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Kinematics Conceptual Understanding: Interpretation of Position Equations as A Function of Time

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Abstract: This article aims at describing the ability of 48 students of physics education in determining the distance traveled, average speed, and acceleration of position functions. To achieve these objectives, three reasoned multiple choice questions were used. The question is part of 20 standard test questions that are used to measure understanding of student mechanics concepts in the Basic Physics course. The study was conducted using a survey method. Data were obtained from student responses in answering questions. Claims of student understanding were seen from the choice of answer options and reasons given. The results of the study indicate that students still have many wrong assumptions regarding x(t), namely as a displacement; determine the distance from x(t) by adding the position of each unit of time and adding the initial and final positions; and assume that acceleration (-) is slowing down.

Key Words: conceptual understanding, function of position, kinematics

Abstrak: Artikel ini bertujuan untuk mendeskripsikan kemampuan 48 mahasiswa pendidikan fisika dalam menentukan jarak tempuh, kecepatan rata-rata, dan percepatan dari fungsi posisi. Untuk mencapai tujuan tersebut digunakan tiga soal pilihan ganda beralasan. Soal tersebut merupakan bagian dari 20 soal tes standar yang digunakan untuk mengukur pemahaman konsep mekanika mahasiswa pada mata kuliah Fisika Dasar. Penelitian dilakukan dengan menggunakan metode survei. Data diperoleh dari respon mahasiswa dalam menjawab soal. Klaim pemahaman mahasiswa dilihat dari pilihan opsi jawaban dan alasan yang diberikan. Hasil penelitian menunjukkan bahwa mahasiswa masih banyak memiliki anggapan yang salah terhadap x(t) yakni sebagai perpindahan; menentukan jarak tempuh dari x(t) dengan menjumlah posisi setiap satuan waktu, dan menjumlah posisi awal dan akhir; dan menganggap bahwa percepatan (-) sebagai perlambatan.

Kata kunci: pemahaman konsep, fungsi posisi, kinematika

INTRODUCTION

Over the past few decades, several researchers have focused their research on the ability of students (and college students) to master the concepts of Physics (Sugara et al., 2016). Good Physics concepts mastery by students is one of the important learning direction (Taqwa et al., 2017). With good mastery of concepts, the ability of students to solve problems will be promoted (De Cock, 2012; Docktor & Mestre, 2014; Hegde & Meera, 2012; Ryan et al., 2016; Sajadi et al., 2013), including understanding and interpreting position equation as a function of time x(t) to determine distance, average speed and acceleration.

Mechanics is a part of Physics that has a broad and fundamental scope because many of the main ideas on Kinematics are the basis for understanding other scientific concepts. Mechanics lesson is often the main target in high school (SMA) education program interventions since there are many applications of concepts in explaining various real-world context phenomena (Singh & Schunn, 2009). To understand the concept of Mechanics as a whole it is necessary to have a strong mastery of concepts on Kinematics (Sutopo, 2015).

Although many parties are aware of the urgency of understanding the Kinematics concept, many students are difficult in understanding concepts in Kine-

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matics to solve related problems. Some of these difficulties include understanding distance and displacement (Taqwa et al., 2016), speed (Taqwa et al., 2017), and acceleration (Angin, Parno, & Sutopo, 2017; Rosenblatt & Heckler, 2011; Shaffer & McDermott, 2005). These difficulties impact on mastering other mechanical concepts, excluding Kinematics. The results that have been done, related to the investigation of students' understanding of the relationship between the resultant direction of force, speed, and acceleration found that many respondents experienced misconceptions (Rosenblatt & Heckler, 2011). Supported by the results of other studies which found that only about 5% (N = 18) Physics teacher candidates, 15% (N = 22) Doctoral students, and 30% (N = 125) graduate students at the University of Washington and Monata State University which was able to explain well the direction of acceleration of objects in simple swings at various points, even if only in an approach (Shaffer & McDermott, 2005). Not only that, but students also experience difficulties in distinguishing speed and acceleration (Hake, 1998).

