An analysis of students’ mental models using temperature and heat transfer-diagnostic test (THT-DT)

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Abstract. Students’ mental models can be identified through a students’ concept understanding. In one study found that one of the students’ difficulties in learning physics is to understand the concepts of physics, so it can be identified that students have a low mental model. The purpose of this study was to analyse students’ mental models based on the level of understanding by using diagnostic tests. The instrument has been developed in the form of four tier test to analyse mental models in temperature and heat concept. The results obtained from the test, classified according to the category of mental models of students. This research method was used as the 4D model (Defining, Designing, Developing and Disseminating). The subject of the study was 26 eleventh grade students (average age 16 years) and has been studying the material temperature and heat transfer. Research results show that 7.37% students in scientific model level, 68.31% students in synthesis level, and 23.72% students in initial model level. In conclusion, the development of THT-DT four-tier test-items is one of potential diagnostic test instrument that able to analyse the level of student’s mental models.

1. Introduction
A mental model is a representation of someone when explaining a phenomenon which is then used to solve a problem [1]. Someone with a high academic level has a higher ability to solve problems that are then identified as having a better mental model [2,3,4]. In solving problems, it takes mastery of a good concept. A good mental model is able to connect problems with concepts that are understood and produce a perception of the concepts given and understood by students [2,5]. Therefore, knowing the mental model possessed by students is something that is needed by an educator.

One important concept in physics is temperature and heat transfer. Meanwhile, there are still many students who experience errors in understanding the concepts of temperature and heat transfer. Previous research explained that one of the alternative conceptions of students is that temperature and heat are the same, boiling point is the maximum temperature of an object and the touch method can determine the temperature and heat of an object [6]. Such errors should be identified in the form of a mental model so that the educator will know what must be done next after getting a portrait of the student's mental model regarding the concept of temperature and heat transfer and then try good learning in order to improve students' mental models.

Temperature is a physical quantity that is shared between systems and other systems in a thermal equilibrium state. When we want to know the temperature of an object, we need a measuring instrument because the terms hot and cold cannot represent a measure of the temperature of an object. A thermometer is a device used to measure temperature, when the thermometer is attached to the armpit,
the thermometer makes thermal contact which is characterized by long movements. When the long movement in the thermometer column stops, it indicates that the armpit and thermometer have experienced a thermal equilibrium state. Meanwhile, heat is defined as the process of transferring energy from one substance to another followed by changes in temperature. The equation that students know when studying temperature and heat transfer is:

\[ Q = mc\Delta T \] (1)

Through these equations, we can calculate heat received or released using heat capacity (c), mass of substance (m) and temperature change (\( \Delta T \)) [7]. This has explained that in fact temperature and heat are not the same. Similarly, the actual boiling point depends on environmental pressure. The lower the environmental pressure the lower the boiling point. So, there is no definite temperature for the boiling point that applies to all places with different conditions.

To identify the level of mental models based on the level of understanding of the student’s concept, a test instrument is needed as a tool. Researchers propose THT-DT as a solution to photograph students' mental models. THT-DT is arranged in the form of four tier diagnostic tests. This form of THT-DT is a test to diagnose a student's mental model based on the conceptual understanding held by students on the topic of temperature and heat transfer. In THT-DT it consists of four levels. The first level is a multiple-choice question on the topic of temperature and heat transfer which consists of 5 answer choices. The second level is the level of confidence of students in choosing THT-DT. The third level contains five choices of students' reasons for choosing THT-DT. Finally, the fourth level is the level of confidence of students in choosing reasons for the third level choice [8]. One of the advantages of this four-tier test is that it can really assess misunderstandings of errors or lack of understanding of students in a concept [9]. This study aims to photograph the mental models possessed by students regarding temperature and heat transfer with diagnostic tests in the form of four-tier tests.

2. Methods

2.1. Participant
The participants involved were 26 people, 11 of whom were male and 15 were female. The average age of participants is 15-16 years. Participants came from one of the secondary schools in the city of Bandung, Indonesia. Participants who were tested under conditions had studied the temperature and heat transfer.

2.2. Research Method
THT-DT is a diagnostic test format for measuring students’ mental models. Development of this instrument using 4D model (Defining, Designing, Developing, Disseminating) [10]. The defining and designing stage is the stage for the formation and development of the THT-DT instrument arranged in the form of a four-tier test so that it can measure mental models based on the understanding of conceptions that students have. For THT-DT, the conceptions used in instruments are temperature and heat transfer materials. Then the developing stage of the assessment instrument that has been prepared by researchers. The assessment was conducted by three experts at the Department of Physics Education at Universitas Pendidikan Indonesia. The things assessed from the instrument include sentence structure, four-tier test structure and the concept involved in the problem. Then, the final stage is disseminating the stage of dissemination of the instrument to students in high school for further analysis of the results of disseminating. This stage lasts for 45 minutes.

