Needs analysis of students' mental model representation through visualisation to support SDGs 4: A preliminary study

Mohd Zaidi Bin Amiruddin¹, Achmad Samsudin²*, Andi Suhandi¹, Suliyanah³, Bayram Costu⁴, and Muhammad Guntur Purwanto⁵

¹Science Education Programme, Faculty of Mathematics and Natural Sciences Education, Universitas Pendidikan Indonesia, Bandung, Indonesia
²Physics Education Programme, Faculty of Mathematics and Natural Sciences Education, Universitas Pendidikan Indonesia, Bandung, Indonesia
³Physics Programme, Faculty Mathematics and Natural Science, Universitas Negeri Surabaya, Surabaya, Indonesia
⁴Department of Science Education, Yildiz Technical University, Istanbul, Turkey
⁵Department of Curriculum and Instruction, University of Minnesota, Twin Cities, United States

Abstract. The development of strong cognitive abilities through education and training is an important aspect of achieving the various SDG targets. In science learning, cognitive psychology is often ignored even though it contributes to learning. This research aims to conduct a needs analysis through a preliminary study related to students' mental models in visualization. Qualitative descriptive was used in this study by describing in detail the answers in the form of graphs interpreted by students on the given question sheet. A total of ten questions were given with three sub-materials of straight motion. The results of this study present that students' mental model instantiation is classified as very poor because it is dominated by the initial category for the three sub-matters, respectively 49% (sub-1), 84% (sub-2), and 94% (sub-3). This states that the category of students' mental models reflects incomplete and unscientific depictions and there are even blank answers. Therefore, further research is needed to evaluate and improve students’ mental models to support sustainable education.

1 Introduction

Education is the main foundation in character building and individual potential, especially at the student development stage. This is evidenced by one of the demands of education described in the Sustainable Development Goals (SDGs), namely education has a very important role in achieving the goals because it is the main foundation in changing mindsets, behaviours, and practices that support sustainable development. The SDGs provide important direction for strengthening education systems globally, with the main goal of creating quality sustainable education [1-3]. One important aspect that needs to be considered in this context

* Corresponding author: achmadsamsudin@upi.edu

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is the understanding of students' mental models. Mental models include how students organize and interpret information as well as how they process new knowledge [4, 5]. Mental models in psychology are internal representations of external reality, which are hypothesized to play a major role in cognition, reasoning, and decision-making [6–8]. The term was coined by Kenneth Craik [9], who stated that the mind constructs a "small-scale model" of reality that it uses to anticipate events. According to Johnson [4] and Holtrop [6], mental models are also defined as assumptions, strategies, perspectives, and rationale that are used and have deep roots in various actions. Mental models, something that is always in our minds and directs all actions, while the model is something that structures our thoughts and actions based on our experiences.

A deeper understanding of these mental models is crucial, as it can provide a better view of how students learn and deal with learning challenges [10–12]. In educational settings, the use of visualization as a tool to analyze students' mental model needs is becoming increasingly important. Visualization provides the ability to illustrate complex relationships between concepts, facilitating better understanding, as well as assisting students in overcoming cognitive barriers [13–16]. By understanding students' mental model needs through visualization, educators can design teaching strategies that are more effective and appropriate to the cognitive characteristics of each student.

Mental models are usually masked and we are not aware of our mental models or the effect they have on our behaviour. In this case, an illustration of a mental model is presented in Figure 1 [17].

![Fig.1. Illustration of a mental model](image)

In the case of mental model education, it is very important to know each learner before learning. This aims to provide insight to the teacher to understand the knowledge or cognition of learners related to what will be learned. Corresponding Figure 1, we can see that the mental model has an important role related to the conception of learners on something that has been learned and will be learned. According to Kurnaz and Eksi [18], there are two ways that can be done to see a person's mental model, namely through descriptive and visualization. Mental models need to be very important because they are capable of seeing students' cognitive construction of what has been learned or will be learned through prior knowledge.

There has been a lot of research related to mental models such as research from Dileo [19]; Chancelloor [20]; and Bohlmeijer [21], but the research still focuses on the mental health field. In the field of education, there is also a lot of work being done to address the urgency [23–24]. Basically, mental models are part of cognitive psychology which is still little studied related to its contribution to physics education, especially in Indonesia. Whereas cognitive psychology is the basis of pedagogy taught at every level so that it can carry out
maximum learning [25, 26]. Therefore, this preliminary study aims to fill the knowledge gap by focusing on the exploration and initial understanding of the needs of students' mental models through the visualization approach. This study examines students' prior knowledge of the physics concept of regular straight motion. Thus, it is hoped that this study can provide a solid foundation for further development in an effort to improve the quality of learning and teaching effectiveness in the educational environment as an effort to support sustainable education SDG no 4.

