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An analysis of first years senior high school students' mental models: a case study on the concept of uniform motion

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ABSTRACT

Difficulties in understanding physics concepts are often experienced by students such as in the material of regular uniform motion. This study aims to describe the mental models of first-year secondary school students on regular straight-line motion. This research utilized a case study method of 167 students at the secondary level with an average age of 16-17 years. The mental model test has been utilized form of essay questions The mental model test has been utilized form of essay questions with two sub-materials on the regular uniform motion. The data were analyzed referring to the descriptive mental model assessment rubric in the related literature. The rubric maps the level of student understanding which is then categorized into scientific, synthetic, and initial mental model categories. The results stated that students' mental models were dominated in the initial category with respective percentages for both sub-categories of 60 and 90%. In addition, there are still terms of understanding that cannot be distinguished by students so it becomes one of the causes of their unscientific mental models. Based on these results, it is suggested that for further research, alternative teaching materials are needed that can have an impact on improving students' mental models.

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1. INTRODUCTION

A deep understanding of the concept of uniform motion is an important foundation for students to understand the basics of physics. However, students often face challenges in mastering this concept well. This is evidenced by the number of students who still experience misconceptions about straight-motion material [1]-[3] Therefore, this study describes students' mental models as well as their level of understanding of straight-motion material in the hope of identifying the patterns that emerge and the factors that influence their understanding. Therefore, it is hoped that this study can provide in-depth insight into the diversity of students' understanding of the concept and lead to the development of more adaptive and effective learning strategies. Through a better understanding of students' mental models and their level of understanding, it is hoped that this research can assist educators in designing more purposeful learning and teaching materials that are better suited to students' individual needs. As such, these steps are expected to

improve students' achievement of understanding in learning the concept of uniform motion and facilitate a more meaningful and in-depth learning process for them.

Physics is often a scary subject for students because of the complexity of the concepts in physics which can feel difficult to understand for some people [4]-[6]. One of the basic concepts in physics is the concept of uniform motion. According to Ardhanariswari *et al.* [7], uniform motion is one of the basic concepts in the study of physics, especially in the kinematics branch, which studies the motion of objects without considering the cause of the movement. As a basic concept, uniform motion provides the basis for understanding more complex movements, such as circular motion, parabolic motion, and motion in three dimensions. Thus, understanding the concept of uniform motion is an important first step in understanding and mastering the field of physics more broadly [8], [9]. This concept forms the basis for further learning in physics, as well as being important in the application of technology and other sciences.

However, misconceptions about uniform motion often arise because this concept involves a fairly complex understanding. Several misconceptions often arise in the sub of regular uniform motion, namely speed, velocity, and acceleration [1], [10], displacement, distance, and time [11], [12]. Several factors can cause misconceptions in physics learning, including the concept of uniform motion, namely, students' prior understanding [13], complex mathematical language [14], contexts that are not relevant to real life [15], and lack of feedback from teachers [16]. Therefore, this is crucial and needs to be addressed, even if only starting from a small scale, especially in students' cognitive development which is directly related to model mental.

Models are created through a process of simplification and reduction of structure, describing the relationships between elements in a system [17]. Mental models are internal or cognitive representations of a system [18], [19] and they exhibit privatized aspects with a focus on predictive and descriptive features [20]. Individuals use mental models to explain, understand, and observe real-world behavior, as well as develop new mental models within an existing framework according to personal context. In essence, mental models stem from how individuals perceive the world through their actions. Meanwhile, external or conceptual models can be developed by interpreting perceptions into codes [19], [21], [22]. Thus, a person's mental model can be identified based on expressions and actions that reflect an understanding of a particular concept. As the learning process involves the construction of mental models [23], [24], and there is a risk of lack of understanding or misperception due to an inadequate learning environment, it is important to examine students' strong mental models in the context of the learning environment. According to Wang *et al*. [25], an understanding of mental models can greatly assist teachers in understanding and addressing students' learning difficulties.

