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Students' Data Collection and Conclusion-Making Skills Through Inquiry using Worksheet-Based Phet Simulation: Projectile Motion

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Abstract

This study investigates students' data collection and conclusion-making skills in projectile motion topics through inquiry using worksheet-based Physics Education Technology (PhET) simulation. The research population comprised all students enrolled in basic physics courses at IAIN Kerinci, with a total sample size of 36 students. Data collection involved student responses to worksheets designed to support PhET simulation-based learning, focusing on two main objectives: directing students to discover the relationship between free-fall time in projectile motion and height, and recognizing the constant horizontal velocity during projectile motion. Descriptive and correlational analyses were conducted, supplemented by regression analysis to explore predictive relationships between data collection and conclusion-making skills. Findings reveal that while students demonstrate stronger proficiency in data collection tasks compared to interpreting data or drawing conclusions, they face challenges in the latter, particularly with more complex concepts. Notably, a significant positive correlation between data collection and conclusion-making skills was observed in simpler scenarios, but not in more advanced ones. Regression analysis did not yield significant results, indicating limited predictability of conclusion-making skills based on data collection abilities alone. This research underscores the importance of scaffolding instructional activities to support students' progression from fundamental concepts to higher-order thinking skills, particularly in physics education. Insights gained can inform the design of effective teaching strategies to enhance students' critical thinking and analytical abilities in physics learning contexts.

Keywords: Inquiry; Physics learning; Projectile Motion; Simulation; Worksheet-based PhET

INTRODUCTION

The scientific method serves as a systematic approach employed by scientists, including physicists, to investigate natural phenomena. It parallels everyday processes of acquiring knowledge through respect for evidence and reason, constituting fundamental principles underlying scientific inquiry (Kosso, 2011). Hence, instilling an understanding and application of this method in students is paramount for their learning journey (Staddon, 2018). Central to the scientific method are data collection and conclusion-making, essential elements in the exploration of scientific phenomena.

In the realm of physics education, inquiry-based learning serves as a cornerstone, with data collection skills representing a crucial aspect. Proficiency in collecting meaningful data and analyzing it accurately constitutes foundational scientific inquiry skills vital for comprehending physics concepts (Wenning, 2011). Despite its importance, individual students often encounter difficulties in mastering data collection skills (Nasir & Afkar, 2023), highlighting the need for effective instructional strategies (Pedro, 2013).

Effective learning in physics entails a transition towards data collection, enabling students to identify and quantify patterns, thereby enhancing their conceptual understanding (Winter & Hardman, 2020). Moreover, inquiry skills, encompassing hypothesizing, experimenting, data analysis, and conclusion formulation, play a pivotal role in fostering students' learning and understanding of physics principles. With a growing emphasis on inquiry-based learning in physics education, students are encouraged to actively explore scientific principles through experimentation and analysis. Data collection and conclusion-making skills empower students to engage actively in the scientific inquiry process, cultivating curiosity, analytical thinking, and problem-solving abilities essential for success in STEM fields (Putri et al., 2024). Developing these skills early in physics education lays a solid foundation for students' future academic and professional pursuits.

To enhance students' data collection and conclusion-making skills, various approaches and learning experiences have been devised, with the application of Physics Education Technology (PhET) simulations emerging as a popular method (Katherine Perkins et al., 2012; Pranata, 2023a; Wieman & Perkins, 2006). Just as scientists construct and expand their knowledge through experimentation, students can simultaneously be constructing and expanding their knowledge through exploration and discovery in interactive simulations (Kathy Perkins, 2020). PhET simulations are also freely available online and accessible to students with internet access. This accessibility ensures equitable learning opportunities for students regardless of geographic location or socioeconomic status, enabling broader participation in physics education. PhET simulations project has created a suite of interactive simulations (sims) that support learning of science and mathematics content through exploration and discovery (Moore & Perkins, 2018). PhET simulations ultimately provide interactive, visual, and customizable learning experiences based on scientific methods process, especially experiments (Kathy Perkins, 2020; Podolefsky et al., 2010).

By engaging with virtual experiments in PhET simulations, student foster their ownership of the sim and the knowledge that they gain through interacting with the sim appears to lead to more authentic experiences around scientific process skills and evidence-based reasoning and improves argumentation and affect. (Katherine Perkins et al., 2012). Students also develop proficiency in collecting, analyzing, and interpreting data, thereby acquiring, and deepening their understanding of physics concepts (Pranata, 2023a) and fostering a lifelong appreciation for scientific inquiry (Kathy Perkins, 2020).

