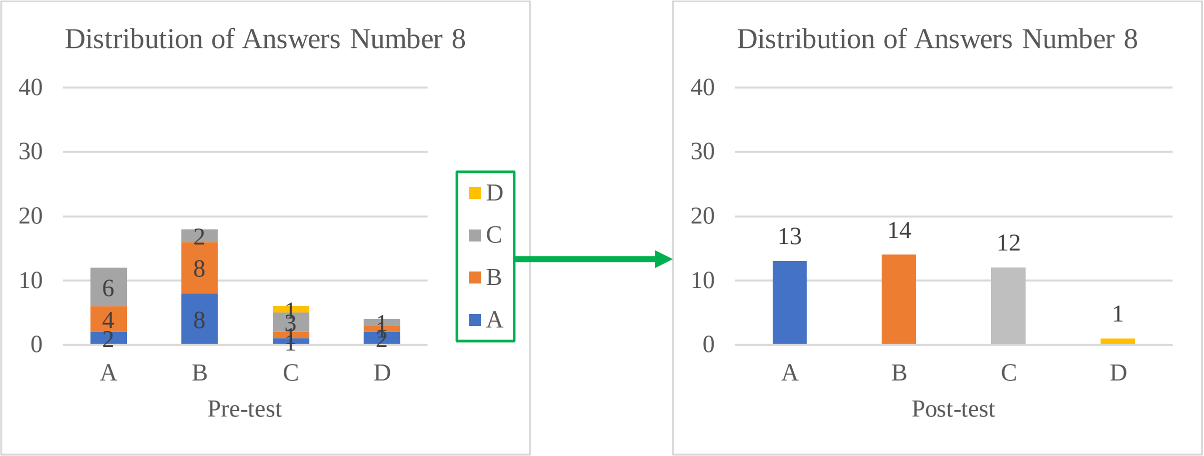

Figure 15. Distribution of Answer Number 8 from Pre-test to Post-test (Correct Answer: **C**)

Overall, the acquisition and understanding of concepts related to motion have improved to varying degrees, as indicated by the N-Gain data, both from the perspective of individual students and questions. Therefore, it can be concluded that learning effectively enhances students' understanding of these concepts. This is consistent with previous studies demonstrating the effectiveness of peer instruction in improving students' conceptual understanding at the university level (Lasry et al., 2008).

However, on the other hand, the data reveals that students continue to hold misconceptions regarding fundamental concepts of vertical motion, as represented by questions 4, 5, and 8, as well as motion graphics, represented by questions 6 and 7. The comprehension of graphical representations still requires special attention. The findings concerning questions 6 and 7 are interesting and merit further investigation to uncover the reasons for the few correct responses and the decline between the pre-test and post-test. Previous studies also found the same results; students struggle with motion graphs as learning progresses, even when they understand mathematical concepts (Hale, 2000). In pre and post-test designs, students' difficulties with the slope in graphs appear robust and do not change after an intervention (Wemyss & Van Kampen, 2013). Similar misconceptions are observed when students are asked to envision graphs of motion (question number 1) and interpret motion from graphs (questions number 6 and 7). These misconceptions pertain to errors in both creating and interpreting slopes.

These two skills, creating and interpreting graphs, are of utmost importance for students to comprehend the fundamental concepts of motion. They also tie in with the fundamental role of representation. Representation is a two-way process: from observing motion, one can graphically represent it, and from a graph, one can reconstruct the motion. Based on the distribution of students' responses to these three questions, it can be deduced that most students comprehend how to construct graphs from motion. However, they still have deep misconceptions about the reverse process of interpreting motion from graphs.

Previous studies have also yielded similar results. Students had difficulties in reconstructing motion from graphs. Students often struggle to differentiate between graphical shapes and motion trajectories. For instance, when a position-versus-time graph shows an upward trend, students incorrectly assume that the object is moving upward as if it were going uphill (Berryhill et al., 2016). Typically, students approach kinematics symbolically or through equations. Past studies have demonstrated that students tend to favour symbolic approaches and quantitative solutions when confronted with various representations to solve kinematics problems, often neglecting qualitative strategies (Ibrahim & Rebello, 2012). Therefore, one-way representation alone is not sufficient to ensure that students have a solid conceptual understanding of kinematics and graphs (Nieminen et al., 2012; Rosenquist & McDermott, 1987).

