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Peer Instruction and PhET Simulations: Strengthening Students' Understanding of Motion

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ABSTRACT

This study investigates the effectiveness of integrating peer instruction with PhET simulations in enhancing students' interpretation and understanding of motion concepts, specifically position, velocity, and acceleration. The primary goal was to assess whether this combined approach could improve conceptual comprehension and reduce misconceptions in kinematics. The study was conducted with 18 students enrolled in a basic physics course, using a pre-experimental one-group pre-test and post-test design. Data was collected through conceptual tests administered before and after instruction. Data analysis included descriptive statistics and N-Gain score calculations to measure learning improvement. The results revealed a significant enhancement in students' interpretation of position-velocity relationships, with an N-Gain score in the high category (1.0). However, misconceptions regarding the velocity-acceleration relationship persisted, as reflected by a medium N-Gain score (0.45). Common misconceptions included the belief that acceleration determines motion direction and that positive acceleration always increases speed. The combination of peer instruction and PhET simulations proved effective in addressing position-velocity misconceptions, fostering student engagement and conceptual learning. However, persistent challenges in velocity-acceleration understanding suggest the need for additional instructional strategies, such as emphasizing vector concepts and graphical analysis. Given the study's small sample size, future research should explore broader implementations, investigate long-term retention, and examine alternative factors influencing conceptual change. This study contributes to physics education research by highlighting effective strategies for improving conceptual understanding and addressing misconceptions in kinematics.

KEYWORDS: Acceleration; Motion; PhET Simulation; Peer Instruction; Position: Velocity

1 INTRODUCTION

When it comes to motion or kinematics, many studies focus on understanding graphs (Beichner, 1994; McDermott et al., 1987; Pranata, 2024a; Zavala et al., 2017). Problems related to graphs require a fundamental understanding of the quantities involved and their application in motion graphs, namely position, velocity, and acceleration. A common kinematics misconception is the confusion between position and velocity (Hestenes et al., 1992; Lin et al., 2023; Trowbridge & McDermott, 1980), as well as misunderstanding changes in velocity and the direction of acceleration (Lichtenberger et al., 2017). These misconceptions are often deeply ingrained in students' thinking, making them difficult to change. Conceptual change is required to address them. The result can be that initial conceptions either no longer exist or persist after a conceptual change (Potvin et al., 2020). Research has shown that misconceptions and correct concepts can coexist in students' minds (Nadelson et al., 2018), which highlights the importance of exploring students' prior knowledge before instruction.

Additionally, the difficulties faced by students also stem from language and terminology (Aprilia et al., 2023; Winter & Hardman, 2020). Students frequently confuse terms that seem similar but have distinct meanings, such as speed and velocity, or velocity and acceleration (Winter & Hardman, 2020). Issues with terminology and language should not be underestimated, as they can contribute to the development of misconceptions in related concepts. Riendeau (2014) classified physics language into three groups: content vocabulary, mathematics and equations, and data representation. These categories, although unfamiliar to many students, are crucial for building a strong conceptual understanding and should be introduced early in the learning process.

Understanding key motion concepts is essential for a smooth progression from kinematics to dynamics without misconceptions hindering students' understanding of force. Previous studies have found that conceptual issues related to velocity and acceleration can lead to further misconceptions when studying force (Lemmer, 2013). For example, students often associate force with velocity rather than acceleration or changes in velocity (Wells et al., 2020). Students also tend to confuse the concepts of position, velocity, and acceleration, often linking them incorrectly (Motlhabane, 2016; Shaffer & McDermott, 2005).

Despite extensive research on motion misconceptions and various instructional strategies, challenges remain in effectively addressing students' persistent misunderstandings. Many studies have examined the role of interactive simulations and peer discussion separately in physics education, but there is a lack of research integrating peer instruction with PhET simulations to improve students’ interpretation of motion. While previous studies have shown that peer instruction facilitates conceptual understanding (Crouch & Mazur, 2001; Gok, 2012; Lasry et al., 2008; Zhu & Singh, 2012) and PhET simulations enhance visualization and engagement (Wieman et al., 2010; Wieman & Perkins, 2006), little research has explored how their combination specifically influences students’ understanding of position, velocity, and acceleration.

It is crucial to identify the most common conceptual challenges students face when learning motion concepts, particularly position, velocity, and acceleration. One promising approach for addressing these issues is peer instruction (Crouch & Mazur, 2001; Mazur, 2014). Peer instruction has been shown to effectively support students' conceptual understanding and problem-solving skills (Lasry et al., 2008). It addresses common misconceptions more effectively than traditional lecturing (Gjerde & Hagane, 2024) and helps students construct knowledge through peer discussion, benefiting all participants in different ways (Körhasan, 2021).