Although there have been many studies confirming that there are still many difficulties found by students in understanding Kinematics concepts, it is still recommended that identification of understanding of this concept is necessary to be done, particularly on fundamental concepts (Taqwa, 2017) considering numerous issues in the learning process. The identification results are important as a basis in developing effective learning in Mechanics lesson (Sadaghiani, 2012; Sayre, Franklin, Dymek, Clark, & Sun, 2012; Taqwa, 2016). This inspired researchers to examine further mastery of the concepts of distance, average speed, and acceleration of students. In this study, the profile of students' ability to determine distance, average speed, and special acceleration on mathematical representations of position equations as a function of time was revealed.

METHOD

This study aimed at describing the understanding of student concepts related to the Kinematics. To achieve this goal, 20 1-dimensional kinematics questions with different representation format questions, such as the image, graph, verbal, and mathematical representation were given to students. The focus of the discussion is the ability of students to determine distance, average speed, and acceleration of the equation of position as a function of time (mathematical representation). The problem used in this study was a question developed for kinematics ability tests on basic Physics courses. This research was a descriptive study using the survey method. The survey was conducted on 48 Physics education students of the fifth semester. All research subjects were students who have passed in Basic Physics 1 and Mechanics courses.

Data obtained was in the form of qualitative data and quantitative data. Quantitative data were obtained from a student answer options. The data was displayed in the form of a table to see the distribution of student answer options when answering questions. Qualitative data was obtained from the reasons students answer the test questions. The reasons given by students were coded and then grouped based on their understanding tendencies. These reasons were displayed in a table to give an idea of student conceptions in interpreting a physical quantity.

RESULTS

To see the ability of students to determine the distance, the average speed and acceleration of objects from the position equation as a function of time, it used three items of the question (an adaptation of Taqwa & Faizah, 2016). The problem is as shown in Figure 1.

Determining the Distance from the Position Equation as a Time Function

Based on the results, students tended to find it difficult to determine the distance traveled from the position equation as a function of time. This is indicated by the number of students who answered correctly question number 1 (choosing option C) only as many as five students (10.42%). To be exact, the distribution the choice of student answer options in answering question number 1 is shown in Table 1 while the reasons given by students in answering question number 1 are shown in Table 2.

Table 1. Distribution of Student Answer Options in Answering Problem Number 1

Option	Student Answer Option	
	N	%
A	2	4,17
B	6	12,50
C*	5	10,42
D	4	8,33
E	24	50,00
F	7	14,58
Total	**48**	**100**

Use the following information to answer the question 1-3!

A moving object takes a straight path with the equation of position as a function of time expressed as $x(t) = 8 + 6t - t^2$. x in metre and t in second. A sign (+)agreed upon as a direction of movement to the right and a sign (-)as the direction of motion to the left.

1. The distance of objects during an interval $0 \le t \le 5$ s is....
   A. 8 meter B. 5 meter C. 11 meter D. 13 meter E. 21 meter F. 83 meter
2. The average speed of objects in time interval $2\ s \le t \le 4$ s is... .
   A. 0 m/s B. 5,33 m/s C. 6 m/s D. 8 m/s E. 16 m/s
3. The correct statement related to the acceleration of the object in time interval $0\ s \le t \le 6$ s is.... .
   A. The object always moves to the left while slowing down to stop
   B. The object always moves to the right while slowing down to stop
   C. The object always moves to the left while accelerating
   D. The object moves to the right while slowing down then turns towards moving to the left while accelerating

Figure 1. Questions on Conceptual Understanding

Table 2. Student Reasons in Answering Question Number 1

Answer Option	Reason	Total number of students (%)
B	If $x(0) = 8m$ and $x(5) = 13m \rightarrow$ distance = $5m$.	4 (8,33%)
C*	Determining $\vec{v}(t) \rightarrow$ composing graph of $\vec{v}(t) \rightarrow$ calculating the area bounded by a curve on the graph $\vec{v}(t)$.**	2 (4,17%)
D	If $x(5) = 13m \rightarrow$ Distance = $5m$.	1 (2,08%)
E	If $x(0) = 8m$ and $x(5) = 13m \rightarrow$ Distance = $x_i + x_f = 21\ m$.	22 (45,83%)
F	Determining $x(t)$ for every second from t = 0 s to t = 5 s then determining the distance as the number of positions per second.	7 (14,58%)
	Give no reason or reasons given are not clear	12 (25,00%)