2 Methods

2.1. Design Study

This research uses descriptive qualitative by examining the results of the question sheets given according to the criteria of the mental model of visualization on the physics concept of regular straight motion. The results of the case study are then summarised and described following the selected rubric criteria. According to Taherdoost [27] and Lichtman [28], descriptive qualitative is a research method that utilizes qualitative data and is described descriptively to describe fully and in-depth the occurrence of various phenomena studied. In this case, the researcher will describe the results of students' answers related to the interpretation of knowledge through mental model visualization.

2.2. Participant

This study was conducted in the 2024/2025 school year. The participants in this study were 163 students from five different classes that used Merdeka Curriculum. The average age of participants was 16-17 years old and was a grade 10 student in the second semester from one of the schools in Banten. Researchers conducted this preliminary study on five grade 10 classes because it is a population for conducting further research. The research location is presented in Figure 2.
2.3. Instrument

This study uses a test instrument of ten questions that refer to the rubric of scientific, synthetic, and initial visualization mental models. The test given is how students interpret their knowledge in the form of graphs. The concept measured is the concept of regular straight motion with details, (Sub-1) position, distance, and displacement, (Sub-2) speed, velocity, and acceleration, and (Sub-3) free-fall motion. The form of one example of the problem is presented in Figure 3.

![Figure 3](image)

Fig. 3. The example of the question

2.4. Analysis

The data obtained was then analyzed using a visual evaluation rubric referring to and adapting the rubric developed by Kurnaz and Eksi [18]; Fratiwi et al. [28]; and Samsudin [29]. The rubric used is presented in Table 1.

<table>
<thead>
<tr>
<th>Level of understanding</th>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correct Depicting (CD)</td>
<td>4</td>
<td>The answer reflects all components of scientific depiction</td>
</tr>
<tr>
<td>Partial Correct Depicting (PCD)</td>
<td>3</td>
<td>The answers reflect some components of scientific depiction</td>
</tr>
<tr>
<td>Correct Drawing reflecting also non-scientific depicting (CD-ND)</td>
<td>2</td>
<td>The answer reflects science or partial science but also describes non-science.</td>
</tr>
<tr>
<td>Incorrect Depicting (ID)</td>
<td>1</td>
<td>Answers that reflect a full depiction that is not scientific</td>
</tr>
<tr>
<td>No Depicting (ND)</td>
<td>0</td>
<td>Empty answer</td>
</tr>
</tbody>
</table>

After the students' answers were evaluated using the visualization rubric in Table 1, further grouping was done based on the mental model categories presented in Table 2 [18].
Table 2. Mental model evaluation method using SSI

<table>
<thead>
<tr>
<th>Category</th>
<th>Criteria</th>
<th>Level of Understanding</th>
<th>Code Visualization</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scientific</td>
<td>Perceptions that coincide at level 4 (CD) or level 3 (PCD)</td>
<td>3 dan 4</td>
<td></td>
</tr>
<tr>
<td>Synthetic</td>
<td>Perceptions that partially coincide or do not correspond to knowledge coincide at level 2 (CD-ND)</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Initial</td>
<td>Perceptions that do not match knowledge. Answers are at level 0 (ND) and level 1 (ID).</td>
<td>0 dan 1</td>
<td></td>
</tr>
</tbody>
</table>

3 Results and Discussion

The results of the preliminary study on straight motion material are divided into three sub-sections, namely, (Sub-1) position, distance, and displacement in Table 3, (Sub-2) speed, velocity, and acceleration in Table 4, and (Sub-3) free-fall motion in Table 5.

Table 3. Result of profile student for sub-1

<table>
<thead>
<tr>
<th>Category</th>
<th>N</th>
<th>Code Visualization</th>
<th>Percentages of category SSI (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scientific</td>
<td>3</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Synthetic</td>
<td>80</td>
<td></td>
<td>49</td>
</tr>
<tr>
<td>Initial</td>
<td>80</td>
<td></td>
<td>49</td>
</tr>
<tr>
<td>Total</td>
<td>163</td>
<td></td>
<td>100</td>
</tr>
</tbody>
</table>

N= Number of samples

Table 3 presents the results of the visualization mental model analysis in sub-1. If we analyze in-depth, it can be seen that the student's ability to interpret their knowledge falls into three categories according to Kurnaz's (2015) evaluation method. In sub-1, we can see how
the students' mental models are related to the material tested. In the scientific categories, there are only three learners who have mental models following the experts and if it is a percentage there are only 2% of learners who fall into the scientific category. Then in the synthetic and initial categories, each learner totalled 80 with a percentage of 49% for both.