To maximize the effectiveness of peer instruction, especially in the current technological era, students can be encouraged to use technology as a learning tool. One effective tool is PhET simulations. Research has shown that PhET simulations support conceptual understanding in various learning environments, such as inquiry-based learning (Pranata, 2023a), blended learning (Pranata & Seprianto, 2023), game-based learning tools (Pranata, 2024c), as a confirmation tool (Pranata, 2023b, 2024b), and in scientific outreach activities (Pranata et al., 2022). PhET simulations provide interactive and visual learning opportunities in physics education (Wieman et al., 2010; Wieman & Perkins, 2006). They are also easily accessible, even on smartphones, allowing students to engage in class discussions while exploring simulations.

Numerous PhET simulations support the learning of motion concepts, including "Moving Man," (https://phet.colorado.edu/en/simulations/moving-man) which allows students to manipulate variables like position, velocity, and time, and visualize motion. Moving Man PhET Simulation. The instructional intervention in this study focuses on peer instruction supported by PhET interactive simulations. This combination aims to improve students' interpretation of motion and conceptual understanding of position, velocity, and acceleration. The research questions are: 1). How effective is peer instruction using PhET simulations in improving students' understanding of motion concepts? What misconceptions persist after the instructional intervention, particularly regarding position, velocity, and acceleration? This study contributes to the improvement of physics education by addressing common misconceptions in kinematics and offering implications for enhancing students' conceptual understanding and critical thinking in physics. The goal of this research is to enhance students' interpretation of motion (position, velocity, and acceleration) through peer instruction using PhET simulation.

2 METHOD

The research employed a pre-experimental one-group pre-test and post-test design to investigate the effectiveness of peer instruction combined with PhET simulations in improving students' understanding of motion concepts, with a focus on position, velocity, and acceleration. This study focused on a specific group of students enrolled in a basic physics course at IAIN Kerinci, allowing for an in-depth exploration of their conceptual development. The methodology involved several key steps, including pre-and post-instruction assessments, instructional interventions, and data analysis, ensuring a comprehensive examination of the instructional approach and its impact.

The peer instruction required students to engage in small-group discussions and answer conceptual questions, with PhET simulations serving as scaffolding tools. These simulations provided a visual and interactive medium for students to dynamically explore kinematic concepts. Students were guided through a series of simulation activities where they could manipulate variables, such as position, time, velocity, and acceleration while observing real-time graphical representations of motion.

The study was conducted with 18 students enrolled in a basic physics course at IAIN Kerinci. Using total population sampling, all students participated in the study. The participants had varying levels of prior knowledge related to motion concepts, having been introduced to basic kinematic principles in earlier lectures. The study spanned several weeks and was integrated into regular class sessions.

To assess the students' conceptual understanding of motion before and after the instructional intervention, two assessments were administered. A pre-test was conducted before the implementation of peer instruction to establish a baseline of students' motion concept understanding. A post-test was administered after the peer instruction sessions, utilizing the same or comparable conceptual questions to measure changes in understanding. Both the pre-and post-tests focused on the students' ability to provide qualitative descriptions of motion. The tests included questions designed to identify common misconceptions, particularly in interpreting velocity and acceleration. For instance, one set of questions addressed scenarios where position and velocity have opposite signs (e.g., positive position with negative velocity), while another set examined cases where velocity and acceleration have opposite signs (e.g., positive velocity with negative acceleration). The test items were validated by two physics education experts to ensure content accuracy and alignment with learning objectives.

The results from the pre-and post-tests were analyzed using descriptive statistics and N-Gain score analysis to measure the effectiveness of the instructional intervention. The N-Gain score was calculated for each student to assess the degree of improvement, using the following formula:

$$N - Gain = \frac{post\ test\ \% - pre\ test\ \%}{100\% - pre\ test\ \%} \quad (1)$$

The N-Gain scores were categorized into categories of low, medium, and high improvement, based on standard criteria (Hake, 1998), as outlined in Table 1.

Table 1. N-Gain (G) Score Criteria

Score N-Gain	Criteria
G < 0.3	Low
0.3 ≤ G < 0.7	Medium
G ≥ 0.7	High

Descriptive statistics, including means, standard deviations, and percentages, were also used to summarize overall performance and compare improvements in understanding different motion concepts (position, velocity, acceleration).