The contributing factors are students' initial understanding and learning experiences (Lasry et al., 2008). In understanding kinematics graphs, students' logical thinking skills were the prominent factors (Bektasli & White, 2012). The learning experiences through peer instruction, involving the persuasion of classmates regarding answers during tests, is believed to systematically increase the percentage of correct responses (Mazur, 1997, 2014). This approach allows students to discuss with their peers, exploring different answers and approaches to questions posed in class (Knight & Brame, 2018).

Interacting with peers in the classroom not only supports discussions on content and physics-related issues but can also enhance emotional aspects, such as empathy and social skills (Pranata et al., 2023). Furthermore, students can discuss and interact with teachers in a designed learning process, specifically through inquiry integrated with PhET simulations. Related studies indicate that inquiry-based learning can enhance students' conceptual understanding. Simulations are also believed to contribute to students' understanding. The combination of these elements has a positive impact on students' understanding of kinematics concepts. For future studies, it might be beneficial to investigate the impact of each treatment separately and in more detail.

The PhET simulation in guided inquiry learning provides an engaging and interactive learning experience. PhET and inquiry have been shown to be effective in improving students' understanding (Haleem et al., 2022). With peer instruction, students have access to discuss their views about physics concepts, especially kinematics. This integrated approach enhances students' conceptual understanding of kinematics.

Studies on the concept of motion or kinematics, particularly in the context of motion graphs, have frequently been conducted, and various solutions have been provided. Several other interesting approaches can be integrated into the learning process. These approaches may include activities involving the arrangement of graphic cards (Berryhill et al., 2016) and asking students to engage in graphic reasoning, encompassing both realistic and unrealistic motion graphics (Sokolowski, 2017). Previous research recommends using standardized tests to assess students' understanding and factors impacting students' misconceptions (Hasan et al., 1999; Soeharto, 2021). Other studies also recommend that students' logical thinking and gender must be considered when teaching kinematics graphs (Bektasli & White, 2012).

Furthermore, interactive teaching methods that utilize multiple representations are recommended for implementation (Nieminen et al., 2012). In addition, teachers can vary learning activities according to content and objectives to enhance student engagement in the learning process (Cahyani & Pranata, 2023). The integration of technology also provides innovative solutions, such as utilizing computer-assisted online learning systems (Laverty & Kortemeyer, 2012), leveraging smartphones (Testoni & Brockington, 2016), and blended learning (Pranata & Seprianto, 2023).

Understanding the distinction between distance and displacement is advantageous for future learning. For instance, it helps in comprehending why work is now defined in terms of distance rather than displacement (Jewett, 2008), and it is also relevant to understanding other concepts like force and torque (Pranata et al., 2017).

This research highlights the impact of integrating peer instruction with PhET simulations in an inquiry-based learning environment on students' understanding of kinematics. By combining these methods, the study demonstrates a novel approach to tackling common misconceptions in motion concepts. Peer instruction encourages collaborative learning and allows students to discuss and refine their understanding, while PhET simulations provide interactive visualizations that make abstract concepts more tangible. This synergy helps students grasp complex ideas more effectively and improves their ability to apply and manipulate equations. The research underscores how this integrated approach can significantly enhance physics education by offering practical solutions to common learning challenges.

CONCLUSION AND SUGGESTION

The study found that integrating peer instruction with PhET simulations significantly improved students' understanding of kinematics. The average N-Gain score increased from 0.26 to 0.38 when excluding cases with negative gains, indicating a moderate improvement. Paired samples t-test results showed a significant rise in post-test scores compared to pre-test scores, with a large effect size ($d = 0.83$), suggesting effective learning. Although these results confirm the effectiveness of the approach, additional analysis is needed to fully understand the impact on student learning. The distribution of student answers revealed that while many misconceptions were corrected, some persisted, particularly related to kinematics graphs and vertical motion. This indicates that the peer instruction and PhET integration successfully addressed some misconceptions but not all.