PhET simulations offer visual representations of physical phenomena, making abstract concepts more tangible and comprehensible for students. Through dynamic animations, graphs, and interactive elements, students can visualize data trends, patterns, and relationships, facilitating data interpretation and analysis. PhET simulations allow educators to customize experiments and scenarios to suit specific learning objectives and student needs. Teachers can design worksheets or guided activities that prompt students to collect specific data points, perform calculations, and draw conclusions based on their observations. PhET simulations provide immediate feedback to students, allowing them to instantly see the effects of changing variables or altering experimental conditions. This rapid feedback loop enables iterative experimentation, hypothesis testing, and refinement of data collection techniques, promoting a deeper understanding of physics principles. To create learning experiences more effective, teacher can design a worksheet based PhET simulations (Pranata, 2023a; Pranata & Seprianto, 2023; Whitacre et al., 2019).

Worksheet based on PhET (Physics Education Technology) simulation was proved to be usefull in various learning physics situtation, in inquiry learning (Pranata, 2023a), blended schema (Pranata & Seprianto, 2023), learning through play (Whitacre et al., 2019), test or exam (Pranata, 2023b), and also ini scientific outreach activity (Pranata et al., 2022). In this study, worksheet-based PhET simulations are interactive digital tools designed to facilitate inquiry-based learning and students' data collection and conclusion-making skills. By using PhET simulations and with worksheet assistance, students are encouraged to adopt an inquiry-based approach to learning, where they actively explore concepts, ask questions, and seek answers through experimentation and analysis. This inquiry-driven process fosters curiosity, critical thinking, and problem-solving skills essential for scientific inquiry. When integrated into physics education, these simulations offer numerous benefits for developing students' data collection and conclusion-making skills. PhET simulations provide students with virtual environments where they can conduct experiments, manipulate variables, and observe outcomes in real-time. This hands-on approach allows students to actively engage with physics concepts and collect data through interactive simulations.

The primary objectives of this study are threefold. Firstly, it aims to investigate students' proficiency in utilizing PhET simulations as a learning tool within the context of physics education. Secondly, the research seeks to explore the intricate relationship between students' data collection and conclusion-making skills, particularly in the domain of projectile motion topics. Lastly, it endeavors to assess the predictive capacity of students' data collection skills in informing their ability to draw accurate conclusions from collected data.

Beyond the classroom, this study offers valuable insights into physics education research, informing the development of effective teaching strategies and curriculum design. By elucidating students' utilization of PhET simulations and their proficiency in data collection and conclusion-making, this research aims to enhance the quality of physics education, equipping educators with evidence-based practices that foster students' skills related to scientific methods.

This study is part of the activities within a basic physics course. The research population comprises all students enrolled in basic physics courses at IAIN Kerinci, with the entire population serving as the sample (total sampling), totaling 36 students. The research aims to explore students' proficiency in data collection and conclusion-making skills, focusing specifically on the topic of projectile motion taught using worksheet-based Physics Education Technology (PhET) simulations.

Data on students' skills were collected through worksheets designed to support PhET simulation-based learning processes (Figure 1a-d). These worksheets featured active links and QR codes leading to the projectile motion simulation and were divided into two parts with different objectives. The first part guided students to discover that the time of free fall in projectile motion (and free fall) does not depend on velocity but on height (Figure 1c), while the second part aimed to help students realize that horizontal velocity remains constant during projectile motion (Figure 1d).

