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Students' Data Collection, Graph-Making, and Conclusion-Making Skills in Inquiry-based Learning Using Interactive Simulations

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Abstract This study investigates students' skills in data collection, graph-making, and conclusion-making during a basic physics course on force and motion using worksheet-integrated PhET simulations. Sixteen students at IAIN Kerinci were selected through total population sampling. Worksheets were designed to guide students through three investigative tasks: examining the effects of resultant forces, exploring the relationship between mass and acceleration under constant force, and analyzing the relationship between force and acceleration under constant mass. Quantitative descriptive and correlational methods were employed to evaluate and analyze students' skill levels and relationships between the skills. Results indicate that students excel in data collection, achieving consistent and high scores, but face challenges in graph construction and conclusion-making, as evidenced by higher variability and errors. Significant misconceptions, such as misunderstanding the conditions of zero resultant force and acceleration, were identified. Correlational analysis revealed a strong, positive relationship between data collection and graph-making skills, but no significant correlation with conclusion-making skills. Regression analysis suggested limited predictive ability of the foundational skills for inferential reasoning. The findings underscore the need to focus on enhancing graph-making and pattern-identification processes to support conclusion-making. This research highlights critical areas for improving physics education and developing scientific reasoning skills.

Keywords: Conclusion-making, Data collection, Force and motion, Graph-making, Inquiry, PhET simulations, Worksheet

INTRODUCTION

Understanding the universe and its underlying principles continues to evolve through the efforts of scientists, including physicists, who rely on the systematic framework of the scientific method. The scientific method enables experts to decipher natural

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phenomena and uncover their mysteries while providing a logical pathway for inquiry and discovery. By engaging with this process, students also develop a critical, informed view of scientific practices, enriched by exploring real-world examples of how scientists approach complex problems (Staddon, 2018). Moreover, the exploration of everyday phenomena often mirrors the stages of the scientific method, bridging the gap between abstract scientific concepts and practical understanding (Kosso, 2011; National Research Council, 2012). Thus, it is imperative to embed this process within educational practices, particularly in science learning environments in schools.

Among the core components of the scientific method, data collection and conclusion-making stand out as fundamental skills required to understand natural phenomena. These skills are pivotal for students to master; however, numerous studies reveal the challenges students face in these areas. Many learners struggle to collect data effectively (Pedro, 2013), and even when they succeed in this aspect, interpreting the data and deriving meaningful conclusions often prove to be significantly more challenging (Pranata, 2024). Teachers play a critical role in this process by guiding students to represent data in structured formats, such as graphs, which can reveal patterns and relationships between variables in collected data. Graphs, therefore, serve as vital tools for aiding students in comprehending data and drawing informed conclusions (Beeken, 2014).

To address these challenges and support the development of these essential skills, it is crucial to employ effective teaching strategies tailored to science learning (Pedro, 2013). One such pedagogical approach is inquiry-based learning, which aligns seamlessly with the iterative processes of the scientific method. Through inquiry-based learning, students engage in authentic scientific practices such as formulating questions, collecting and analyzing data, and deriving conclusions (Wenning, 2011a). This model has been particularly effective in fostering critical thinking and a deeper conceptual understanding of science (Pranata, 2025a; Winter & Hardman, 2020).

Inquiry-based learning is strongly emphasized in modern curricula, including Indonesia's Merdeka Curriculum, which recommends its application in science education (Putri & Pranata, 2024). Among the various approaches and levels of inquiry (Bell et al., 2005; Wenning, 2011b), this study employs structured inquiry, where students investigate phenomena following teacher-guided procedures. Structured inquiry provides scaffolding that supports novice learners in navigating complex scientific tasks, ensuring they remain focused and engage in the learning process.

To enhance the efficacy of inquiry-based learning, technology-driven tools have been introduced, such as interactive simulations. These tools serve as virtual laboratories that enable students to conduct experiments, collect data, and visualize outcomes in a controlled environment (Edelson, 2001). Among the most widely used tools are PhET simulations, developed by the University of Colorado, which have been recognized for their effectiveness in promoting inquiry-based, interactive learning experiences (Wieman & Perkins, 2006). PhET simulations are freely accessible and versatile, applicable to various educational settings, including inquiry-based learning (Pranata, 2023a), game-based learning (Whitacre et al., 2019), outreach initiatives (Pranata et al., 2022), and assessment design (Pranata, 2023b). Furthermore, well-integrated PhET simulations significantly enhance students' exploration of phenomena and foster conceptual understanding (Moore & Perkins, 2018; Perkins, 2020).

