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Analysis of Consistency in Students' Understanding of Multi-Representations in the Context of Determining One-Dimensional Kinematics Distance

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Abstract

A structured and comprehensive understanding of physics concepts is crucial to physics learning. Such proficiency is characterized by the consistency in students' thought processes across multiple representations. This research aims to ascertain the consistency in the thought processes of first-year students when determining distance in multiple representations. This study employed a descriptive research design with a quantitative-qualitative approach, involving 77 students as research subjects. The participants are divided into classes: Class H with 41 students and Class I with 36 students. Data analysis techniques included quantitative descriptive analysis and Huberman and Miles' analysis. The research instrument consisted of 28 reasoned multiple-choice items that have undergone validation. The findings indicate that only 8 (10.39%) students possess a precise and consistent understanding of the definition of distance, applying it across various representations. A small proportion (12.99%) experiences misconceptions. These research findings corroborate previous studies, emphasizing that, in general, first-year students are novices in physics.

Keywords: concistency of understanding; distance**;** multi representation

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INTRODUCTION

Structured and comprehensive understanding of physics concepts that can be effectively used to solve problems is crucial in physics education (Affriyenni et al., 2020; Diyana et al., 2020; Docktor & Mestre, 2014; Kattayat & Josey, 2019; Sutopo, 2019). Through such understanding, the complexity of natural phenomena can be well-explained using a small set of physics laws and principles (Sutopo, 2019). The infrequent physics laws and principles compared to the complexity of natural phenomena trains students to become accustomed to thinking systematically. The role of such conceptual understanding is essential in physics education and is a competency that every student must possess when learning physics.

However, ensuring that students understand concepts correctly is not an easy task. Previous research results show conditions where the lack of learning activities and the minimal use of new concepts in various contexts make students' understanding of physics concepts weak and easily forgotten (Adha & Taqwa, 2022; Docktor & Mestre, 2014; Singh et al., 2023). Additionally, one factor to consider is the tendency of students when answering questions. A common tendency among first-year students is to use mathematical equations without understanding the meaning of the equations (Gaigher et al., 2007; Ratnaningdyah, 2017). Mathematical equations are a form of external representation that contains a lot of information but has a concise presentation. A common mistake among first-year students is the tendency to "plug and chug," matching formulas with known information in the problem (Sutopo, 2019).

Four external representations are commonly combined to help students construct their conceptual understanding: tables, graphs, diagrams, and mathematical equations. Multirepresentations (varied representations) are aimed at enabling students to describe the same phenomenon in different forms (Masrifah et al., 2020; Munfaridah et al., 2020). One indicator that students understand a concept is when they recognize the same concept in different representations (Hestenes, 1997; Munfaridah et al., 2020). The findings of this research can serve as a guide for educators in carrying out their role as facilitators of learning activities.

One fundamental topic that plays a crucial role in physics education is kinematics. Kinematics is a topic that deals with the motion of an object without considering its causes (Jufriadi et al., 2021). Understanding topics such as distance, displacement, speed, velocity, acceleration, linear motion, and projectile motion will be frequently used in the discussion of subsequent physics topics such as vibrations, waves, thermodynamics, electricity, magnetism, nuclear physics, and solid-state physics (Syuhendri, 2021). The earliest sub-topic of kinematics is one-dimensional kinematics, which discusses the motion of an object in a straight line. Understanding this topic will significantly influence students' conceptual understanding of more complex physics topics (Kusairi et al., 2019). Knowledge related to the meaning of acceleration as a change in velocity over a specific period and the meaning of acceleration as an indicator of the presence of force is one example of knowledge carried from the kinematics topic to Newton's Laws (Taqwa & Nadhor, 2020).

Although kinematics is crucial for students to master when learning physics, some previous studies indicate that students often struggle to understand and apply the terms in kinematics. These challenges include (1) students' inability to differentiate between speed and acceleration (Ayop & Ismail, 2019), (2) distinguishing instantaneous speed and average speed (Bollen et al., 2016), (3) describing motion based on graphs of position, speed, and acceleration versus time (Ismail & Ayop, 2016), (4) errors in interpreting position equations, where position equations are often mistaken for displacement equations (Zainuddin et al., 2019). The impact of these difficulties can potentially hinder the formation of concepts in subsequent topics (Sutopo, 2019).

One factor contributing to the emergence of these difficulties is a lack of comprehensive foundational understanding. Such incomplete understanding can potentially lead to misconceptions (Nadhor & Taqwa, 2020). In this research, "misconception" is defined as naive thinking consistently used in various external representations. However, there is still limited research specifically investigating the level of consistency in students' understanding of the "distance traveled" topic, especially when presented in multiple representations. Therefore, the main focus of this research is to determine the consistency in the thought processes of first-year students when determining distance traveled in multi-representations. Thus, this study aims to fill the existing knowledge gap and enhance our understanding of students' challenges in determining the distance traveled.