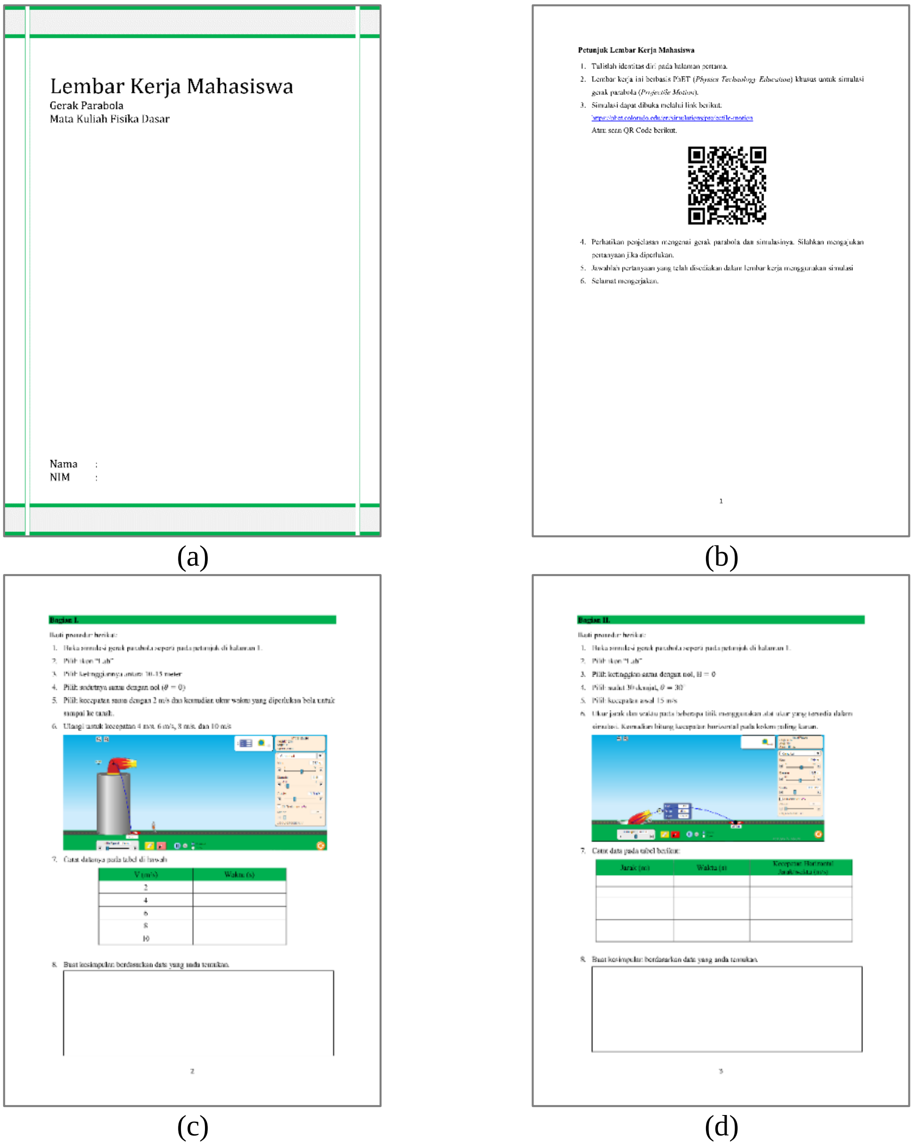

Figure 1. Worksheet-based PhET Simulation: Projectile Motion

RESEARCH METHOD

Quantitative descriptive and correlational methods were employed in the research, chosen for their suitability in revealing and analyzing an overall picture of students' skills in data collection and conclusion-making, particularly in projectile motion topics. Additionally, the analysis was supported by a correlational approach connecting two student skills: collecting data using PhET simulation (projectile motion) and making conclusions based on the collected data.

Data obtained from students' responses on the worksheets, including observational data and conclusions, were assessed using a scoring system totaling 40 points (10 points for data collection and 10 points for conclusions for both part), converted to a scale of 100 points. Descriptive analysis involved statistical measures such as minimum, maximum, range, mean, standard error, standard deviation, skewness, and standard error, presented in tables and diagrams to provide an overview of student skill conditions in projectile motion topics. Correlational analysis utilized correlation tests, namely Pearson or Spearman's rho, depending on the conditions of the data groups. Moreover, regression analysis was employed to further explore the relationship between data collection skills and conclusion-making skills, aiming to predict students' conclusion-making abilities based on their proficiency in gathering data. This analysis aimed to identify potential predictors of students' conclusion-making skills, enhancing understanding of the factors influencing these abilities.

RESULTS AND DISCUSSION

After collecting the data, both descriptive and correlational analyses were conducted. However, two incomplete datasets were excluded from the analysis. Descriptive statistical results are presented in Table 1, while the mean scores are illustrated in Figure 2.