2.3. Instrument
The instruments were compiled, four-tier diagnostic test instruments for temperature and heat transfer (THT-DT) materials.
Table 1. Expert assessment results of THT-DT instruments.

| No | Validation Indicator                                                                 | V1 | V2 | V3 | Average | Valid/Not Valid |
|----|---------------------------------------------------------------------------------------|----|----|----|---------|-----------------|
| 1  | Item question are made according to the question indicator                            | 0.9| 1  | 0.5| 0.8     | Valid           |
| 2  | Conformity of the concept in the item with the concept put forward by the experts     | 1  | 1  | 1  | 1       | Valid           |
| 3  | Item question are made for understanding the concepts of students                     | 1  | 1  | 1  | 1       | Valid           |
| 4  | Use language that is in accordance with Indonesian rules                               | 1  | 1  | 1  | 1       | Valid           |
| 5  | The language used is easily understood by students                                    | 1  | 1  | 0.8| 1       | Valid           |
| 6  | The choice of answers and reasons are homogeneous and logical in terms of material    | 0.9| 1  | 1  | 1       | Valid           |
| 7  | There is only one answer key                                                           | 1  | 1  | 1  | 1       | Valid           |
| 8  | The question does not provide clues to the answer to the correct answer               | 1  | 1  | 0.9| 1       | Valid           |
| 9  | The choice of answer does not use the statement "all answers are correct" or "all answers are wrong" | 1  | 1  | 1  | 1       | Valid           |
| 10 | Information on the questions in the form of images can help students understand the meaning of the problem | 0.9| 1  | 1  | 0.8     | Valid           |

Average: 1, Valid

One of the questions in THT-DT is shown in the following picture:

5.1. A piece of metal with a temperature of 75°C is put into water in a glass with a temperature of 25°C.

After being left for some time, how is the temperature of the metal and water?

a. The temperature of the metal will decrease, while the temperature in the water remains.
b. The temperature of the metal will decrease and the decrease will not be the same as adding the temperature to the water.
c. The temperature of the metal will decrease and the decrease will be the same as adding the temperature to the water.
d. The temperature of the metal will not decrease while the temperature in the water increases.
e. The temperature of the metal will always be higher than water.

5.2. Are you sure of your answer in number 5.1?
A. Sure
B. Not sure

5.3. What is the reason you answer the question above?

a. In accordance with the principle of black, the exit temperature is the same as the temperature received.
b. Heat transfer occurs from metal to water.
c. The temperature of metals, water and the environment will unite and affect the temperature of metals and water.
d. Water vapor arises due to heat moving from metal to water.
e. The type of heating value for metals and water is different.

5.4. Are you sure of your reason in number 5.3?
A. Sure
B. Not sure

Figure 1. Questions on THT-DT.

2.4. Data Analysis
Data can be analyzed after students who have studied the temperature and heat transfer fill the THT-DT. The division of mental models based on conceptual understanding is the scientific model, synthesis model and initial model. With synthesis model which is divided into four groups, namely Synthesis-A, Synthesis-B, Synthesis-C, and Synthesis D (Misconception). The clearer explanation of the THT-DT grouping answers into mental models can be seen through Table 2 below with number 1 in the table.
showing students choosing the right answer while number 0 indicates students choosing the wrong answer:

**Table 2. Levels of students' mental models based on conceptual understanding**

| Answer | Sure/Not Sure | Reason | Sure/Not Sure | Level of Conceptual Understanding | Mental Model |
|--------|--------------|--------|--------------|----------------------------------|--------------|
| 1      | Sure         | 1      | Sure         | U                                | Scientific   |
| 1      | Not Sure     | 1      | Not Sure     |                                  |              |
| 1      | Not Sure     | 1      | Not Sure     |                                  |              |
| 1      | Sure         | 0      | Sure         |                                  |              |
| 1      | Sure         | 0      | Not Sure     |                                  |              |
| 1      | Not Sure     | 0      | Sure         | PU                               | Synthesis-B |
| 1      | Not Sure     | 0      | Not Sure     |                                  |              |
| 0      | Sure         | 1      | Sure         |                                  |              |
| 0      | Sure         | 1      | Not Sure     |                                  |              |
| 0      | Not Sure     | 1      | Sure         |                                  |              |
| 0      | Not Sure     | 1      | Not Sure     |                                  |              |
| 0      | Sure         | 0      | Sure         |                                 | M            |
| 0      | Not Sure     | 0      | Not Sure     |                                  |              |
| 0      | Not Sure     | 0      | Sure         | NU                               | Initial      |
| 0      | Not Sure     | 0      | Not Sure     |                                  |              |

