Development of four-tier diagnostic test (FTDT) to identify student’s mental models on static fluid

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Abstract. Four Tier diagnostic test on some previous studies are usually used to diagnose misconceptions and conceptual change. In this study, the four-tier diagnostic test (FTDT) has been used to identify students’ mental models on static fluid. Based on the mastery of students concept on static fluid, mental models will have classified into three categories: 1) initial model, 2) synthetic model and 3) scientific model. The research method utilized is the Dick and Carey model, which has four steps: 1) development of analysis diagnostic test, 2) diagnostic test design, 3) implementation and 4) evaluation. The instrument has been collected to 28 students at senior high school in Bandung. Result study shows that students mental models, which are Initial model (20.5%), synthetic partial understanding model A (8.9%), synthetic partial understanding model B (30.4%), synthetic partial understanding model C (17.3%), synthetic-misconception model (11.3%) and scientific model (11.6%). It can be concluded that four-tier diagnostic test (FTDT) is able to identify student’s mental models in static fluid.

1. Introduction

The Four tier test diagnostic test is a form of instrument used to diagnose misconceptions and change student conceptions of several fields, including physics concepts [1-7]. The Four tier test diagnostic test is a multiple-choice test of a semi closed answer consisting of four selected tiers. The first tier contains a knowledge question consisting of five answer choices. The second tier contain a choice of confidence in the first tier, which is a question about belief in the answer selected on the first tier, with a yes or no answer. While the third tier shows the reason for the choice of the answer to the first tier with four choices of closed-choice reasons and one reason for open choice (semi-open ended). And the fourth tier are a choice of belief in the answer to the third tier, which is a question on belief on the reason chosen on the third tier, with a yes or no answer. In this study, the Four tier test diagnostic test was used to identify the mental model of the students. The Four tier test diagnostic test consists of questions about the concept of static fluid. This is because, the mental models identified is based on the mastery of the student’s concepts on static fluid.

The mental model is a dynamic and generative representation that can be manipulated mentally to provide a causal explanation of physical phenomena and make predictions about the state of the physical world [8]. The mental model can express the internal representation that students construct to understand a concept [9]. In addition to expressing the concept representation and ensuring the description of scientific phenomena, the mental model also ensures that the formation of the individual's mind is revealed [9]. In some previous studies [9-13], mental models were identified using open-ended questions. In addition, there are studying that identify mental models using student worksheets [9].
mental model studies were identified using the Four tier test diagnostic test. The mental model is classified into three categories 1) initial model, 2) synthetic model and 3) scientific model [11]. The three categories are based on the mastery of student concepts on static fluid. Here is a table of student’s mental model criteria based on the level of mastery of the concept:

**Table 1. Criteria of the student’s mental model.**

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

The Fluid Concepts studied includes the concept of fluid flowing under the influence of gravity to occupy the lowest area of the container. Thus, the fluid tends not to maintain its shape, but follows the shape of where the fluid is located. The gas is a fluid, because the expanding gas fills its container regardless of the shape of the container.

![Figure 1. Fluid example.](image)

When an object is immersed in a fluid like water, the fluid will provide a force perpendicular to each point of the surface of the object. If the object is small enough that the difference in fluid depth is negligible, the broad unit force applied to each point of the surface of the object will be the same. This broad unit force is called fluid pressure.

\[
P = \frac{F}{A}
\]

The pressure in the lake or the sea will increase to increasing depth. Similarly, atmospheric pressure will decrease as the altitude increases. For fluids such as water density constant at each point, the pressure will increase linearly to depth. The pressure in the same depth will be the same at each point. Thus, when the fluid inside a vessel is added pressure by pressing down the top of the surface, the pressure increase will be the same at each point. This is known as the Pascal principle, which reads: "the pressure applied to a closed liquid is passed without diminishing each point in the fluid and into the vessel wall".
If an object immersed in water is weighed using a spring balance then the scales show a smaller value than weighed in the air. This is because water gives an upward force that partially offsets gravity. The force given by the fluid to a drowning object is called buoyancy. This force depends on the fluid density and volume of the object, but not on the composition or weight of the object and is equal to the weight of the fluid transferred by the object. This is known as the Archimedes principle.

\[ P = \rho gh \]

Based on Archimedes principle, when an object is placed in a fluid, there will be three conditions: 1) sinking, 2) floating, and afloat.