METHOD

This research is a descriptive study with a quantitative-qualitative approach. The research instrument consists of 28 items of multiple-choice questions with explanations that have undergone validation. These questions cover various one-dimensional kinematics topics in the form of multi-representations. This research focuses on students' responses to the "distance traveled" topic scattered in items 2, 9, 16, and 23. The representation forms of these items are presented in Table 1. It is important to note that other topics are not the main focus of this research.

Table 1 Mapping of test instrument on the distance traveled topic

No	Question Representations
2	Mathematical Representation
9	Table Representation
16	Graphical Representation (x-t)
23	Motion Diagram Representation

The subjects of this research consist of 77 students, divided into two classes: Class H with 41 students and Class I with 36 students. The sampling technique used is cluster random sampling. Classes H and I are independent and do not influence each other.

There are two types of data analysis in this research. Descriptive analysis of quantitative data is obtained through the scores of student responses. This data assesses the student's ability to determine the distance traveled in multi-representations. Meanwhile, qualitative data analysis uses the Huberman and Miles stages (Miles & Huberman, 1984). Qualitative data is obtained through students' reasons for choosing answer options. The results of qualitative data analysis are then grouped based on students' thinking patterns (Ding & Beichner, 2009).

RESULTS AND DISCUSSION

Quantitative Data Results

The ability to determine the distance traveled in multi-representations is one of the Course Performance Criteria (*Capaian Pembelajaran Mata Kuliah*) for the Basic Physics I course. Quantitative descriptive statistical data on students' understanding of distance traveled in multi-representations are presented in Table 2.

Table 2 Descriptive statistical analysis of student responses when determining distance traveled

Information	Score
Average	37.67
Maximum Score	100.00
Minimum Score	0
Standard deviation	33.60

Based on the data in Table 2, it is apparent that students' understanding of distance traveled in multi-representations tends to be low. This is indicated by the mean value, which only reaches 37.67. The percentage of students answering correctly for each representation is presented in Figure 1.

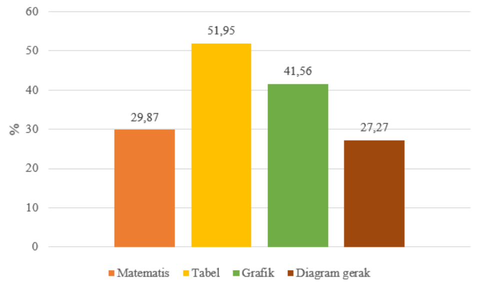


Figure 1 Percentage of students answering correctly for each representation

Based on the data in Figure 1, it is evident that students' ability to determine the best distance in table representation is notable. Approximately 51.95% of students answered correctly in determining distances in Table representation. However, students struggled the most when determining distances in motion diagram representation, with only 27.27% successfully providing correct answers.

Student Responses for Each Representation

The outcomes of students' responses when determining distances in mathematical representation are presented in Figure 2. Regarding this instrument, 44 (57.1%) students demonstrated correct reasoning, but only 23 (29.9%) were able to answer correctly. In this group, 21 students made errors in mathematical calculations and/or misunderstood the definition of distance. Examples of research subject responses with correct reasoning and answers are presented in Figure 3.

Then, concerning students' response outcomes when determining distances in table representation, they are illustrated in Figure 4. Based on Figure 4, it is revealed that 39 (50.6%) students answered with correct reasoning. However, two students in this group made conceptual errors related to displacement. Examples of research subject responses with correct reasoning and answers are presented in Figure 5.

Furthermore, the results of student responses when determining distances in graphical representation are presented in Figure 6. Based on Figure 6, approximately 33 (42.9%) students demonstrated correct reasoning. However, one student from this group made a mathematical calculation error. Examples of research subject responses with correct reasoning and answers are presented in Figure 7.

An object moves in a straight line with a position as a function of time according to the following equation,

$$\vec{x}(t) = t^2 - 4t$$

With $\vec{x}$ in meters and t in seconds. The positive sign (+) on the vector quantity is agreed upon as the direction to the right, and the negative sign (-) on the vector quantity is agreed upon as the direction to the left.