Understanding the causes of misconceptions is the first step in addressing the problem. By identifying the causes of misconceptions and designing appropriate learning strategies, teachers can help students overcome misconceptions and gain a better understanding of physics concepts, including the concept of uniform motion [2], [26]. Several ways can be done to identify students' misconceptions, namely by giving test instruments in the form of tier tests, and also by knowing the mental models of students with the characteristics of the developed understanding questions [27], [28]. This article is a preliminary study to find out the conceptions of students through their mental models. The specific purpose of this study is to determine the profile of students' mental models on the material of regular uniform motion with the descriptive evaluation method as follows: i) What is the level of students' understanding of the material of uniform motion? and ii) What is the student's mental model about the material of regular uniform motion?

2. METHOD

2.1. Research design

The research method used in this research is a case study. According to Priya [29], case studies are an integral component of qualitative descriptive analysis research, where the focus lies on thoroughly observing and analyzing a specific case until it is fully understood and interpreted. Case studies were chosen because researchers are looking for scientific truths that are tentative and able to reveal problems in the field related to student's mental models. The steps taken in the case study are presented in Figure 1.

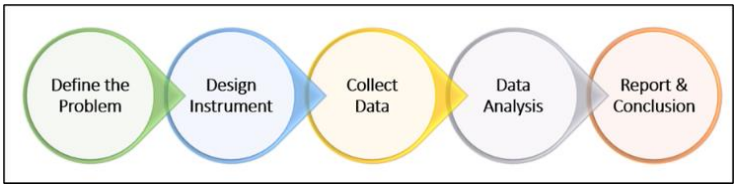


Figure 1. Steps in a case study

2.2. Sample of research

This study involved 167 students with an average age of 16-17 years to obtain basic information about students' mentality related to the concept of uniform motion. These 167 participants came from the same school and were first-year senior high school students in Tangerang, Banten, Indonesia. Purposive sampling was used in the study with criteria (e.g., using Merdeka curriculum, first-year students, and already received straight-motion material). The illustration of the research location is presented in Figure 2.

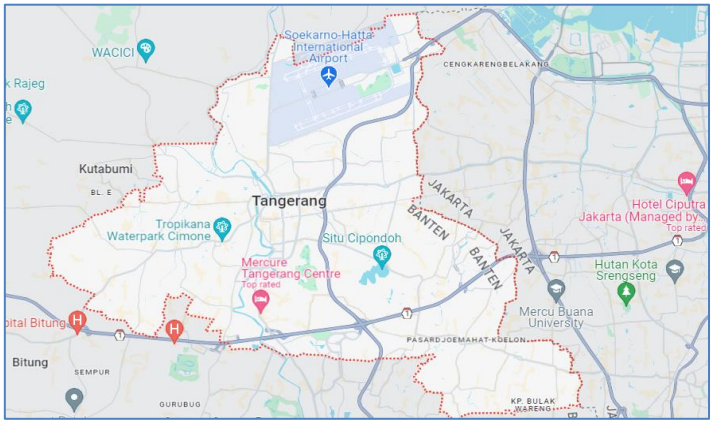
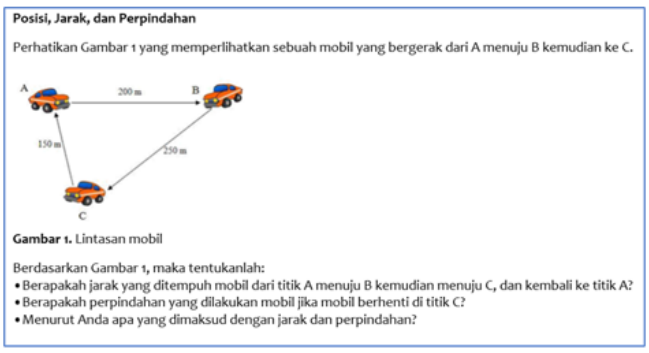