If a needle is placed carefully above the water surface transversely, then the needle will float. The forces that support the needle is not buoyant forces but are caused by surface tension. At these conditions the molecules on the water surface to get downward pressure in the needle. Thus, the water molecules will provide a restoring force, the force that makes the needle float. The interaction between the molecules in the fluid is called the cohesion style. While the force between fluid molecules with other materials, for example a thin pipe wall called adhesion style. When the liquid surface of the concrete pipe is upward, the liquid will rise in the pipe until the net up force caused by the surface tension is offset by the weight of the fluid. This increase is called capillary movement or capillarity.

In some previous studies [9-13] students' mental models had been identified whit some physical, such as on the frictional, heat and principles of Archimedes. Taher (2017) has examined the student's mental model on the part of the static fluid, that is the Archimedes principle. Mental models were identified using a multi representative approach to students. However, in this study mental models were identified based on mastery of student concepts on static fluid.
2. Methods

2.1. Participants
Participants in this study are students in senior high school at the city of Bandung. Participants were dominated by women, as many as 28 people, while only 12 men. Participants are students that have studied static fluid.

2.2. Method
The research method used is the development of Dick and Carey, which has four stages of development: 1) diagnostic test analysis, 2) diagnostic test design, 3) implementation and 4) Evaluation. A literature review was conducted to facilitate the analysis of diagnostic tests. In the development stage of the test design test validation test by the expert. For the implementation stage, diagnostic tests are showed to high school students. Then tested the ability to identify the mental model after testing.

2.3. Instrument
Instrument used in this research is diagnostic test form Four tier test (FTDT). Four tier tests diagnostic test (FTDT) consist of 15 questions that contain questions about the concept of static fluid. Participants were asked to take a diagnostic test of 30 minutes. Here is one example of the Four tier test diagnostic test (FTDT):

| A child inserts an object with a mass of 20 g into a broken glass filled with water with the surface of the water right at the mouth of the shower. Spilled water is accommodated with a measuring cup as shown in the following picture: The buoyant force acting on objects with a mass of 20 g is |
|---|
| a. Not the same as the weight of fluid contained in a measuring cup. |
| b. Will be equal to the weight of the fluid contained in the measuring cup plus the weight of the object 20 g. |
| c. will be equal to the weight of the fluid contained in the measuring cup |
| d. will be equal to the weight of the fluid contained in the measuring cup minus the weight of the object |
| e. will equal the weight of an object 20 g contained in a measuring cup. |

Are you sure of the answer above?

- a. Sure
- b. Not sure

Reason:

- a. Every object that is partially or completely inserted into a fluid will receive a force that pushes an object called buoyancy
- b. The volume of objects inserted into the fluid will be the same as the volume of fluid coming out
- c. The amount of buoyancy force will be equal to the weight of the fluid plus the weight of the object.
- d. The buoyant force acting on an object is equal to the weight of the displaced fluid
- e. If an object with a mass of 20 g is inserted into the fluid, the volume of fluid will increase as much as the mass of the object entering the fluid
- f. The weight of the object inserted into the fluid will be equal to the weight of the spilled fluid
- g. The pressure acting on the load will be the same as the fluid released, so the mass of water released will be equal to the mass of the load

Are you sure of the answer above?