2. The distance traveled by the object in the first 3 seconds is...
A. 3 meters (22,1%)
B. 5 meters (29,9%)*
C. 11 meters (16,8%)
D. 19 meters (2,6%)
E. 42 meters (0.0%)
F. Others:......... (28,6%)

Figure 2 Instrument for determining distance in mathematical representation (correct answers)

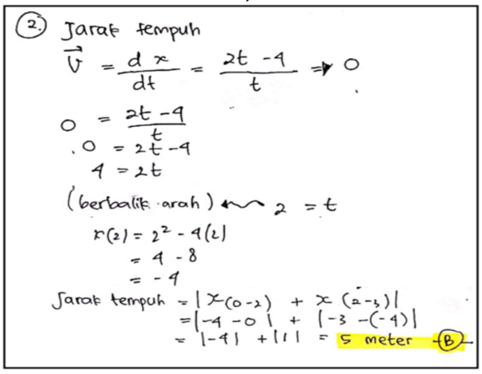


Figure 3 Thought process and correct answers of students for question 2

Objects move in a straight line with a position as a function of time according to the following table!

t	0	1	2	3	4	5	6	7	8
x	10	5	2	1	2	5	10	17	26

With x in meters and t in seconds. The positive sign (+) on the vector quantity is agreed upon as the direction to the right, and the negative sign (-) on the vector quantity is agreed upon as the direction to the left.

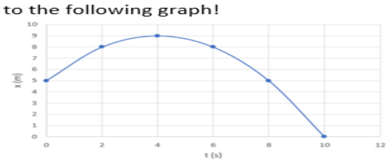
9. The distance traveled by the object in the first 4 seconds is...
A. 2 meters (7,8%)
B. 8 meters (14,3%)
C. 10 meters (51,9%)*
D. 12 meters (5,2%)
E. 20 meters (5,2%)
F. Others: (15.6%)

Figure 4 Instrument for determining distance in table representation (correct answers)

9) Jarak tempuh · berbalik saat t = 3
x 0-3 = |-5+(-3)+(-1)
= |-9|
x 3-4 = |1-2|
= |-1|
Jarak = |8| + |-1|
= 9 + 1 = 10m (C)

Figure 5 Thought process and correct answers of students for question 9

Objects move in a straight line with a position as a function of time according to the following graph!



With x⃗ in meters and t in seconds. The positive sign (+) on the vector quantity is agreed as the direction to the right and the negative sign (-) on the vector quantity is agreed as the direction to the left.

16. The distance traveled by the object in the first 6 seconds is...
A. 3 meters (13,0%)
B. 5 meters (41,6%)*
C. 8 meters (7,8%)
D. 13 meters (5,2%)
E. 20meters (2,6%)
F. Others:..... (29,8 %)

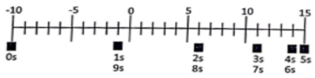
Figure 6 Instrument for determining distance in graphical representation (correct answers)

(16) Jarak tempuh objek dlm 6 detik.
pertama ... |Δx 0-2| + |Δx 2-4| + |Δx 4-6|
= |8-5| + |9-8| + |8-9|
= 3 + 1 + 1 = 5 meter (B)

Figure 7 Thought process and correct answers of students for question 16

The results of students' responses when determining distances in the representation of the motion diagram over time are obtained, as shown in Image 8. Students' responses when determining distances in the diagram representation are as follows: 24 (31.2%) students demonstrated correct reasoning, but three students in this group made mathematical errors. Examples of research subjects' responses with correct reasoning and answers are presented in Image 9.

For 9 seconds, the object is observed to be moving in a straight line with a position every second as shown in the following figure.



With x⃗ in meters and t in seconds. The positive sign (+) on the vector quantity is agreed as the direction to the right and the negative sign (-) on the vector quantity is agreed as the direction to the left.

23. The distance traveled by the object in the first 6 seconds is...
A. 4 meters (5,2%)
B. 14 meters (11,7%)
C. 24 meters (16,9%)
D. 26 meters (27,3%)*
E. 49 meters (1,3%)
F. Others: (37,6%)

Figure 8 Instrument for determining distance in motion diagram representation (correct answers)

23. V(t) : Δx⃗(4-6)/Δt = 14-14/6-4 = 0/2 = 0 m/s berbalik arah pd arah ke-5
Jarak tempuh : |Δx⃗ 0-5| + |Δx⃗ 5-6|
= |25| + |-1|
= 26 m ke kanan (D)

Figure 9 Thought process and correct answers of students for question 23

Through the students' responses to these four representations, it can be concluded that individuals with correct reasoning choose to establish a turning point first, then proceed to sum their displacements or detail the displacements at each time interval. However, in the graphical representation, this approach becomes more complex. As a result, most students who initially chose to determine the turning point shifted to determining displacement at each second. Nevertheless, summing displacements at each second becomes less accurate when an object changes direction at a non-integer time (for example, the object changes direction at 3.5 seconds).