The mental model category refers to grouping based on conceptual understanding described in Table 3 below [5]:

**Table 3. The level of mental models of students is based on conceptual understanding.**

| Mental Model     | Level of Conceptual Understanding       | Criteria                                                                 |
|------------------|-----------------------------------------|---------------------------------------------------------------------------|
| Initial model    | No Response (NR)                        | Cannot answer or explain                                                  |
| Synthesis model  | No Understanding (NU)                   | Answers or explanations do not make sense scientifically                  |
| Scientific model | Partial Understanding (PU)              | Only partial answers or explanations of students are valid and scientific and some misconceptions (misconceptions) |
|                  | Sound Understanding (SU)                | Answering or explaining all aspects with valid and scientific answers     |

3. **Result and Discussion**

3.1. *Diagnostic test development analysis*

Based on previous research, diagnostic tests in the form of four-tier test is widely used in determining the level of misconception experienced by students [6,7]. Another study of student mental model analysis [5], an instrument used in the form of open-ended questions. Thus, researchers developed a diagnostic test in the form of a four-tier test to handle students' mental models based on students' understanding of the concept of temperature and heat transfer.

Figure 3 is a snippet of THT-DT. The problem is that there is a piece of metal whose temperature is higher than the water in the glass. In this case students are given a case of what happens when the metal enters the water. There are several options that students can choose from. Based on the concept of temperature and heat transfer, when two objects with different temperatures interact, there will be thermal contact and temperature changes at both objects until finally reaches thermal equilibrium where the temperature of both objects becomes the same. The addition of temperature in water will be much smaller than the temperature reduction in metal. This happens because the heat types of metals such as...
iron and aluminum 5 - 10 is smaller than water. While the heat leaves the metal and enters the water, the temperature change of water will be 5 - 10 smaller than the metal.

3.2. Implementation
At this stage, an instrument trial was carried out to get the results of students' mental models based on conceptual understanding of temperature and heat transfer. The time given to students to work 12 items is 45 minutes.

3.3. Formative evaluation
After the instrument implementation phase, the instrument is then evaluated regarding the ability to analyze students' mental models and the results of students' mental models in several concepts are shown in Table 4 below:

Table 4. The results of students' mental models on several concepts.

| Concept                         | Model Mental (%) | Sc | Sy-A | Sy-B | Sy-C | Sy-D | In  |
|--------------------------------|------------------|----|------|------|------|------|-----|
| Boiling point                  |                  |    |      |      |      |      |     |
| Expansion                      |                  |    |      |      |      |      |     |
| Application expansion in daily life |                  |    |      |      |      |      |     |

Based on the data in the table above, students' mental models in the boiling point concept are dominated at the initial model level, as well as the other two concepts. This shows that the mental model possessed by students is still low. Students still do not understand that the temperature at the boiling point is affected by pressure on the surrounding environment. Boiling point is a temperature where the vapor pressure is saturated with the pressure above the surface of the liquid, so the lower the environmental pressure, the lower the temperature at the boiling point. Meanwhile, on the concept of expansion, students still do not understand the expansion coefficient. For example, the value of the expansion coefficient indicates the ability to change the volume of a substance every degree Celsius. Therefore, in answering the problem of applying expansion in everyday life, for example in the bimetal, students are still confused. The following are excerpts of questions about applying the concept of expansion in everyday life:

13.1. Look at the following picture!

The picture above is the working principle that occurs on an electric iron. Figures A and B show two different conditions in a bimetal chip. At first the bimetal pieces are straight as in Figure A, over time the bimetal pieces bend as the iron heats up. Which of the following statements is true regarding this phenomenon?

a. the bimetal will curve towards the metal which has a large heat capacity.
b. the bimetal will curve towards the metal which has a large amount of heat.
c. the bimetal will curve towards the metal which has a large expansion coefficient.
d. the bimetal will curve towards the metal which has a small long expansion coefficient.
e. the bimetal will curve towards the metal which has a small heat capacity.

13.2. Are you sure of the answer?

a. Sure
b. Not sure

13.3. What is the reason for you answering this question?

a. the long expansion coefficient shows the ability of a substance to change the length during which it is given heat.
b. the long expansion coefficient shows the ability of a substance to change the length of each degree Celsius.
c. heat is given to the bimetal bottom. Large heat capacity directly shows the ability to expand the object. (Synthetic)
d. the greater the heat of the object, the easier it is to expand.

13.4. Are you sure of the answer?

a. Sure
b. Not sure

Figure 2. Questions on THT-DT.