Table 1. Descriptive Statistic

Data	N	Min	Max	Mean		Std. Deviation	Skewness	
				Statistic	Std. Error		Statistic	Std. Error
Data Part 1	34	50.00	100.00	89.71	3.52	20.52	-1.52*	0.40
Conclusion Part 1	34	50.00	100.00	71.76	3.49	20.37	0.39	0.40
Score Part 1	34	50.00	100.00	80.74	2.90	16.93	-0.73	0.40
Data Part 2	34	40.00	100.00	77.65	1.82	10.61	-1.24*	0.40
Conclusion Part 2	34	50.00	100.00	60.88	3.36	19.60	1.44*	0.40
Score Part 2	34	45.00	92.50	69.26	1.97	11.49	0.63	0.40
Both Data	34	60.00	100.00	83.68	1.86	10.82	-0.99	0.40
Both Conclusion	34	50.00	100.00	66.32	2.55	14.89	0.29	0.40
Final Score	34	54.00	96.00	76.15	1.96	11.41	-0.63	0.40

*Data is not normally distributed

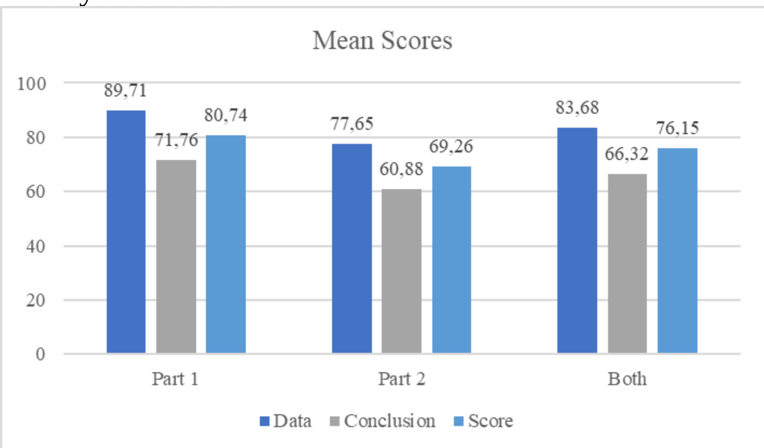

Figure 2. Mean Scores

Based on the descriptive analysis results shown in Table 1 and Figure 2, several findings can be concluded. Firstly, students demonstrated stronger proficiency in collecting and organizing data compared to interpreting data or drawing conclusions. This trend was evident across both parts of the worksheet, with higher average scores observed in data collection tasks. In Part 1, the average score of students in collecting and organizing data was 89.71. A lower score was found for their ability to interpret data or make conclusions, which was 71.76. The same pattern was found in Part 2, with scores of 77.65 for data collection and 60.88 for conclusion-making.

Secondly, when comparing Part 1 and Part 2, students' average scores tended to be higher in Part 1, both for data collection and conclusion-making abilities. The challenges were encountered in interpreting complex data and drawing conclusions, particularly in Part 2, which introduced more advanced concepts related to projectile motion. Part 1, focusing on fundamental concepts, yielded higher average scores compared to Part 2, which introduced more complex concepts related to constant horizontal velocity during projectile motion. This indicates that students may struggle more with interpreting complex data and drawing conclusions when presented with advanced physics concepts.

Part 1 of the worksheet directed students to discover that the time for a free-falling object in projectile motion is not dependent on velocity but on height. Most students initially assumed that higher speeds would result in shorter fall times, consistent with prior research (Frank et al., 2008). However, their data revealed that changes in velocity did not affect the time to reach the ground. Some students were surprised by their findings, as changes in velocity did not impact the time for objects to reach the surface, aligning with previous research (Pranata & Seprianto, 2023). This discrepancy forced students to reconsider their initial understanding of motion, particularly regarding free fall and projectile motions.

Meanwhile, Part 2 guided students to recognize that horizontal velocity remains constant during projectile motion. These findings align with the difficulty levels indicated in the worksheet, as depicted in Figures 1c-d, where Part 2 tended to be more challenging for both data collection and interpretation. Initially, some students believed that objects moved at varying speeds, slowing down as they approached the highest point and then accelerating as they descended back to the surface. However, based on their data and velocity calculations, they concluded that the horizontal velocity of objects during motion remained constant, consistent with previous research (Pranata & Seprianto, 2023).