*Correct option
**Correct reason

Table 3. Distribution of Student Answers in Answering Question Number 2

Option	Student Answer Option	
	N	%
A*	27	56,25
B	0	0,00
C	9	18,75
D	2	4,17
E	10	20,83
Total	**48**	**100**

Table 5. Distribution of Student Answers in Answering Question Number 3

Option	Student Answer Option	
	N	%
A	26	54,17
B	3	6,25
C	7	14,58
D*	12	25,00
Total	**48**	**100**

Table 4. Student Reasons in Answering Question Number 2

Answer Option	Reason	Total number of students (%)
A*	(1) Defining $\vec{v} = \frac{x(t)}{t} \rightarrow \vec{v}_{avg} = \frac{\vec{v}_1 - \vec{v}_2}{2}$	9 (18,75%)
	(2) Determining $\vec{v}(t)$ then stated that $\vec{v}_{avg} = \frac{\vec{v}_f + \vec{v}_i}{2}$	2 (4,17%)
	(3) Determining $\vec{v}(3)$ the average speed in the time interval 2 s to 4 s.	1 (2,08%)
	(4) Defining $\vec{v}_{avg} = \frac{\vec{v}_f - \vec{v}_i}{\Delta t}$**	13 (27,08%)
C	Defining $\vec{v} = \frac{x(t)}{t} \rightarrow \vec{v}_{avg} = \frac{\vec{v}_1 + \vec{v}_2}{2}$	7 (14,58%)
D	Defining $\vec{v}_{avg} = \frac{x(t)}{\Delta t} \rightarrow$ average speed 8 m/s	2 (4,17%))
E	Defining $\vec{v}_{avg} = \frac{x(2)+x(4)}{\Delta t} \rightarrow$ average speed 8 m/s	1 (2,08%)
	Give no reason or reasons given are not clear	13 (27,08%)

*Correct option
**Correct reason

Table 1 shows that some students chose option E, as many as 24 students (50%). Of the students who chose option E, 22 students (45.83%) included defining distance as $x_i + x_f$. Two students chose option A (4.17%) but neither of them provided a reason for the answer. This indicates that they have not understood the concept well, thus they just tried to use numbers and equations in the questions to obtained answers. Six students (12.5%) who chose option B, four of them provided a reason that the distance by objects was the difference between the starting position and the final position of the object within a certain travel time interval. Four students (8.33%) who chose the D option, one student (2.08%) defined the distance in the interval of 0 seconds to 5 seconds equal to the position of the object when t = 5 seconds. Students who chose option F was seven students (14.58%). They determined the position of objects every second, which is from 0 seconds to 5 seconds and add the number together. Figure 2 presented the reason for students choosing option F.

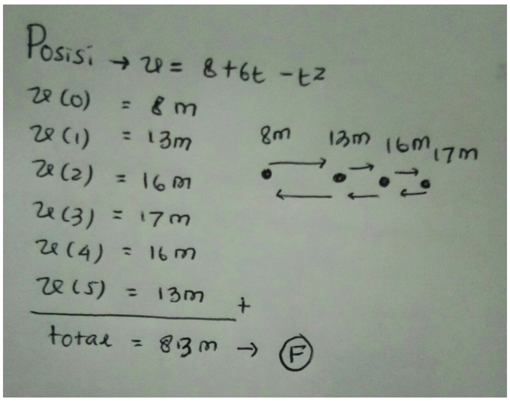

Figure 2. Student's Reason in Choosing Option F

Determining the Average Speed of Position Equation as a Time Function

Student scores in answering question number 2 were the highest. Most students chose the correct option (27 students or 56.25%). In general, the distribution of student answer options is shown in Table 3.

In answering question number 2, some students have chosen the correct option. But some of them still provided the wrong answer. There were nine students (18.75%) choosing option C, two students (4.17%) choosing option D, and 10 students (20.83%) choosing option E. The reasons given by students in answering questions number 2 are shown in Table 4.