The findings suggest that teachers can use this method to enhance students' grasp of kinematics concepts and graphical representations of motion. However, the study's limitations include its reliance on a single-group pre-test and post-test design due to logistical constraints. Future research could benefit from a more robust design, such as comparing experimental and control groups and exploring the method's effectiveness at different educational levels and for various physics concepts.

REFERENCES

Bao, L., & Koenig, K. (2019). Physics education research for 21st century learning. *Disciplinary and Interdisciplinary Science Education Research*, *1*(1), 1–12. https://doi.org/10.1186/s43031-019-0007-8

Beichner, R. J. (1994). Testing student interpretation of kinematics graphs. *American Journal of Physics*, *62*(8), 750–762. https://doi.org/10.1119/1.17449

Bektasli, B., & White, A. L. (2012). The relationships between logical thinking, gender, and kinematics graph interpretation skills. *Egitim Arastirmalari - Eurasian Journal of Educational Research*, *48*(48), 1–19.

Berryhill, E., Herrington, D., & Oliver, K. (2016). Kinematics Card Sort Activity: Insight into Students' Thinking. *The Physics Teacher*, *54*(9), 541–544. https://doi.org/10.1119/1.4967894

Bollen, L., Cock, M. De, Zuza, K., Guisasola, J., & Kampen, P. Van. (2016). *Generalizing a categorization of students ' interpretations of linear kinematics graphs*. *010108*, 1–10. https://doi.org/10.1103/PhysRevPhysEducRes.12.010108

Bunterm, T., Lee, K., Ng Lan Kong, J., Srikoon, S., Vangpoomyai, P., Rattanavongsa, J., & Rachahoon, G. (2014). Do Different Levels of Inquiry Lead to Different Learning Outcomes? A comparison between guided and structured inquiry. *International Journal of Science Education*, *36*(12), 1937–1959. https://doi.org/10.1080/09500693.2014.886347

Cahyani, V. D., & Pranata, O. D. (2023). Studi Aktivitas Belajar Sains Siswa di

SMA Negeri 7 Kerinci. *Lensa (Lentera Sains): Jurnal Pendidikan IPA*, *13*(2), 137–148. https://doi.org/10.24929/lensa.v13i2.317

Chamberlain, J. M., Lancaster, K., Parson, R., & Perkins, K. K. (2014). How guidance affects student engagement with an interactive simulation. *Chemistry Education Research and Practice*, *15*(4), 628–638. https://doi.org/10.1039/c4rp00009a

Cohen, J. (1988). *Statistical Power Analysis for the Behavioral Science. Second Edition*. Lawrence Erlbaum Associates.

Cohen, L., Manion, L., & Morrison, K. (2018). *Research Methods in Education* (Eighth edi). Routledge.

Creswell, J. W., & Clark, V. L. P. (2017). *Designing and Conducting Mixed Methods Research* (Third Edit). Sage.

Crouch, C. H., & Mazur, E. (2001). Peer Instruction: Ten years of experience and results. *American Journal of Physics*, *69*(9), 970–977. https://doi.org/10.1119/1.1374249

Fagen, A. P., Crouch, C. H., & Mazur, E. (2002). Peer Instruction: Results from a Range of Classrooms. *The Physics Teacher*, *40*(4), 206–209. https://doi.org/10.1119/1.1474140

Guidugli, S., Gauna, C. F., & Benegas, J. (2005). Graphical Representations of Kinematical Concepts: A Comparison of Teaching Strategies. *The Physics Teacher*, *43*(6), 334–337. https://doi.org/10.1119/1.2033514

Hake, R. R. (1998). Interactive-Engagement vs. Traditional Methods: A Six-Thousand-Student Survey of Mechanics Test Data for Introductory Physics Courses. *American Journal of Physics*, *66*(64), 1–26.