Collecting accurate and reliable data is a key focus of learning. Data collection skills are assessed as students collect data within simulations. Students must consider potential errors and their confidence in their findings (Winter & Hardman, 2020). Analysis of the collected data revealed that 7 students (20.58%) made errors in collecting data on the time taken for an object to reach the ground in Part 1. Additionally, in Part 2, while errors in data collection were only found in 2 students, there were more inaccurately presented data. This lack of data accuracy primarily contributed to the lower data collection score in Part 2 compared to Part 1. These errors underscore the importance of providing clear instructions and guidance to ensure accurate data collection, especially in physics education where precision is crucial. Previous studies recommend including scaffolding in data collection inquiry skills, as scaffolding facilitates the acquisition of these skills and positively impacts the transfer of inquiry skills across domains (Pedro, 2013).

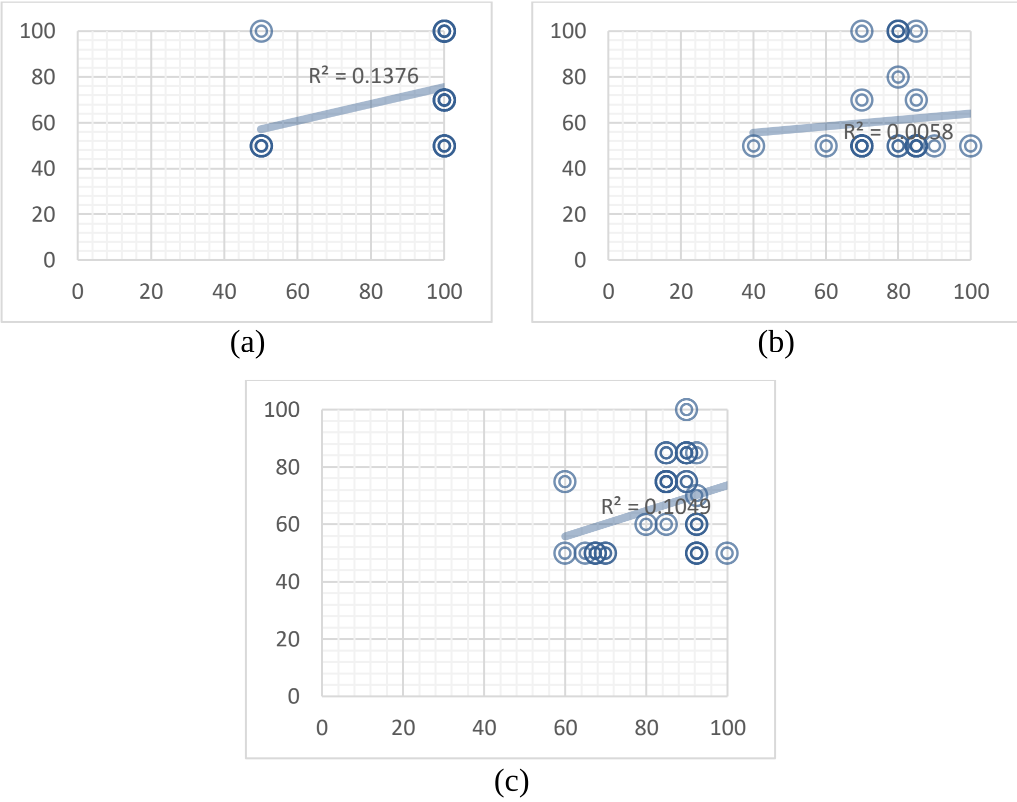

Figure 3. Scatterplot: (a) Part 1, (b) Part 2, and (c) Both Score

Thirdly, the results of the descriptive statistical analysis also indicated that some data were not normally distributed because the skewness statistics were greater than 1 or less than -1 (Leech et al., 2005; Morgan et al., 2004). These data points are denoted with an asterisk (*) in Table 1. Consequently, different correlation tests were employed to analyze the data. The correlation between data collection and conclusion-making scores in both Part 1 and Part 2 was assessed using Spearman's rho. Additionally, Pearson correlation tests were utilized to determine the overall relationship between data collection and conclusion-making abilities.

Furthermore, scatterplots were generated for each pair of connected data, as depicted in Figures 3a-c, to validate the presence of a linear relationship between the data sets. All scatterplots showed a linear correlation between data collection and conclusion-making abilities.

The results of the correlation tests between data collection and conclusion-making in Part 1 using Spearman's rho are presented in Table 2. Subsequently, the correlation results between data collection and conclusion-making in Part 2 using Spearman's rho are displayed in Table 3. Finally, the correlation results between overall data collection abilities and conclusion-making using Pearson correlation are shown in Table 4.