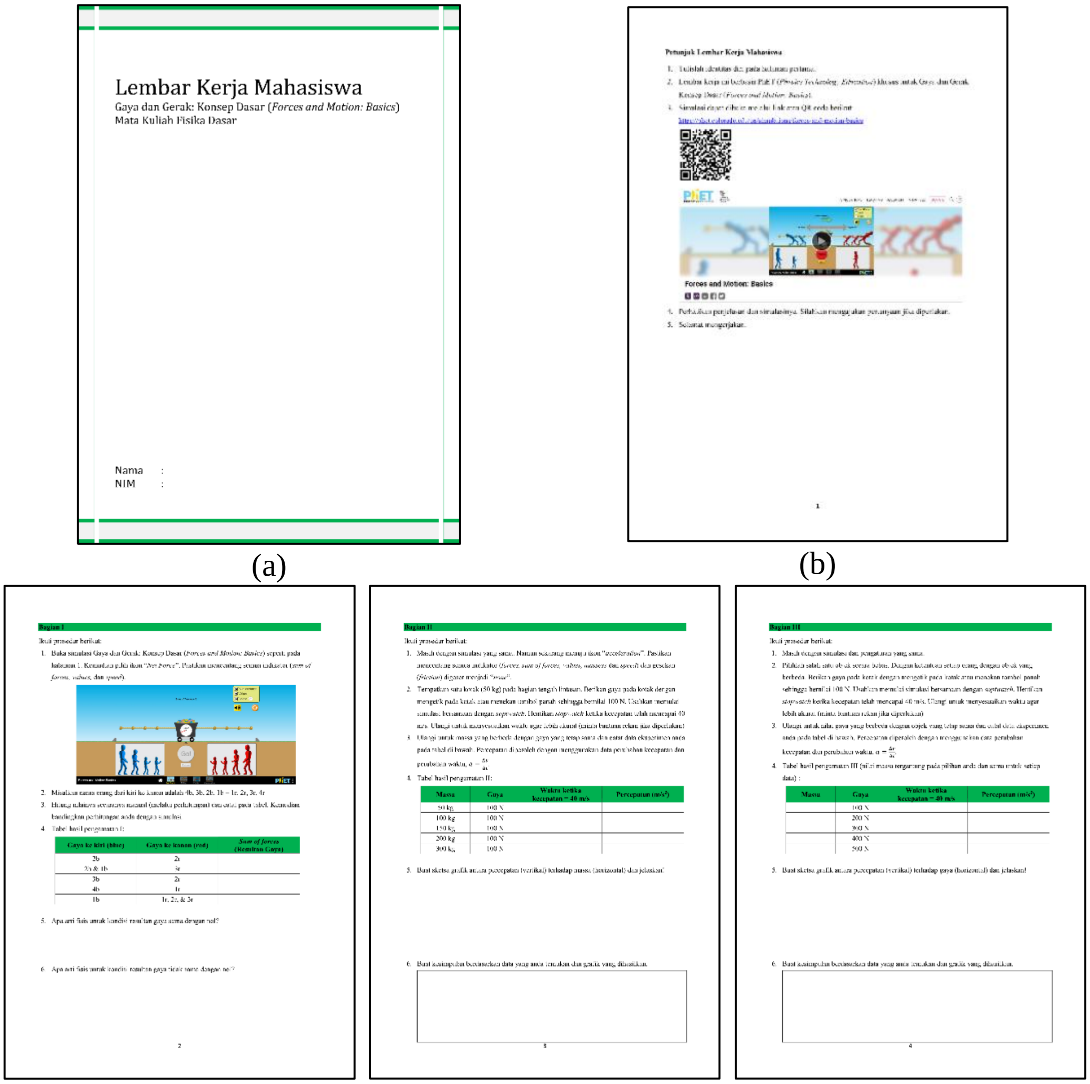
Research has shown that integrating PhET simulations with inquiry-based learning, coupled with scaffolding techniques like graphical representations, can further support students in identifying patterns within data and deriving accurate conclusions (Pranata, 2024). Data visualization tools such as tables, graphs, and statistical analysis not only simplify the interpretation of data but also allow for the communication of findings to others. The National Research Council's framework for K–12 science education underscores the importance of recognizing patterns as one of seven crosscutting concepts in scientific disciplines (National Research Council, 2012). The ability to identify patterns in data is integral to understanding complex relationships and solving scientific problems, making these tools indispensable in science education.