- b. Sure
- b. Not sure

Figure 6. Example question Diagnostic test form Four tier test (FTDT).
2.4. Data analysis
The data obtained from the test results is processed. Here is the data processing of trial results:

Table 2. Data processing.

| T-1 | T-2 | T-3 | T-4 | MM        | The Number of Student |
|-----|-----|-----|-----|-----------|-----------------------|
| 1   | Y   | 1   | Y   | SC        | 1 9 2 2 7 7 7 0 0 1 1 2 |
| 1   | Y   | 1   | TY  | SY-A     | 1 5 6 2 5 5 1 1 0 3 0 1 |
| 1   | TY  | 1   | Y   | SY-A     | 1 5 6 2 5 5 1 1 0 3 0 1 |
| 1   | Y   | 0   | Y   | SY-A     | 1 5 6 2 5 5 1 1 0 3 0 1 |
| 1   | Y   | 0   | TY  | SY-B     | 12 0 13 6 9 10 3 15 8 10 5 11 |
| 1   | TY  | 0   | Y   | SY-B     | 12 0 13 6 9 10 3 15 8 10 5 11 |
| 1   | TY  | 0   | TY  | SY-A     | 1 5 6 2 5 5 1 1 0 3 0 1 |
| 0   | Y   | 1   | Y   | SC        | 1 9 2 2 7 7 7 0 0 1 1 2 |
| 0   | Y   | 1   | TY  | SY-C     | 4 10 2 4 4 3 12 1 4 7 5 2 |
| 0   | TY  | 1   | Y   | SC        | 1 9 2 2 7 7 7 0 0 1 1 2 |
| 0   | Y   | 0   | Y   | SY-M     | 2 1 1 5 0 1 4 5 6 2 7 4 |
| 0   | Y   | 0   | TY  | SY-M     | 2 1 1 5 0 1 4 5 6 2 7 4 |
| 0   | TY  | 0   | Y   | SC        | 1 9 2 2 7 7 7 0 0 1 1 2 |
| 0   | TY  | 0   | TY  | SC        | 1 9 2 2 7 7 7 0 0 1 1 2 |

MM: Model Mental; T: tier; SC: Scientific; SY-A: Synthesis-Partial Understanding (A); SY-B: Synthesis-Partial Understanding (B); SY-C: Synthesis-Partial Understanding (C); SY-M: Synthesis-Misconception; I: Initial or No Understanding; 0: Wrong, 1: Correct, Y: Sure, TY: Not Sure.

Figure 7. Percentage of student’s mental model.

Based on figure 7, students with a scientific model mental model only around 11.6% of the number of participants. For students on synthetic-partial understanding model A is 8.9%, synthetic understanding model B is 30.4%, synthetic understanding model C is 17.3%, synthetic-misconception model is 11.3% and for initial model is 20.5%. Thus, most students still do not really understand the concepts in static fluid material. In fact, not a few students that do not understand the concepts in static fluid. This is because participants practice more about the problem than deepening the concept of static fluid.
3. Results and Discussion

In this study the Four tier test diagnostic test was developed to identify students' mental models on static fluid. The development uses the development model of Dick and Carey, which has four stages of development, as follows:

3.1. Development of analysis diagnostic tests

At this stage a literature study was conducted to analyse the development and usefulness of the Four tier test diagnostic test in a previous study [1-5]. This Four tier test diagnostic test initially consists of two-tier questions [6] that measured students' ability to answer questions and why students choose the answer. Diagnostic tests with this two-tier format cannot reveal the student's mistake in choosing an answer, the election is because they do not understand or students have misunderstandings of the concept. In addition, these two-tiered diagnostic tests cannot distinguish whether the student answers correctly because they guess the answer or really based on the concept understood. Therefore, a two-tiered diagnostic test is developed into a three-tier test (7) diagnostic test. It was later developed into a four tier with the addition of two levels used to specify the level of confidence in the answers and the selection of the reasons chosen by the students [9]. Four tier diagnostic tests in previous studies [4-7, 9-10] was used to diagnose misconceptions. Meanwhile, in this study the four-tier test diagnostic test is used to identify the mental model. Mental models are identified based on the students' level of understanding on static fluid materials.