Table 2. Correlation Test (Spearman's rho)

		Conclusion Part 1
Data Part 1	Correlation Coefficient	0.425*
	Sig. (2-tailed)	0.012
	N	34

*Correlation is significant at the 0.05 level (2-tailed).

Table 3. Correlation Test (Spearman's rho) 2

		Conclusion Part 2
Data Part 2	Correlation Coefficient	-0.025
	Sig. (2-tailed)	0.888
	N	34

Table 4. Correlation Test (Pearson Correaltion) Final Score

		Both Conclusion
Both Data	Pearson Correlation	0.324
	Sig. (2-tailed)	0.062
	N	34

Among the three correlation tests conducted, a significant correlation between data collection and conclusion-making abilities was only observed in Part 1. The results in Table 2 reveal a correlation coefficient value of 0.425 with a significance level of 0.012, which is below 0.05. This value indicates a medium level of relationship (Cohen, 1988). For students engaged in inquiry-based learning, they must make observations, collect data, formulate predictions based on those observations, and design and conduct experiments to validate their conclusions. This process involves relating independent and dependent variables to establish meaningful relationships and then making informed decisions and drawing conclusions based on the gathered data. Encouraging students to articulate their collected data promotes valuable discussion and communication skills (Winter & Hardman, 2020). Investing time in developing students' graphing abilities based on their data can be highly beneficial. Moreover, educators can enhance learning by challenging students to interpret and explain relationships and trends within their data. The collection and analysis of data are integral components of physics education, facilitating the exploration of relationships and phenomena (Winter & Hardman, 2020). Additionally, students must defend their conclusions based on evidence and present their findings to their peers (Wenning, 2011). Overall, proficiency in data collection and conclusion-making empowers students to actively engage in the scientific inquiry process, fostering curiosity, analytical thinking, and problem-solving abilities crucial for lifelong learning and success across various domains.

Simple regression analysis was conducted to investigate whether students' data collection and organization skills could predict their ability to interpret and draw conclusions from data. However, the results were not statistically significant, with an $F(1,32)=3.75$ and a significance level greater than 0.05. Despite the non-significant overall F-test, regression results may still provide some predictive utility when the goal is prediction. The regression equation for this relationship is conclusion making score = $19.05 + 0.45 \times$ (data collection score). with an adjusted R-squared value of 0.08. This indicates that 8% of the variance in conclusion-making scores can be explained by students' data collection abilities, a small effect (Cohen, 1988). The statistical findings are presented in the appendix.

CONCLUSIONS AND SUGGESTIONS (5%)

In summary, the study findings demonstrate that students generally excel in collecting and organizing data compared to interpreting and drawing conclusions. This trend persisted across both parts of the worksheet, with higher average scores achieved in data collection tasks. However, students encountered challenges in interpreting complex data and drawing conclusions, particularly evident in Part 2 of the worksheet, which introduced more advanced concepts related to projectile motion. Moreover, a notable difference in performance was observed between Part 1 and Part 2, emphasizing the difficulty of interpreting complex data. Errors in data collection were also identified, underscoring the importance of clear instructions and guidance for accurate data collection in physics education. Furthermore, while a significant positive correlation between data collection and conclusion-making skills was found in Part 1, this correlation was not observed in Part 2, suggesting variability in the relationship between these skills depending on task complexity. Despite this, regression analysis did not establish strong predictive links between data collection and conclusion-making skills, highlighting the need for further research with larger sample sizes and refined methodologies to explore these relationships in greater depth.

This research underscores the significance of nurturing both data collection and conclusion-making skills within the realm of physics education, particularly concerning projectile motion topics. Educators are urged to devise instructional materials and activities that scaffold students' learning journey from fundamental principles to more intricate applications, while also prioritizing the cultivation of critical thinking and analytical abilities essential for deriving meaningful conclusions from gathered data. For further exploration, attention could be directed towards assessing the efficacy of PhET simulations in enhancing students' comprehension of projectile motion concepts, examining how worksheet-based activities complement the simulation experience, and investigating the specific methodologies students employ for data collection during these activities. Furthermore, delving into how students analyze the amassed data and formulate conclusions based on their observations could yield valuable insights into their learning processes and the effectiveness of utilizing PhET simulations in physics education.

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