The analysis specifically focused on identifying persistent misconceptions. While significant improvement was observed in interpreting motion in terms of position and velocity, challenges with understanding acceleration persisted. Many students continued to struggle with cases where velocity and acceleration had opposite signs. A qualitative analysis of students' responses and group discussions during the peer instruction sessions provided further insight into these persistent misconceptions, informing recommendations for future instructional interventions.

3 RESULT AND DISCUSSION

Based on students' responses to the motion interpretation questions in both the pre-test and post-test, a general overview of the data was obtained using descriptive statistics, as shown in Table 2.

Table 2. Descriptive Statistics

Data	Test	Min	Max	Mean		Std. Deviation	Skewness		Kurtosis	
				Statistic	Std. Error		Statistic	Std. Error	Statistic	Std. Error
Position-Velocity	Pre-	0.00	100.00	65.43	5.69	24.15	-0.93	0.54	2.30	1.04
	Post-	100.00	100.00	100.00	0.00	0.00	.	.	.	.
Velocity-Acceleration	Pre-	0.00	100.00	43.06	5.48	23.26	0.10	0.54	1.64	1.04
	Post-	0.00	100.00	68.52	6.41	27.20	-0.75	0.54	0.57	1.038

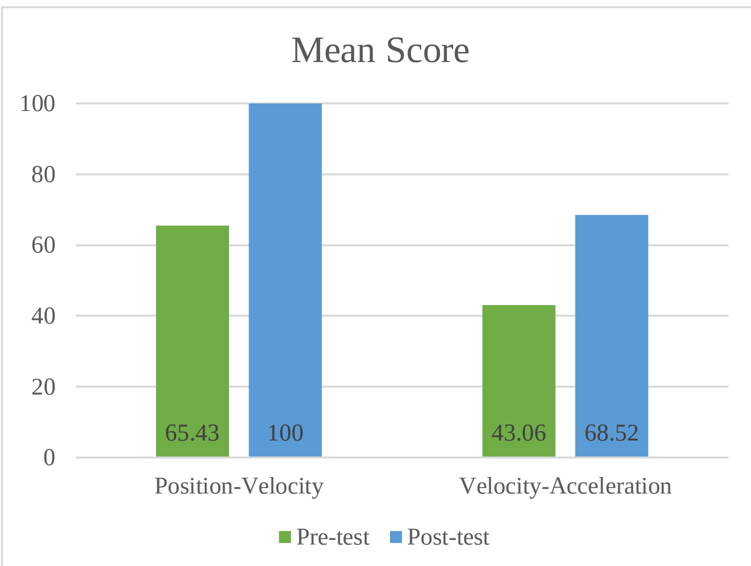


Figure 1. Mean Score

The data in Table 2 and Figure 1 indicate an increase in scores from the pre-test to the post-test for both categories of concept interpretation. First, the explanation of the position-velocity concept showed a significant increase, falling into the high category, with an N-Gain score of 1. Second, the explanation of the velocity-acceleration concept also showed improvement, but only in the medium category, with an N-Gain score of 0.45.

Further analysis was conducted by examining individual student scores, as illustrated in Figure 2. The plot of student scores confirmed a score improvement from the pre-test to the post-test (shift to the right or positive x-axis). To support a more in-depth analysis, the N-Gain data for each student is also calculated, as shown in Figure 3.