3.2. Design of diagnostic test

The Four tier test diagnostic test is a matter that contains concepts on static fluid materials. Thus, the Four tier test diagnostic test is capable of measuring the mastery of student concepts on static fluid. Here is the development of diagnostic test design form Four tier test:

| Design three-tier | Design four-tier |
|-------------------|------------------|
| 1.1. Problem description (first tier) | 1.1 Problem description (first tier) |
| a. (Answer choices) | a. (Answer choices) |
| b. (Answer choices) | b. (Answer choices) |
| c. (Answer choices) | c. (Answer choices) |
| d. (Answer choices) | d. (Answer choices) |
| e. (Answer choices) | e. (Answer choices) |
| 1.2. Confidence level against 1.1 (second tier) | 1.2 Confidence level against 1.1 (second tier) |
| a. Sure | a. Sure |
| b. Not sure | b. Not sure |
| 1.3. Reason based on answer choice on 1.1 (second tier) | 1.3 Reason based on answer choice on 1.1 (third tier) |
| .................. | a. .............. |
| (blank options that can be filled by students) | b. .............. |
| | c. .............. |
| | d. .............. |
| | e. .............. |
| 1.4 Confidence level against 1.3 (fourth tier) | a. Sure |
| a. Sure | b. Not sure |

3.3. Implementation

At this stage judgment is performed by the expert on the Four tier test diagnostic test before being used to identify the mental model. After that, the Four tier test diagnostic test was tested to the students at senior high school in Bandung.
Table 3. Expert assessment results of diagnostic test instruments.

| No | Validation Indicator                                                                 | V1 | V2  | V3  | Average | Category |
|----|---------------------------------------------------------------------------------------|----|-----|-----|---------|----------|
| 1  | Item questions are made according to the question indicator                           | 0.8| 0.8 | 1   | 0.8     | Valid    |
| 2  | Conformity of the concept in the item with the concept put forward by the experts     | 1  | 0.8 | 1   | 0.9     | Valid    |
| 3  | Item questions are made for understanding the concepts of students                    | 0.9| 0.8 | 1   | 0.9     | Valid    |
| 4  | Use language that is in accordance with Indonesian rules                               | 1  | 0.8 | 1   | 0.9     | Valid    |
| 5  | The language used is easily understood by students                                     | 1  | 0.7 | 1   | 0.9     | Valid    |
| 6  | The choice of answers and reasons are homogeneous and logical in terms of material    | 0.8| 0.8 | 1   | 0.9     | Valid    |
| 7  | There is only one answer key                                                           | 1  | 0.7 | 1   | 0.9     | Valid    |
| 8  | The question does not provide clues to the answer to the correct answer               | 1  | 0.8 | 1   | 0.9     | Valid    |
| 9  | The choice of answer does not use the statement "all answers are correct" or "all answers are wrong" | 1  | 0.8 | 1   | 0.9     | Valid    |
| 10 | Information on the questions in the form of images can help students understand the meaning of the problem | 0.9| 0.8 | 1   | 0.9     | Valid    |

Here is an example of the student answers:

![Figure 8. One of the student’s answers.](image)

In question number four students answer correctly, but the reasons stated are incomplete. Students only know that the large buoyant force acting on the body is equal to the weight of the fluid transferred by the object. Students do not fully understand the concept of buoyancy style. Thus, the model of students still exists in the category of synthetic model with the level of mastery of the concept in the category of partial understanding.

3.4. Evaluation

At this stage an evaluation of the ability of diagnostic tests of Four tier test forms in identifying students' mental models on static fluid. After the instrument is validated by the expert, an evaluation is carried out in the form of repair of the question indicators, repair of the data presented on each question, and changes in writing the answer options that were originally numbers into words. The repaired instrument was then tested. After the trial process, the instrument is repaired again in the answer option section. This is because there are several answer options that were not chosen by the participants.
4. Conclusion
Four tier test (FTDT) diagnostic test is an instrument that can identify students' mental models on static fluid materials. By using FTDT the students' mental models on static fluid materials can be classified into three categories, 1) initial model, 2) synthetic model and 3) scientific model. In addition, a four-tier test (FTDT) diagnostic test can be developed to identify changes in mental models in students after treatment of static fluid.

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