In the question there are two pictures of bimetal conditions, namely state A and condition B. It is explained that condition A is a bimetal state before being heated, then condition B is a bimetal condition after being heated. The bimetal will curve towards the metal that is more difficult to increase in length. The more difficult the bimetallic lengths are, the harder it is to bend and this can be seen
from the coefficient values of the two bimetal metals. Then the results of the student mental model are shown by the following table:

Table 5. The results of the students' mental models from THT-DT.

| Mental Model | Students Answers                                                                 | Total |
|--------------|----------------------------------------------------------------------------------|-------|
| Scientific   | S2 (2,12), S3 (10), S4 (4), S6 (4,11), S8 (3,4), S9 (2,9), S13 (2), S14 (4), S18 (1,4), S20 (2,9), S21 (5), S23 (9), S24 (9), S25 (1,7,9,10) | 23    |
| Synthesis-A  | S1 (1), S3 (4), S6 (1), S8 (1), S9 (4), S10 (8), S17 (6), S19 (11), S21 (1,2), S22 (2), S26 (1) | 12    |
| Synthesis-B  | S1 (4,7,11), S2 (1,11), S3 (3,7,11), S4 (3,7), S5 (7,11), S6 (3,7,8), S7 (2,10), S8 (2,8), S9 (7,8,11), S10 (3,4,7), S11 (3,4,7,10), S12 (2), S13 (3,4,7), S14 (5,7,8,10,11), S15 (2,3,5,6,7,11), S16 (7,11), S17 (3,5,7,11), S18 (2,3,7,11), S19 (3,8), S20 (4,7,11), S21 (7,11), S22 (3,7,11), S23 (3,6,7,8), S24 (3,7,10), S25 (4,6,8,11), S26 (4,7,8,11) | 79    |
| Synthesis-C  | S1 (3,5,9,12), S2 (8), S3 (2,8,12), S4 (1,2,9), S5 (2,9,10), S6 (9), S7 (4,5,9,12), S8 (9), S9 (1,12), S10 (1,2,6,9), S11 (2,8), S12 (3,5,6), S13 (1,9), S14 (1,2,3,9), S15 (1,4,10), S16 (1), S17 (2,10), S18 (9), S19 (4,7), S20 (1,10), S22 (1,5), S23 (11), S24 (1,2,4,6), S25 (3), S26 (2) | 57    |
| Synthesis-D  | S1 (2,10), S2 (3,4,5,6,7,9,10), S3 (5,6,9), S4 (5,8,10), S5 (5,6,12), S6 (5,6), S7 (8), S8 (5,6,7,10,11,12), S9 (3,5), S10 (5), S11 (1,5,9,11,12), S12 (7,9), S13 (5,10,11), S14 (6), S15 (9), S16 (8), S17 (1,9), S18 (5,6,8,10,12), S19 (9,10), S21 (4,8), S22 (9), S23 (1,2,4,5,11,12), S24 (5), S25 (3,5,12), S26 (5,12) | 67    |
| Initial      | S1 (6,7), S3 (1), S4 (6,11,12), S5 (1,3,4,8), S6 (2,10,12), S7 (1,3,6,7,11), S9 (6,10), S10 (10,11,12), S11 (6), S12 (1,4,8,10,11,12), S13 (6,8,12), S14 (12), S15 (8,12), S16 (2,3,4,5,6,9,10,12), S17 (7,8,12), S19 (1,2,5,6,12), S20 (3,5,6,8,12), S21 (3,6,9,10,12), S22 (4,6,8,10,12), S24 (1,11,12), S26 (3,6,9,10) | 74    |

Then shown through the graph in the following figure:
Figure 3. The results of the students' mental models on the concept of temperature and heat transfer.

Based on the graph above, it shows that the student's mental model possessed by students towards the concept of temperature and heat is 7.37% for the Initial model, 68.31% for the synthesis model with 3.85% synthesis-A, 25.32% synthesis-B, 18.27% synthesis-C, 21.47% synthesis-D and 23.72% for scientific models. The data shows that the dominant students have synthesis and initial models, while the expected outcomes after students study the temperature and heat transfer are the scientific models. Several studies have been conducted to increase the level of understanding of students' concepts which will then influence the level of students' mental models, some of which are through learning approaches [12,13], learning models [14] as well as teaching materials [15].

4. Conclusion
Based on this study, THT-DT can analyze the mental models that students have. With this, THT-DT can be used to analyze mental models before students learn the concept of temperature and heat transfer, so that THT-DT can be developed for pretest and posttest. In the pretest, the teacher can know the initial mental model that the student has and then can plan a good learning strategy in order to improve the student's mental model. While in the posttest, the teacher can know the extent to which students experience changes in mental models after given a particular learning strategy.

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