Given this context, the present study aims to investigate high school students' data collection, graph-making, and conclusion-making skills in the context of physics learning. Specifically, the study seeks to (1) explore the relationships between these three critical skills, (2) determine whether data collection and graph-making abilities can predict students' capacity for conclusion-making, and (3) provide actionable insights into enhancing these skills through effective teaching strategies. The findings of this study hold significant implications for physics education, offering guidance on fostering scientific skills essential for both academic and real-world applications. By linking these skills to the activities of professional scientists, this research also aims to cultivate a deeper appreciation for the scientific method among students, ultimately preparing them for future careers in science and technology.

METHOD

This study is an essential component of a foundational physics course, focusing on enhancing student proficiency in core scientific skills. The research was conducted with students enrolled in an introductory physics course at IAIN Kerinci. Using a total population sampling method, the entire cohort of 16 students participated in the study, ensuring comprehensive coverage of the target population.

The primary objective of this research is to investigate students' abilities in data collection, graph-making, and conclusion-making, with specific attention to the topic of force and motion, taught through worksheet-integrated Physics Education Technology (PhET) simulations. These skills are crucial for fostering scientific reasoning and understanding and are directly tied to the analytical processes inherent in the scientific method.



(c) (d) (e)

Figure 1. Worksheet-based PhET simulation: force and motion.

To achieve these objectives, data were collected using specially designed worksheets that integrated PhET simulations, as shown in Figure 1. These worksheets served as interactive tools guiding students through the learning process and facilitating exploration and conceptual understanding. Each worksheet included active links and QR codes (Figure 1b) that directed students to the PhET Force and Motion simulation and was structured into three distinct sections, each targeting specific learning outcomes:

1. Understanding the Effect of Resultant Force on Motion (Figure 1c): Students explored how zero and non-zero resultant forces impact an object's motion, forming the foundation of force analysis.

2. Exploring the Relationship Between Mass and Acceleration (Figure 1d): This section aimed to help students understand how varying masses affect acceleration when the force applied remains constant, highlighting Newton's second law.
3. Analyzing the Impact of Force Magnitude on Acceleration (Figure 1e): Students examined how different force magnitudes influence acceleration while keeping mass constant, further reinforcing their grasp of Newtonian mechanics.

The research employed a quantitative descriptive and correlational methodology to examine students' skills in these areas and uncover relationships between them. Quantitative descriptive analysis was used to provide a comprehensive overview of students' performance levels in data collection, graph-making, and conclusion-making. Correlational methods were then applied to explore the interplay among these skills, such as the link between the ability to acquire accurate data, construct graphs to identify patterns, and make logical inferences.

Data were derived from students' responses recorded in the worksheets, which included observations and analyses made during the simulation tasks. A scoring system was employed to evaluate the students' performance in each skill: 30 points for data collection, 20 points for graph-making, and 30 points for conclusion-making. The scores were normalized to a 100-point scale to standardize results and facilitate comparison. Descriptive statistics, including minimum, maximum, range, mean, standard deviation, skewness, and standard error, were calculated to provide insights into the students' performance and skill distribution. The findings were visualized using tables and diagrams for clear and accessible presentation.

For correlational analysis, statistical tests, such as Pearson's correlation or Spearman's rho, were utilized based on the data characteristics to explore the relationships between the three measured skills. Additionally, regression analysis was conducted to delve deeper into the predictive relationship among these skills. Specifically, the study aimed to determine the extent to which students' abilities in data collection and graph-making could predict their proficiency in drawing meaningful conclusions.

FINDINGS AND DISCUSSION

Descriptive Statistical Analysis

The analysis of the descriptive statistical data, as outlined in Table 1, reveals several noteworthy findings regarding students' skills in data collection, graph-making, and conclusion-making on the topic of force and motion.

Table 1. Descriptive statistics.