In answering question number 2, even if the student chose option A (correct answer) not all students provided the correct reasons. Only 13 students (27.08%) were able to give the correct reasons, defining the average speed as $\vec{v}_{avg} = \dfrac{\vec{v}_f - \vec{v}_i}{\Delta t}$. In addition, some students provided reasons that were not in accordance with Physical concepts, including nine students (18.75%) who determined the speed with the equation $\vec{v} = \dfrac{x(t)}{t}$ then defined the average velocity as $\vec{v}_{avg} = \dfrac{\vec{v}_1 - \vec{v}_2}{2}$, two students (4,17%) provided reasons, by determining $\vec{v}(t)$ then stating that $\vec{v}_{avg} = \dfrac{\vec{v}_f + \vec{v}_i}{2}$, and one student (2.08%) stated that determining $\vec{v}(3)$ as the average speed in the interval of 2s to 4s. Seven students (14.58%) who chose option C reasoned that the definition of speed was $\vec{v} = \dfrac{x(t)}{t}$ and defined the average speed as $\vec{v}_{avg} = \dfrac{\vec{v}_1 + \vec{v}_2}{2}$. While two students (4.17%) who chose option D defined the average speed as $\vec{v}_{avg} = \dfrac{x(t)}{\Delta t}$ and one student (2.08%) who chose option E said the average speed as $\vec{v}_{avg} = \dfrac{\vec{v}(2) + \vec{v}(4)}{\Delta t}$ thus the average speed is 8 m/s.

Determining the Acceleration of Position Equation as a Time Function

The question to identify students' ability to determine the acceleration of position equality as a function of time tends to be difficult for students. The distribution of student answers is presented in Table 5.

In Table 5, only 12 students (25%) chose the correct option, option D. While 25 students (54.17%) chose option A, three students (6.25%) chose option B, and seven students (14.58%) students chose option C. In answering this question, all students (100%) determined the acceleration of an object with the definition of $\vec{a}(t) = \dfrac{dx}{dt}$. The purpose is to see the meaning of a negative sign on the acceleration by students. The answer option in the question is used to express the meanings of the sign (-) in the acceleration according to the student. Thus the answers given by students were their thoughts in interpreting the sign (-) at acceleration.

DISCUSSION

The results indicate that there are still many students who are difficult in determining distance, average speed and acceleration of the position equation as a function of time. The ability to interpret mathematical equations needs to be possessed by students since in explaining various kinds of phenomena, a model is needed, one of which is a mathematical model. The ability to understand Physics through mathematical representation is an important aspect (Ayesh et al., 2010; Kohl & Finkelstein, 2006). The ability to comprehend Physics concepts in learning activities increases with good multi-representation mastery, including in mathematical representations. This is, in addition to supporting students in understanding the concepts carefully it supports the communication of concepts (Meltzer, 2002). In this article, students are required to be able to determine some fundamental concepts in Kinematics from the problems presented in the form of mathematical representations namely equation of position as a function of time.

When determining the distance from the equation of position as a function of time (number 1), students encountered the most mistakes by "calling" irrelevant knowledge. Some of these errors included defining distance as x(t) - x(0) which should be a displacement. This indicates that some students were confused in understanding the concepts of movement and distance. Many students did not understand the physical meaning of displacement and distance correctly, so when solving problems, they often made mistakes (Taqwa & Faizah, 2016). In addition, some students defined distance as $x_i + x_f$. This is the most thought "invoked" by students in completing the problem. The reason was that students only tried the equations which they did not understand well, but because the wrong answers that were in accordance with the students' calculations were included in the answer options, they kept choosing the option. In addition, students who chose option F also seemed to have a not too different understanding from students who chose option E. Yet, students who chose option F added up the position of objects every second according to the time interval in the question (Figure 2). Without sufficient understanding, students tried to use the knowledge they have but were not relevant to the problem until they find results. This is because knowledge still tends to be fragmented (Rivaldo, et al., 2018), thus they often do not verify the truth of the knowledge they use in solving problems. Therefore, the ability of students to determine the distance from the equation of position as a function of time still tends to be low with an indication of the number of students who give incorrect reasons.