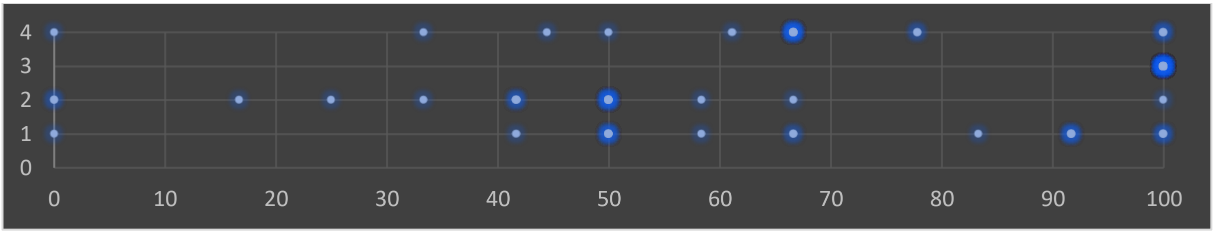
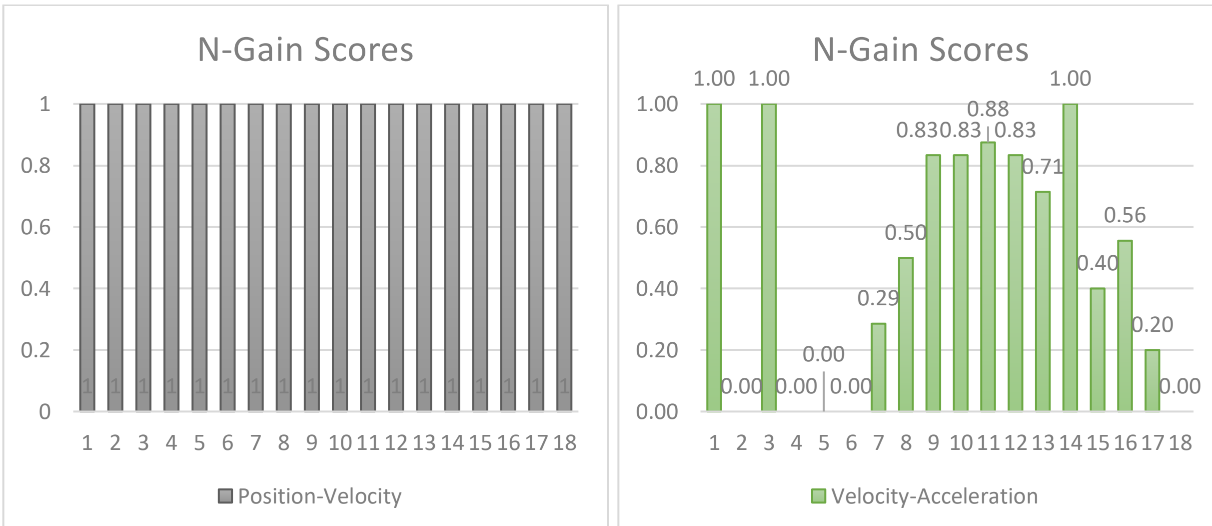


Figure 2. Students' Scores (y-axis: 4 for pre-test position-velocity, 3 for post-test position-velocity, 2 for pre-test velocity-acceleration, and 1 for post-test velocity-acceleration).



(a) (b)

Figure 3. N-Gain Score for Each Student: (a) Position-Velocity and (b) Velocity-Acceleration

The distribution of N-Gain scores for the position-velocity concept confirms the effectiveness of the learning process in improving the accuracy of students' interpretation of motion concepts. However, the N-Gain scores varied for the velocity-acceleration concept. While 44.44% of students achieved a high N-Gain, 27.78% of students had an N-Gain of zero, indicating that misconceptions related to velocity acceleration persisted even after instruction.

Before instruction, various misconceptions were identified among students regarding position-velocity and velocity-acceleration concepts, as summarized in Table 3. In the simulations, the position-velocity concept was demonstrated with constant velocity, while the velocity-acceleration concept was shown with constant acceleration. The motion was confined to one dimension using a Cartesian coordinate system, with positive values on the right and negative values on the left.

For position-velocity concepts, a consistent pattern of misconceptions was found across different situations. For instance, students mistakenly believed that positive velocity indicated faster motion than negative velocity. This misconception arises from the mathematical concept that positive numbers are larger than negative numbers. However, in physics, positive and negative velocities indicate direction on a coordinate plane, not speed. Students treated velocities as scalars, a misconception previously identified in the literature (Barniol & Zavala, 2014). Another misconception was that velocity always increased, even when the simulation indicated that it remained constant. This misunderstanding stemmed from the fact that the simulation initially paused, leading students to believe that the "man" in the Moving Man simulation was stationary and would begin to move when resumed. Based on these findings, teachers should carefully guide students when using PhET simulations to address misconceptions early.