Skills	N	Range	Min	Max	Mean		Std. Deviation	Skewness	
					Statistic	Std. Error		Statistic	Std. Error
Data Collection	16	36.25	63.75	100.00	93.05	2.30	9.19	-2.56	0.56
Graphics Making	16	80.00	20.00	100.00	57.50	5.59	22.36	1.18	0.56
Conclusion Making	16	92.00	0.00	92.00	65.50	5.48	21.93	-1.92	0.56
Average Score	16	64.00	33.33	97.33	72.02	3.56	14.25	-0.70	0.56

The mean scores across the three assessed skills demonstrate a significant disparity. Data collection skill ($mean = 93.05$) stands out as the highest, significantly outperforming graph-making and conclusion-making skills. This is visually illustrated in Figure 2, highlighting the gap in average scores.

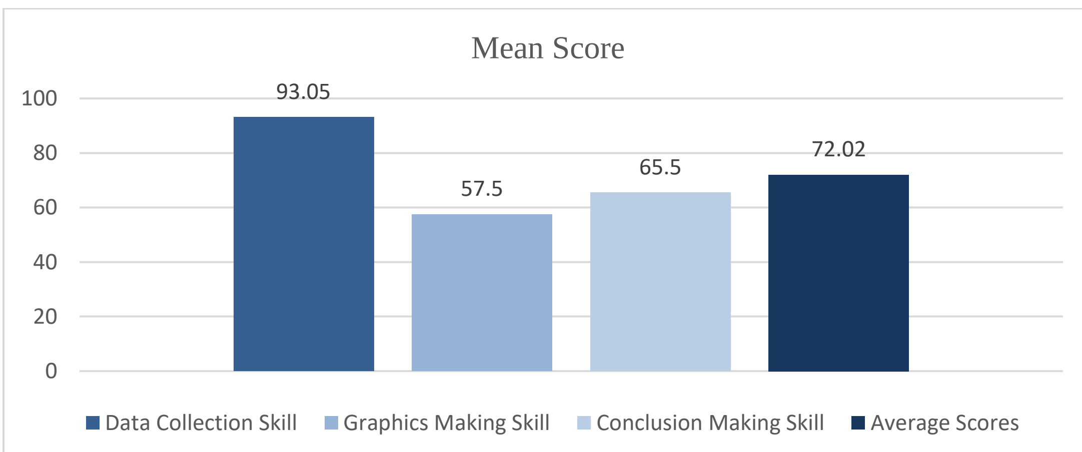
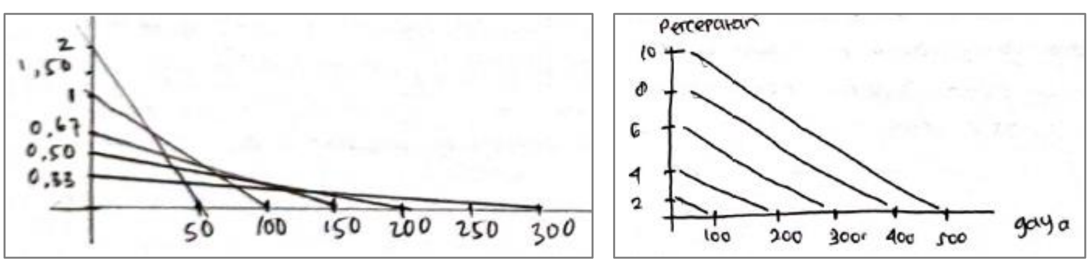


Figure 2. Mean scores.



(a) (b)

Figure 3. Graph misconceptions: (a) mass vs. acceleration with constant force and (b) force vs. acceleration with constant mass.

A deeper inspection reveals that the overall high mean score for all three skills (72.02) is primarily driven by the exceptional performance in data collection. Despite this, notable challenges exist in both graph-making and conclusion-making, which indicate areas requiring further instructional support.

Students demonstrated strong competence in data collection, particularly in recording and calculating the resultant force. However, two prevalent misconceptions were identified. First, when the resultant force equals zero, some students misinterpreted this as the absence of any force acting on the object. Second, a belief that a moving object must always have acceleration, contrary to Newtonian principles.

The analysis of students' graphical work, as seen in Figure 3, indicates critical errors. Two major issues emerged. First, when plotting mass versus acceleration under a constant force (Figure 3a), students often connected data points with a direct line rather than plotting points correctly on the Cartesian plane. Similarly, when plotting force versus acceleration under constant mass (Figure 3b), the relationships were often misrepresented, obscuring the underlying physical principles. These difficulties in constructing accurate graphs highlight a critical barrier to students' ability to analyze data and draw correct conclusions.

Interestingly, despite the graph-making challenges, some students correctly inferred the relationship between force and acceleration (Newton’s second law). However, conclusion-making errors were prominent in tasks related to interpreting the effects of a zero resultant force on motion and understanding the relationship between mass and acceleration under a constant force.