Figure 2. Map of the research location

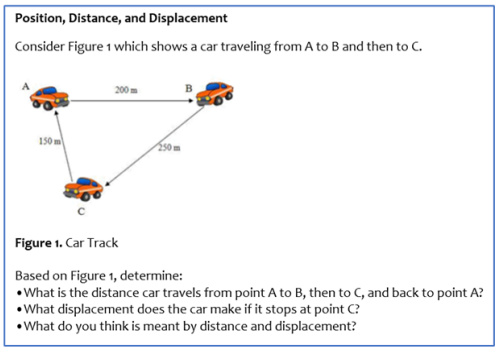
2.3. Instrument

The data collection tool used to obtain students' mental models is an essay-shaped question that refers to one of the information dimensions in the mental model according to Wilke and Losh [30], namely identifying information related to the modeled reality. Then adjusted to the criteria of Kurnaz and Ekşi [31], namely initial, synthetic, and scientific. The concept of uniform motion that is measured to determine students' mentality is uniform motion which is divided into two sub-concepts, namely, i) position, distance, displacement, and ii) speed, velocity, and acceleration. According to Kurnaz and Ekşi [31], questions that refer to theoretical concepts can be used to reveal the mental models of students. The form of essay questions given to students is presented in Figure 3. Figure 3(a) shows the essay question form in Indonesian and Figure 3(b) shows the essay question form in English.



Indonesian

(a)



English

(b)

Figure 3. Example questions for (a) in Indonesian and (b) in English

2.4. Analyzing the data

The data from this study were adjusted to the level of understanding adapted and referred from Kurnaz and Ekşi [31], and Saglam-Arslan and Devecioglu [32] to reveal students' mental models. This study used the evaluation rubric from Kurnaz and Ekşi [31] developed by Abraham *et al*. [33] in determining the level of comprehension of students through the given essay test. The summary of the rubric is presented in Table 1.

Table 1. Descriptive mental model evaluation rubric

Level of Understanding	Score	Criteria
"Sound understanding (SU)"	4	The answer contains all scientifically accepted components
"Partial understanding (PU)"	3	The answer contains some scientifically accepted components
"Partial understanding with alternative conception (PU-AC)"	2	The answer shows the concept can be understood but also contains other conceptions
"Alternative conception (AC)"	1	The answers that are scientifically incorrect and contain incorrect information
"No understanding (NU)"	0	Blank, irrelevant, and unclear answers

Understanding is indeed an essential thing to pay attention to in students. In this case to analyze students' answers related to the results of the descriptive essay test by adjusting the results of understanding in Table 1. The categorization is based on the adaptation of several studies [31], [34], [35] with evaluation methods of the scientific, synthetic, and initial. The categories of level understanding are presented in Table 2.

Table 2. Rubric for mental model

Category	Criteria	Level of Understanding
"Scientific"	"Perceptions that coincide at level 4 (SU) or level 3 (PU)"	3 and 4
"Synthetic"	"Perceptions that partially coincide or do not correspond to knowledge coincide at level 2 (PU-AC)"	2
"Initial"	"Perceptions that do not match knowledge. Answers are at level 0 (NU) and level 1 (AC)"	0 and 1

3. RESULTS AND DISCUSSION

The findings of this study are presented in two parts, namely the level of understanding and students' descriptive mental models. Then it will be described in the form of categorization to make it easier for readers to understand. Therefore, the following is presented in 3.1 and 3.2 along with the discussion.

3.1. Students' understanding level

Students' level of understanding of the given essay questions is divided into two sub. Both sub-subjects have been explained in section 3.3. The level of students' understanding of regular uniform motion and the amount at each level are presented in Table 3.

Table 3. Distribution of students' understanding

Level of Understanding	Sub-1	Percentage (%)	Sub-2	Percentage (%)
SU	1	1	3	2
PU	1	1	1	1
PU-AC	63	38	12	7
AC	87	52	140	84
NU	15	9	11	7
Total	167	100	167	100

Analysis in Table 3 presents data that at the SU level for sub-1 there is only 1 student with a percentage of 1% and in sub-2 there are only 3 students with a percentage of 2%. The level of student understanding is dominated at the AC level for both sub-materials. In sub-1 there were 87 students with a percentage of 52% and in sub-2 there were 140 students with 84%. Some examples of answers in Sub-1 for the AC category from students who explain are, *S1: "Distance has units of m and cm while displacement has no units", S2: "Distance is an object that is different and creates a distance, while displacement is two objects that are far apart and then move to get closer or further away", S3: "Distance is the starting point to the starting point again, while displacement is the movement of an object away or closer"*. While students who get the SU level of understanding state, *S4: "Distance is the length of the path traveled by an object, while displacement is a change in position from one place to another"*.