Table 4. Result of profile student for sub-2

<table>
<thead>
<tr>
<th>Category</th>
<th>N</th>
<th>Code Visualization</th>
<th>Percentages of category SSI (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scientific</td>
<td>1</td>
<td><img src="image" alt="Visualization" /></td>
<td>1</td>
</tr>
<tr>
<td>Synthetic</td>
<td>23</td>
<td><img src="image" alt="Visualization" /></td>
<td>14</td>
</tr>
<tr>
<td>Initial</td>
<td>139</td>
<td><img src="image" alt="Visualization" /></td>
<td>85</td>
</tr>
<tr>
<td>Total</td>
<td>163</td>
<td><img src="image" alt="Visualization" /></td>
<td>100</td>
</tr>
</tbody>
</table>

N= Number of samples

Table 4 presents the results of the visualization mental model analysis in sub-2. If we analyze it in depth, it can be seen that the students' ability to interpret their knowledge falls into three categories according to Kurnaz's [19] evaluation method. In sub-2, we can see how students' mental models are related to the material tested. In the scientific categories, there is only one learner who has a mental model following the experts and if it is a percentage there is only 1% of learners who fall into the scientific category. Then in the synthetic category, there are 23 students with a percentage of 14% and in the initial category, there are 123 students with a percentage of 85%.

Table 5. Result of profile student for sub-3

<table>
<thead>
<tr>
<th>Category</th>
<th>N</th>
<th>Code Visualization</th>
<th>Percentages of category SSI (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scientific</td>
<td>0</td>
<td><img src="image" alt="Visualization" /></td>
<td>0</td>
</tr>
<tr>
<td>Synthetic</td>
<td>10</td>
<td><img src="image" alt="Visualization" /></td>
<td>6</td>
</tr>
<tr>
<td>Initial</td>
<td>153</td>
<td><img src="image" alt="Visualization" /></td>
<td>94</td>
</tr>
<tr>
<td>Total</td>
<td>163</td>
<td><img src="image" alt="Visualization" /></td>
<td>100</td>
</tr>
</tbody>
</table>

N= Number of samples

Table 5 presents the results of the visualization mental model analysis in sub-3. If we analyze in-depth, it can be seen that the student's ability to interpret their knowledge falls into three categories according to Kurnaz's [18] evaluation method. In sub-3, we can see how students' mental models are related to the material tested. In the scientific category, there is
not a single learner who has a mental model following the experts, and if per cent, that is 0% of learners who fall into the scientific category. Then in the synthetic category, there are 10 students with a percentage of 6% and in the initial category, there are 153 students with a percentage of 85%.

Overall, the results presented in Tables 3, 4, and 5 state that the mental models of students on the tested sub-material are still classified as poor because they are dominated by the initial category for all three sub. Of the three subs, the level of understanding of students for each answer to the ten questions which are divided into three sub respectively, Correct Depicting (2), Partial Correct Depicting (2), Correct Drawing reflecting also non-scientific Depicting (117), Incorrect Depicting (283), and No Depicting (85). The specifics of each category are presented in the preceding Table 1. Related research. According to Charlie Munger (1995) stated that:

"You can't really know anything if you just remember isolated facts and try to reply to them. These facts if they don't depend on lattice theory, you can't use them. You have to have a model in mind. You have to manage your experience with this model."

This is reinforced by the results of research from Khasanah [31] stated that mental models are not easily recognizable psychological systems because of several characteristics, including being inconsistent, unstable, and dynamic or often changing as more information is obtained or recalled. However, the gradual development of mental models can certainly be a good change for a person's mentality in certain domains. This states that the mental model of learners is very important because it can affect understanding related to a domain of knowledge so it must be considered and adjusted to the latest science that is believed or agreed upon by experts. In line with the quality education expected in the SDGs, it not only includes the transfer of knowledge and skills, but also pays attention to the psychological and cognitive aspects of learners, including their understanding of mental models or how they understand the world around them. Therefore, mental models can lead students to new information by utilizing these mental models to predict and explain a phenomenon [32–34].

4 Conclusion

Based on the results of the preliminary study for mental models with visualization of students, it can be concluded that the ability of students' mental models is dominated in the initial category, which means that the answers reflect a full depiction that is not scientific and the answers are filled in blank. This indicates that the learning done before contains information that does not follow the experts so the results of students' interpretations are still in the initial category. This study was limited to a school with 163 students from five different classes in one batch and only tested on three sub-materials, namely sub-1 position, distance, and displacement, sub-2 speed, velocity, and acceleration, and sub-3 free fall motion. Further research is needed to provide learning that is able to increase or improve the mental model of visualization of students in accordance with the conception of experts. In addition, it can also utilize technology for visualization assistance so as to provide concrete examples for each event in the sub-matter being studied thus providing an opportunity to realise sustainable education.

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