Further statistical analysis shows that data collection skills displayed the lowest standard deviation among the three skills, indicating greater consistency across students. In contrast, graph-making and conclusion-making scores exhibited higher variability, reflecting a wider range of proficiency levels. These trends are further supported by the score range for data collection skills, which is relatively narrow compared to the other two categories.

Normality and Correlation Analysis

The skewness values for all three skills fell outside the range of -1 to +1 (Morgan et al., 2004), indicating a lack of normal distribution in the data. As a result, Spearman’s rho test was employed for correlation analysis, and the results are summarized in Table 2.

Table 2. Correlations: spearman's rho.

		Data Collection Skill (DCs)	**Graphics Making Skill (GMs)**	**Conclusion Making Skill (CMs)**
Data Collection Skill (DCs)	Coefficient	1.000		
	Sig. (2-tailed)	.		
Graphics Making Skill (GMs)	Coefficient	**0.765****	1.000	
	Sig. (2-tailed)	**0.001**	.	
Conclusion Making Skill (CMs)	Coefficient	0.218	0.486	1.000
	Sig. (2-tailed)	0.416	0.056	.

**. Correlation is significant at the 0.01 level (2-tailed).

A significant positive correlation was identified between data collection and graph-making skills ($r = 0.765,\ \rho < 0.01$). This high correlation suggests that proficiency in data collection strongly supports students' ability to construct graphs. The relationship is visualized in the scatterplot (Figure 4).

No significant correlation was found between conclusion-making skills and the other two skills. This indicates that students' ability to interpret data and draw conclusions is not inherently tied to their performance in data collection or graph-making, underscoring the unique challenges associated with conclusion-making.

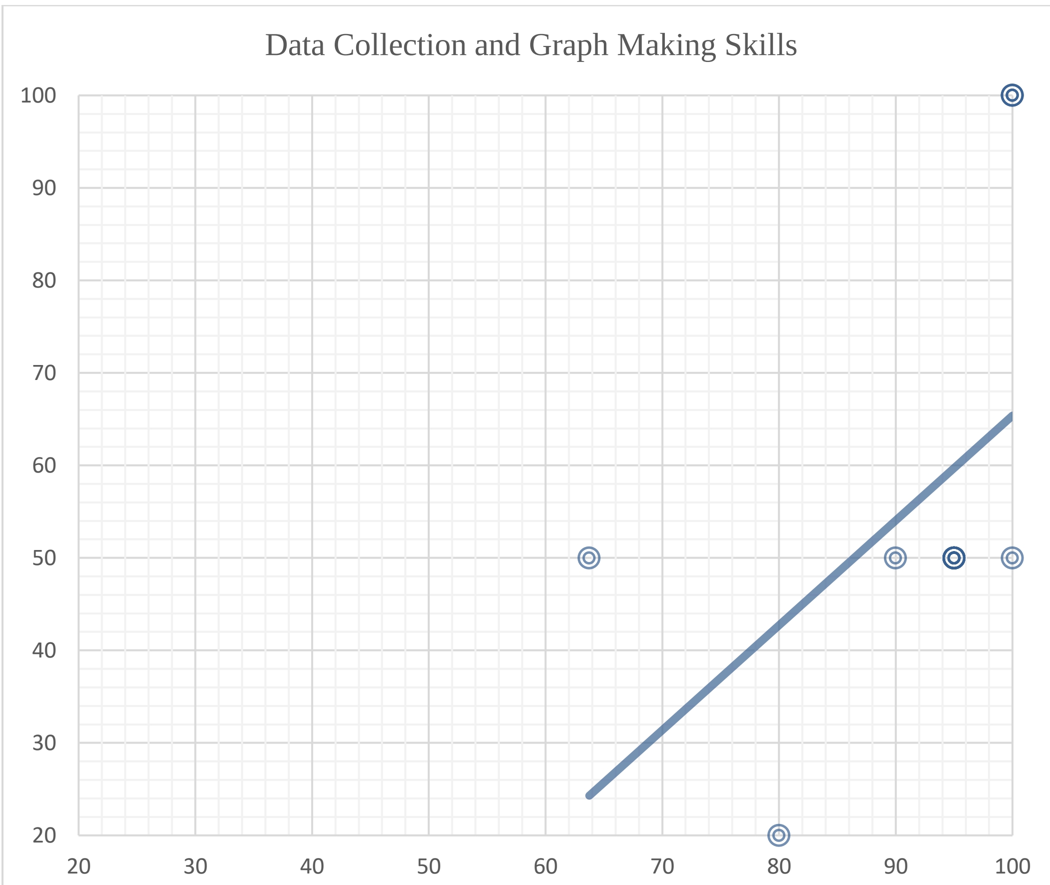


Figure 4. Scatterplot.