Hale, P. L. (2000). Kinematics and Graphs : Students ' Difficulties and CBLs. *The Mathematics Teacher*, *93*(5), 414–417.

Haleem, A., Javaid, M., Qadri, M. A., & Suman, R. (2022). Understanding the role of digital technologies in education: A review. *Sustainable Operations and Computers*, *3*(1), 275-258. https://doi.org/10.1016/j.susoc.2022.05.004

Hasan, S., Bagayoko, D., & Kelley, E. L. (1999). Misconceptions and the certainty of response index (CRI). *Physics Education*, *34*(5), 294–299. https://doi.org/10.1088/0031-9120/34/5/304

Heydari, H., Zarei, E., Zainalipour, H., & Abbas, B. (2013). *Survey the Effect of Cooperative Learning on Confidence*. *3*(4), 360–363.

Ibrahim, B., & Rebello, N. S. (2012). Representational task formats and problem solving strategies in kinematics and work. *Physical Review Special Topics - Physics Education Research*, *8*(1), 1–19. https://doi.org/10.1103/PhysRevSTPER.8.010126

Jewett, J. W. (2008). Energy and the Confused Student I: Work. *The Physics Teacher*, *46*(1), 38–43. https://doi.org/10.1119/1.2823999

Jufriadi, A., Kusairi, S., & Sutopo, S. (2021). Exploration of student’s understanding of distance and displacement concept. *Journal of Physics: Conference Series*, *1869*(1). https://doi.org/10.1088/1742-6596/1869/1/012195

Jugueta, E. A. D., Go, C. K. C., & Indias, J. M. M. (2012). Free fall misconceptions: A comparison between science and non-science university majors. *Am. J. Phys. Educ*, *6*, 145. http://www.lajpe.org

Knight, J. K., & Brame, C. J. (2018). Peer instruction. *CBE Life Sciences Education*, *17*(2), 1–4. https://doi.org/10.1187/cbe.18-02-0025

Lasry, N., Mazur, E., & Watkins, J. (2008). Peer instruction: From Harvard to the two-year college. *American Journal of Physics*, *76*(11), 1066–1069. https://doi.org/10.1119/1.2978182

Laverty, J., & Kortemeyer, G. (2012). Function plot response: A scalable system for teaching kinematics graphs.

American Journal of Physics, *80*(8), 724–733. https://doi.org/10.1119/1.4719112

Lemmer, M. (2013). Nature, Cause and Effect of Students' Intuitive Conceptions Regarding Changes in Velocity. *International Journal of Science Education*, *35*(2), 239–261. https://doi.org/10.1080/09500693.2011.647110

Mazur, E. (1997). *Peer Instruction: A user's manual*. Prentice Hall.

Mazur, E. (2014). *Peer Instruction: A User's Manual* (Person New). Pearson Education.

McDermott, L. C., Rosenquist, M. L., & van Zee, E. H. (1987). Student difficulties in connecting graphs and physics: Examples from kinematics. *American Journal of Physics*, *55*(6), 503–513. https://doi.org/10.1119/1.15104

Morgan, G. A., Leech, N. L., Gloeckner, G. W., & Barret, K. C. (2004). *SPSS for Introductory Statistics. Use and Interpretation*. Lawrence Erlbaum Associates, Inc. All.

Motlhabane, A. (2016). Learner's alternative and misconceptions in physics: A phenomenographic study. *Journal of Baltic Science Education*, *15*(4), 424–440. https://doi.org/10.33225/jbse/16.15.424

Nieminen, P., Savinainen, A., & Viiri, J. (2012). Relations between representational consistency, conceptual understanding of the force concept, and scientific reasoning. *Physical Review Special Topics - Physics Education Research*, *8*(1), 1–10. https://doi.org/10.1103/PhysRevSTPER.8.010123

Pranata, O. D. (2023). Physics Education Technology (PhET) as Confirmatory Tools in Learning Physics. *Jurnal Riset Fisika Edukasi Dan Sains*, *10*(1), 29–35. https://doi.org/10.22202/jrfes.2023.v10i1.6815