Then in sub-2 for the AC category of students explained in the answers they wrote, namely, *S1:" Speed is the calculation of a speed, speed is a speed, and acceleration is a system of speed and speed", S2: "speed is a graph, speed is a number, and acceleration is a unit"*. As for students who get the SU level of understanding, *S3: "Speed is the displacement per unit time, speed is the distance traveled per unit time, and acceleration is the derivative of speed per unit time"*. Based on the results made in Table 3, the mental models of students for both sub-materials are still dominated at the AC level of understanding.

3.2. Students' mental model

Knowledge representation can be known from students' mental models which are determined based on the level of understanding previously described. In this case, mental models play an important role in the learning process, especially in cognitive abilities. The criteria used in the student mental model category are presented in Table 4.

Table 4. Distribution of students' mental models

No	Category Sub-1	Total Participants	Percentage (%)	Category Sub-2	Total Participants	Percentage (%)
1	Scientific	2	1	Scientific	4	2
2	Synthetic	63	38	Synthetic	12	7
3	Initial	102	61	Initial	151	90
	Total	167	100	Total	167	100

As seen in Table 4, in sub-1 more than half of the students 61% have mental models with the initial category, and in sub-2 almost all students 90% are in the initial category. While in the scientific category, there are only 2 students for sub-1 and 4 students for sub-2. This states that the average mental model of students related to their level of knowledge is not in line with the conception of experts related to the material being studied.

3.3. Discussion

The examination of students' mental models of regular uniform motion was limited to first-year students with short-answer essay questions. The results of this study state that regular uniform motion and students' perceptions contain varied alternative answers. With varied ideas, students' mental models differ from scientific attributes. Despite the fact that most students do not have scientific mental models, which are still dominated by synthetic and initial mental models. Although many students are still in the initial category, some students are in the synthetic category. According to Fazio *et al*. [36], and Zarkadis *et al*. [37], students with initial mental models have answers that are not in accordance with scientific concepts and there are no answers to the questions given. In addition, in the synthesis mental model, students have some conceptions that are in accordance with scientific knowledge, but other conceptions are not scientific [19], [38], [39].

Students in junior high school have actually received uniform motion material in science learning which is divided into physics. Therefore, the measurement of students' mental models is needed as an initial study to map how their level of knowledge is related to the material of regular uniform motion. According to Jivet *et al*. [40]; Halder *et al*. [41]; and Sointu *et al*. [42], the preliminary study helps in setting goals and objectives and ensuring that the efforts made have a clear and more informed direction to maximize the chances of success in learning. On the other hand, the answers of students who are at the AC level on average have not found the keywords of each concept being discussed so the answers are too broad and not in accordance with scientific knowledge. According to Marougkas *et al*. [43] and Mariani *et al*. [44], keywords are important elements in physics concepts because they help in understanding, formulating, and applying physics principles in a particular context. In this context, Motion refers to the change in position of an object concerning time. It involves concepts such as velocity, speed, acceleration, and change in position. Thus, a basic understanding of the subject is very important so that there is no confusion on any of the concepts discussed.

Based on the results of the level of understanding presented in Table 3, students need more attention to learning related to the concept of uniform motion so that their mental models can be changed and remediate understanding in accordance with the scientific concepts of experts. The correct scientific concept will form a more directed mental model for students and can support learning that will be carried out after the straight-motion material is completed [43], [45]. In this case, students said that tests to measure conceptions and mental models have never been done at all on any concept they have learned, even though it is very crucial for learning that requires basic concepts of motion.

The distribution of students' mental models only refers to the level of students' understanding so that the improvement that needs to be considered is at the stage of their understanding of the concept of uniform motion that is tested. This is very important to execute because many factors affect their understanding (e.g. personal experience, prior learning, environment, learning context, self-awareness, and motivation and interest). By knowing these factors, it is possible to choose the right way to design learning strategies that take into account individuals' prior understanding and facilitate deeper and sustainable learning.

4. CONCLUSION

The study of students' mental models is needed to determine their level of understanding related to the material of regular uniform motion. The results presented in this case study are that the average students' mental models are still in the initial category in both sub-1 and sub-2, which are 61% (102) and 90% (151) of the total 167 students respectively. This study plays an important role in organizing and implementing future teaching activities for regular straight-line motion materials. However, the results of this study are not generalizable, but rather seek to assist teachers in knowing the mental models of students, especially in regular straight-line motion. As a practical implication, the researcher recommends that for further research, alternative teaching materials and media are needed that can have an impact on improving students' mental models.

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