In answering question number 1, it should be solved by determining the speed equation as a function of time first. Where the speed of each moment is defined as $\vec{v}(t) \equiv \frac{dx}{dt}$. After obtaining the equation $\vec{v}(t)$, then students must be able to construct the graph $\vec{v}(t)$. In 1-dimensional motion with 'special cases', namely the motion of objects without changes in direction, to determine the distance is equal to the amount of displacement (Δx), with the definition of $\Delta x \equiv \int_{t_i}^{t_f} \vec{v}\, dt$. Then $\int_{t_i}^{t_f} \vec{v}\, dt$ can be determined by calculating the area bounded by the curve in the graph $\vec{v}(t)$. For 1-dimensional motion on objects that move in a changing direction (in one dimension to reverse direction), the distance is different as displacement. To determine the distance, it can be done by summing the area bounded by the curve on the graph $\vec{v}(t)$ for regions $\vec{v}(+)$ and area $\vec{v}(-)$. Only two students could performed it well (4.17%).

Problem number 2 aims to identify the ability of students to determine the average speed in a certain time interval of the equation of position as a function of time that has been known. In answering this question, the accomplishment of students is good if the parameter used is the number of students who chose the correct option. However, if it is observed from the reasons given, not all students who chose the correct option are supported by understanding the correct concepts. There are a number of erroneous reasons expressed by students who chose the answer option A. First, it was assumed that speed is a position per unit of time while speed is half of the difference between instantaneous velocities for that time interval. Second, it was defined that the average velocity as the amount between instantaneous velocities for time intervals divided by two. This indicates that students determined the average speed as well as determining statistical data averages, whereas the meaning of 'average' in both cases is different. As with previous research findings, students were not able to distinguish average velocities with instantaneous speed well (Halloun &

Hestenes, 1985), and students were still confused in distinguishing between position and speed (Trowbridge & McDermott, 1980). They often think that objects will not have the same speed if they are not in the same position or side by side (Daud et al., 2015).

In question number 3, students were asked to determine the acceleration possessed by the object and its direction of motion based on the position equation as a function of time. In general, students have been able to determine the quantity of acceleration using the definition of $\vec{a}(t) = \frac{dx}{dt}$. But they were mistaken in understanding that the sign (-) at acceleration is always considered a slowdown, and some of them assume that the sign (-) is accelerated only as a direction of motion. These findings indicate that students' understanding of the concept of speed is insufficient, even in understanding simple problems (Wind, et al., 2017). The data shows that students are still confused in determining distance, average speed and acceleration. Students are still not able to understand the physical motion of objects from how to interpret acceleration. Often the sign (-) on acceleration represents the direction of motion of objects, because they do not yet understand the difference in speed with acceleration clearly (Jones, 1983). The difficulties of students in understanding the main ideas in Kinematics are also due to the lack of understanding in vector concepts.

This finding indicates that students have not been able to determine physical quantities related to fundamental concepts in Kinematics even in mathematical representations which tend to be simple since these problems have often been raised during high school. Research to uncover student difficulties still needs to be continued, with the same topic and more in-depth study, on other representations, or identifying difficulties on other topics. This is important as the information that can be used by the teacher (or lecturer) to make the basis for developing a teaching approach.

CONCLUSION

In determining the distance, the average speed, and the acceleration of the equation of position as a time function students remain difficult. The difficulty is most often found in determining the distance since many students provided false arguments. Some errors in determining the distance from the position equation as a function of time include (1) using the equation x(t) - x(0) which should be a displacement not distance, (2) substituting the value of t in the interval tt in the function x(t) then add up the position each time, (3) adding the initial position to the final position. These results indicate that students are still confused in distinguishing the meaning of movement and distance. In addition, students are also still confused to distinguish between speed and acceleration. Mostly, they assume the sign (-) at an acceleration which is always a slowdown or direction of motion to the left.

The ability to understand the position, displacement and distance, speed and velocity, and acceleration have indeed been the focus of researchers to reveal. Even those studies have become a long history. Nevertheless, research on understanding this Physics concept still needs to be done particularly in a narrow but deeper context, in other representations, or in other subjects. These findings are important to be the basis of the development of teaching by teachers (or lecturers). For students, it is important to be consistent in interpreting symbols such as x(t) which is a function of position, not distance or displacement. The consistency of students is needed in using the definition of physical quantities on Kinematics because in discussing kinematics there are no specific laws, principles, or theorems.

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