Pranata, O. D., Sastria, E., Ferry, D., & Zebua, D. R. Y. (2023). Analysis of Students' Emotional Intelligence and Their Relationship with Academic Achievement in Science. *Proceedings of the International Conference on Social Science and Education, ICoeSSE*, 395–410. https://doi.org/10.2991/978-2-38476-142-5

Pranata, O. D., & Seprianto, S. (2023). Pemahaman Konsep Siswa Melalui Skema Blended learning Menggunakan Lembar Kerja Berbasis Simulasi. *Karst : Jurnal Pendidikan Fisika Dan Terapannya*, *6*(1), 8–17. https://doi.org/https://doi.org/10.46918/karst.v6i1.1724

Pranata, O. D., Yuliati, L., & Wartono. (2017). Concept Acquisition of Rotational Dynamics by Interactive Demonstration and Free-Body Diagram. *Journal of Education and Learning (EduLearn)*, *11*(3), 291–298. https://doi.org/10.11591/edulearn.v11i3.6410

Rosenquist, M. L., & McDermott, L. C. (1987). A conceptual approach to teaching kinematics. *American Journal of Physics*, *55*(5), 407–415. https://doi.org/10.1119/1.15122

Soeharto, S. (2021). Development of A Diagnostic Assessment Test to Evaluate ScienceMisconceptions in Terms of School Grades: A Rasch MeasurementApproach. *Journal of Turkish Science Education*, *18*(3), 351–370. https://doi.org/10.36681/tused.2021.78

Sokoloff, D. R., Thornton, R. K., & Laws, P. W. (2011). *RealTime Physics Active Learning Laboratories Module 1 Mechanics* (Vol. 15). http://books.google.com/books?hl=en&lr=&id=GjkvDKvZVrYC&pgis=1

Sokolowski, A. (2017). Graphs in kinematics - A need for adherence to principles of algebraic functions. *Physics Education*, *52*(6). https://doi.org/10.1088/1361-

6552/aa873d

Sutopo, Hidayah, N., Wisodo, H., & Haryoto, D. (2020). Improving students’ understanding of kinematics concepts through multi-representational learning. *AIP Conference Proceedings*, *2215*(April). https://doi.org/10.1063/5.0004063

Sutopo, & Waldrip, B. (2013). Impact of a Representational Approach on Students ’. *International Journal of Science and Mathematics Education*, *12*(November 2012), 741–766. https://link-springer-com.ezproxy.utm.my/content/pdf/10.1007%2Fs10763-013-9431-y.pdf

Testoni, L. A., & Brockington, G. (2016). The use of smartphones to teach kinematics: An inexpensive activity. *Physics Education*, *51*(6). https://doi.org/10.1088/0031-9120/51/6/063008

Wee, L. K., Tan, K. K., Leong, T. K., & Tan, C. (2015). Using Tracker to understand “toss up” and free fall motion: A case study. *Physics Education*, *50*(4), 436–442. https://doi.org/10.1088/0031-9120/50/4/436

Wemyss, T., & Van Kampen, P. (2013). Categorization of first-year university students’ interpretations of numerical linear distance-time graphs. *Physical Review Special Topics - Physics Education Research*, *9*(1), 1–17. https://doi.org/10.1103/PhysRevSTPER.9.010107

Wenning, C. J. (2011). The Levels of Inquiry Model of Science Teaching. *J. Phys. Tchr. Educ. Online*, *6*(2), 9–16.

Wieman, C. E., Adams, W. K., Loeblein, P., & Perkins, K. K. (2010). Teaching Physics Using PhET Simulations. *The Physics Teacher*, *48*(4), 225–227. https://doi.org/10.1119/1.3361987

Wieman, C. E., & Perkins, K. K. (2006). A powerful tool for teaching science. *Nature Physics*, *2*(5), 290–292. https://doi.org/10.1038/nphys283

Winter, J. de, & Hardman, M. (2020). Teaching Secondary Physics. In J. de Winter & M. Hardman (Eds.), *Teaching Secondary Science* (3rd ed.). https://books.google.com.my/books?id=ZSoryQEACAAJ