Qualitative Data Results

Based on the stages of qualitative data analysis by Huberman and Miles, a categorization of students' thinking when determining distance was obtained. The results of this categorization are presented in Table 3.

Table 3 Students thinking when determining distance in multi-representations (corrected thinking)

Code	Representation			
	Mathematics	**Table**	**Graph**	**Motion Diagram**
A*	43 (55.8%)	39 (50.6%)	33 (42.9%)	24 (31.2%)
B	2 (2.6%)	10 (13%)	9 (11.7%)	13 (16.9%)
C	2 (2.6%)	1 (1.3%)	6 (7.8%)	-
D	10 (13%)	1 (1.3%)	3 (3.9%)	7 (9.1%)
.E	4 (5.2%)	6 (7.8%)	3 (3.9%)	1 (1.3%)
F	3 (3.9%)	6 (7.8%)	9 (11.7%)	5 (6.5%)
G	-	1 (1.3%)	-	-
H	2 (2.6%)	2 (2.6%)	3 (3.9%)	-
I	11 (14.3%)	12 (15.6%)	11 (14.3%)	27 (35.1%)

Information:
A: Determine the turning point, then sum the displacements or sum the displacements at each time interval.
B: Distance is equal to displacement.
C: Distance is equal to the initial position plus the final position.
D: Distance is equal to the final position.
E: Distance is equal to the sum of positions at each second.
F: Distance is equal to velocity.
G: Distance is equal to the final position multiplied by time at that moment.
H: Distance is equal to instantaneous velocity multiplied by time.
I: Answering without a method or not answering.

Overall, the number of students who successfully maintained thinking method A without mathematical errors or conceptual errors in all representations is 8 (10.4%) students. A total of 11 (14.3%) students successfully maintained thinking method A in three different representations. In addition, 15 (19.5%) students succeeded in two different representations. Meanwhile, 21 (27.3%) students only succeeded in one different representation. There were 22 (28.6%) students did not think with method A, whereas 10 (12.99%) had misconceptions by maintaining relatively different naive thinking. Some students were found to use memorization strategies in solving problems, as shown in Figure 10.

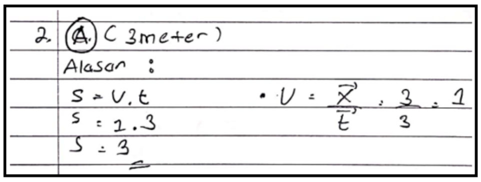


Figure 10 Example case of memorization strategy

The results show that the consistency of students' thinking methods and mathematical abilities is relatively low.

Generally, first-year students have fragmented and incomplete knowledge, which triggers inconsistency in their thinking methods (Bao, 2021; Gerace, 1998; Xu et al., 2020). Additionally, low mathematical abilities often accompany first-year students (Docktor & Mestre, 2014; Nguyen, 2011). Such fragmented knowledge often drives students to use memorization strategies in problem-solving (Chen et al., 2020).

The resources theory can explain the consistency of thinking methods well. According to the resources theory, every student attending lectures already has prior knowledge (Docktor & Mestre, 2014; Xu et al., 2020). Usually, this prior knowledge is not entirely scientifically justified but contains facts that make students feel their knowledge is sufficient to answer physics phenomena. This situation makes prior knowledge difficult to eliminate and consistently used in various contexts. Using knowledge that is not scientifically justified but consistently used by students is then labeled as "misconceptions" (Nadhor & Taqwa, 2020).

Overall, this research strengthens the notion that first-year students are generally novices. The fragmented knowledge and the use of memorization strategies align with findings from previous studies (Bao, 2021; Chen et al., 2020; Gerace, 1998; Xu et al., 2020). However, this study cannot describe the impact of fragmented knowledge. Sweller states that such knowledge can trigger cognitive overload (a condition where working memory processes information beyond its capacity) (Sweller, 1994, 2011). Therefore, the findings in this study are expected to provide considerations in designing future physics learning.

Additionally, some previous studies suggest that a recommended solution to address fragmented knowledge is a self-learning program (usually called computer-based recitation) that can provide personal feedback to students (Adha & Parno, 2022; Diyana et al., 2020). Providing this solution allows students to repeat their learning process independently, where intense repetition makes it easier to activate working memory and form interconnected information structures (Singh et al., 2023).

CONCLUSION

The average score of students in determining travel distance in multi-representations is 37.67. By categorizing thinking methods, it is known that most first-year students have inconsistent thinking methods. Only a small percentage (10.39%) of students have consistently and scientifically correct thinking methods. In addition, a small percentage (12.99%) of students consistently use naive thinking in various representations. Meanwhile, most students (76.62%) have relatively inconsistent thinking methods. This research finding reinforces previous research that, in general, first-year students are novices.

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