Table 3. Some Misconceptions

Position-Velocity Concepts	Velocity-Acceleration Concepts
At position 0 (coordinate) and with the same and constant velocity: a) Velocity increases, whether positive or negative. b) Positive velocity is perceived as fast motion, and negative velocity as slow motion. c) The object is considered stationary, even though it has a velocity value.	-
Position in the positive part of the coordinate and with the same and constant velocity: a) Velocity increases, whether positive or negative. b) Initially stationary, then velocity increases when positive and decreases when negative. c) Positive velocity is perceived as fast motion, and negative velocity as slow motion. d) Moves back and forth only on the positive side of the coordinate when velocity is positive. e) Always moves in the positive direction initially, then toward the negative when velocity becomes negative.	**When velocity is positive:** a) Positive acceleration is perceived as a movement to the right and negative acceleration as a movement to the left. b) Negative acceleration shows leftward movement with decreasing velocity. c) Constant velocity. d) Fast motion when acceleration is positive, and slow motion when acceleration is negative.
Position in the negative part of the coordinate and with the same and constant velocity: a) Velocity increases, whether positive or negative. b) Initially stationary, then velocity increases when positive and decreases when negative. c) Positive velocity is perceived as fast motion, and negative velocity as slow motion. d) Moves back and forth only on the negative side of the coordinate when velocity is negative. e) Always moves in the negative direction initially, then toward the positive when velocity becomes positive.	**When velocity is negative:** a) Positive acceleration is perceived as a movement to the right and negative acceleration as a movement to the left. b) Positive acceleration shows rightward movement with increasing velocity. c) Stationary when acceleration is negative. d) Constant velocity. e) Fast motion when acceleration is positive, and slow motion when acceleration is negative.

In the velocity-acceleration concepts, a common pattern of misconceptions was also identified. Many students incorrectly assumed that acceleration determines the direction of motion and that velocity remains constant even when acceleration is present. Similar misconceptions have been reported in previous studies, where students perceived constant acceleration as if the velocity remained unchanged (Lemmer, 2013). Velocity must change when there is acceleration. Additionally, students often believed that positive acceleration always increases speed, while negative acceleration always decreases speed. An increase in speed occurs only when acceleration and velocity are in the same direction, including when both are negative. In extreme cases, some students thought that positive acceleration indicated fast motion and negative acceleration indicated slow motion.

These misconceptions were all identified during the pre-test. Misconceptions related to position-velocity concepts were largely corrected following the instructional intervention. Peer instruction combined with PhET simulations proved to be an effective learning approach, enhancing students' understanding and boosting their confidence and accuracy in interpreting motion concepts. However, some misconceptions related to velocity acceleration persisted, albeit with less frequency. This finding is consistent with previous research, which suggests that understanding the concept of position change does not necessarily transfer to an understanding of velocity change (Zavala et al., 2017). In this study, misconceptions regarding velocity acceleration remained, such as students believing that acceleration determined the direction of motion rather than velocity. For example, some students thought that rightward motion indicated positive acceleration and leftward motion indicated negative acceleration. Similar misconceptions have been reported in previous studies, where students correctly answered questions but mistakenly related acceleration to the direction of the final velocity, rather than to changes in velocity (Motlhabane, 2016). One student maintained the misconception that velocity remains constant despite acceleration, while another believed that positive acceleration equates to fast motion and negative acceleration to slow motion.

Kinematics presents many challenges for learners, as evidenced by this research, which highlights the incomplete understanding students often have of key concepts such as velocity and acceleration. Previous studies have reported similar findings (Motlhabane, 2016; Shaffer & McDermott, 2005; Zavala et al., 2017). The teaching of kinematic concepts must be approached carefully to ensure that students achieve a complete understanding of fundamental concepts, particularly position, velocity, and acceleration. The introduction of vector concepts should be emphasized to further enhance students' comprehension and interpretation of motion. Applying these concepts to graphical representations will further deepen students' understanding of kinematics comprehensively.

This study highlights the effectiveness of combining peer instruction with PhET simulations to enhance students' understanding of motion concepts. The approach significantly improved position-velocity interpretation and helped address misconceptions, though challenges remained in velocity-acceleration understanding. For broader implementation, instructors should integrate structured peer discussions with interactive simulations, emphasizing vector representations and motion graphs. This method scales well to larger classes by using small-group discussions and classroom response systems for engagement. Given its potential, future studies should explore its application in other physics topics and long-term conceptual retention.

4 CONCLUSION

This study examined the effectiveness of combining peer instruction with PhET simulations to enhance students' understanding of motion concepts. The results showed a significant improvement in position-velocity interpretation, while some misconceptions about velocity-acceleration persisted. Peer discussions and interactive simulations effectively addressed common misunderstandings, though challenges remained in grasping acceleration's role in motion.

Despite the study's contributions to improving physics instruction, the small sample size limits generalizability. Student engagement levels and prior knowledge may also have influenced the results. Future research should explore larger samples, emphasize vector representations, and investigate long-term retention. Additionally, integrating blended learning or flipped classrooms could further refine instructional strategies for addressing persistent misconceptions in kinematics.

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