Regression Analysis

A simple regression analysis was conducted to assess whether data collection and graph-making skills could predict conclusion-making performance. While the overall regression model was not statistically significant ($F(1,13) = 1.875, \rho > 0.05$), the regression equation provides some insights into the relationship:

$$\text{CMs Scores} = 23.277 + 0.193(\text{DCs score}) + 0.42(\text{GMs Score})$$

The adjusted R-squared value of 0.105 indicates that 10.5% of the variance in conclusion-making scores can be explained by data collection and graph-making abilities. Although this represents a small effect size (Cohen, 1988), it suggests a starting point for exploring predictors of conclusion-making skill. More detail statistical findings are presented in the appendix.

The findings underscore the crucial role of graph construction in facilitating conclusion-making. Properly constructed graphs enable students to discern patterns in data, such as the proportional relationship between force and acceleration and the inverse relationship between mass and acceleration. These patterns are fundamental to understanding Newton's Second Law. Previous research highlights the importance of an integrated approach to teaching physics and mathematics, where mathematical concepts (such as graphs, proportionality, coordinates, and equations) are aligned with physics principles to enhance conceptual understanding (Beeken, 2014; Pranata, 2025b; Woolnough, 2000). Building on this foundation, teaching Newton's Second Law can be expanded to include the use of free-body diagrams and mathematical expressions to deepen understanding of force and motion concepts and to develop critical thinking skills (Pranata & Noperma, 2023).

However, the challenges students face in graph construction indicate that misconceptions or technical errors in plotting may impede their ability to draw accurate conclusions. This emphasizes the need for educators to provide targeted support in graph-making activities and to scaffold the process of conclusion-making to bridge gaps in understanding.

CONCLUSION

The findings of this study reveal significant variability in students' proficiency across three key scientific skills: data collection, graph-making, and conclusion-making in the context of force and motion topics using PhET simulation-based worksheets. While students demonstrated strong and consistent abilities in data collection, significant challenges persisted in constructing accurate graphs and drawing valid conclusions. The lack of significant correlations between conclusion-making and the other skills highlights the complexity and independence of this cognitive process, emphasizing that even high performance in foundational skills does not guarantee success in inferential reasoning. These results underscore the need to focus educational strategies on scaffolding higher-order skills like graph interpretation and conclusion-making to bridge gaps in scientific reasoning and promote a deeper understanding of physical concepts.

Future research should explore strategies to enhance students' graph-making and conclusion-making skills, focusing on integrating explicit scaffolding mechanisms such as step-by-step graph construction guidance and targeted prompts for identifying patterns in data. Investigating the role of alternative instructional interventions, such as incorporating peer collaboration or adaptive feedback within PhET simulations, could provide additional insights. Moreover, longitudinal studies tracking the development of these skills over time and across varying instructional settings may yield a more comprehensive understanding of how data analysis and interpretation abilities evolve. Expanding the scope to include a larger and more diverse student sample would also enhance the generalizability of the findings and support the refinement of evidence-based teaching practices in physics education.

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APPENDIX

Regression Test Results

Table A.1. Variables Entered/Removed[b]

Model	Variables Entered	Variables Removed	Method
1	Data[a]	.	Enter

a. All requested variables entered.
b. Dependent Variable: Conclusion Making Skill

Table A.2. Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.473[a]	0.224	0.105	20.750

a. Predictors: (Constant), Data

Table A.3. ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1614.801	2	807.401	1.875	0.193[a]
	Residual	5597.199	13	430.554		
	Total	7212.000	15			

a. Predictors: (Constant), Data Collection Skill, Graph Making Skill
b. Dependent Variable: Conclusion Making Skill

Table A.4. Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	23.277	56.045		0.415	0.685
	Data Collection Skill	0.193	0.659	0.081	0.293	0.774
	Graph Making Skill	0.422	0.271	0.430	1.558	0.143

a. Dependent Variable: Conclusion Making Skill