Investigating K-11 students’ mental models: An example of hydraulic system

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Abstract. Mental models aid us to comprehend the establishment of objects, the progress of the process and to assert a notion about a certain concept. This study consigns to investigating the mental model used by K-11 students in describing the hydraulic system. Research methods utilized the case study. The age of the participants is between 16th and 17th-year-olds (N = 105) of the eleventh graders in one of the Secondary Schools in West Java. The data unruffled through Two-Tier Open-Ended Tests (2TOET) was analyzed both quantitatively and qualitatively. Through quantitative analysis, the descriptive mental model is more widely used than the exploratory mental model. The results assert that the participants built a diversity of mental models about system hydraulic and almost all students including defective mental models rather than a scientifically appropriate one.

1. Introduction

The basic purpose of physics education is to teach concepts which concerned with the phenomena experienced by students in everyday life and the scientific facts underlying the relationship of concepts. According to the constructivist model, learning is an alive and student-oriented process. The learning process is influenced by preconception such as information on how to interpret concepts. The preconception that is inconsistent with scientific theory induce to learning difficulties [1, 2]. Mostly, difficulties arise from the problem of mental representation constructed by students in their interactions in the world.

Mental models as an internal delineation, which acts out as a structural analog of situations [3-5]. Its role is to know the individual's reasoning when predicting and explaining physical phenomena in the world [6-8]. The mental model relating to the human knowledge of the world is the way people understand some domain of knowledge [4, 9,10]. They can reveal how students define various scientific concepts and ideas [4,11]. Identification of mental models needs to be done to create meaningful learning, because teachers can know the students’ difficulties, for example on a hydraulic system. Student statements such as “when the distance of two containers contains the liquid closer than the distance of piston when moving up is higher” is an example of an unscientific mental model.

A review of the literature suggests that there is some research on the mental model and conceptual understanding of static fluids, but there has been no such research on Hydraulic System. Hydraulic system is one application of technology that applies Pascal’s Principle. Figure 1 shows that the hydraulic
system consists of two fluid-filled containers which are covered with pistons and both are connected to each other.

Figure 1. Hydraulic system.

Note first, the two pistons in the above hydraulic system have the same height, so there is no pressure difference due to the depth difference. The force to that of $F_1$ on the left piston creates the pressure transmitted to all parts of the enclosed liquid. This results in an upward force $F_2$ on the right piston larger than $F_1$, because the left piston has a larger area. According to Pascal's law that a pressure applied to a fluid in a closed container is transmitted equally to every point of the fluid and the walls of the container, as seen in equation (1).

$$P_1 = P_2$$ (1)

Since pressure equals force per unit area, then it follows that:

$$\frac{F_1}{A_1} = \frac{F_2}{A_2}$$ (2)

If the left piston $A_1$ is pressed by distance $d_1$, then the right piston $A_2$ moves upward with distance $d_2$. Based on these, the volume of fluid displaced must be considered. The volume of fluid suppressed by the left piston is equal to the volume of fluid being pushed upward by the right piston, so:

$$V_1 = V_2$$ (3)

volume of a container is equal to the container’s surface area multiplied by its height, so:

$$A_1 d_1 = A_2 d_2$$ (4)

The main goal of physics education is to help students build scientifically compatible mental models [3,11-14]. To achieve that goal, the investigation of what mental models the students have is important in the learning process, as suggested by the constructivist framework. This study consigns to investigating the mental model used by K-11 in explaining the physical quantities that affect the distance of piston in hydraulic systems when moving upward. The importance of investigating students’ mental model is to know the variations of mental models who can provide information for teachers. Such information not only helps students to avoid the development of misconceptions but also move toward scientifically. In addition, the students’ reasoning about the models also provides an important clue as to whether the models are scientific or not [15,16].
2. Methods

2.1. Research design

The case study method was conducted on 105 eleventh graders in secondary school. A special case of this research is the determination of the mental model regarding the physical quantities that affects the distance of the piston when moving upwards in the hydraulic system. This research consists of three stages, i.e. design, implementation, and analysis.

The first step at the design stage is to identify one of the difficulties students have in understanding the hydraulic system. After conducting discussions with several experts, it was found that students could not understand the physical quantities that affected the distance of the piston when moving upwards. The next step to get information about the case is making an instrument. The instrument was examined by two experts on terminology that was unclear or ambiguous, the difficulty level of the question, the language used, and the logic of the content presented.

The second stage is implementation by providing instruments to participants. Students are assumed to have a cognitive structure that underlies their answers to each question referred to as mental model.

The last stage is analyzing student answers on tier-2 in 2TOET. That is carried out twice. First, student answers are classified into several categories. The mental model category in this study refers to Fazio, Battaglia, & Paola [8]. There are practical, descriptive, and explanatory. Second, answers that have been in each category were analyzed related to the level of student understanding as in Table 1.

| Level of Understanding | Description |
|------------------------|-------------|
| Sound Scientific       | The distance of the piston as it moves upward ($d_2$) is influenced by the cross-sectional area ($A$) because the volume of liquid transferred piston 1 is equal to piston 2. So, to make $d_2$ larger then $A_2$ is changed to smaller or $A_1$ to larger. |
| Partial Scientific     | The distance of the piston as it moves upward ($d_2$) is influenced by the cross-sectional area ($A$), with further reasons not quite right. Example: To make $d_2$ larger then $A_2$ is changed to larger. |
| Unscientific           | The distance of the piston as it moves upward is influenced by physical quantities other than the cross-sectional area. Example: The distance of piston when moving upward is influenced by the distance between the pistons in the containers |
| No Model (NM)          | Students do not choose the answer at the first tier or give no reason at the second tier in the 2TOET instrument. |

2.2. Participants

The purposive sampling method was used in this study. The participants consist of 105 students (68 women, 37 men) at the secondary school who adhere in science class. The participants are students aged between 16th - 17th years old who have studied static fluid matter consist of hydrostatic pressures, the law of Pascal, and Archimedes. Therefore, they were assumed to have constructed a basic understanding of the concept of static fluid in the hydraulic system.

The concept of static fluid is taught using traditional teaching methods that are teacher-centered. Instructional techniques such as predicts, analogies, questions, and examples from daily life are not used to augment the learned concepts. Participants incline to focus on the rehash and depiction of concepts they have learned, often only from a mathematical viewpoint.
2.3. Instrument
Two-Tier Open-Ended Test (2TOET) is given toward participants to complete for one hour. This instrument is the development of a multiple-choice test that students often encounter consisting of one tier, while the 2TOET instrument consists of two tiers. At the first tier, there is a question consisting of five answer choices (four wrong answers and one correct answer). Furthermore, in the second tier, it contains questions related to the student’s reason for the choice of answers at the first tier. The reasons given by the students, in addition to the explanation but also can be equipped with images that are the result of their visualization about the movement of the pistons in the hydraulic system.

3. Results and Discussion
Through the question given to the 2TOET instrument on the physical amount that affects the distance of the piston when moving upwards in the hydraulic system, the student’s mental model can be determined. The distribution of students in each mental model category related to the level of understanding is given in figure 2.

![Figure 2. Students’ distribution of the mental model category.](image)

According to Figure 2, there are only two mental models of the three mental models found by Fazio, Battaglia, & Paola [8]. From 105 students none of the students used the practical mental model. That means no student provides an explanation based on the daily context or other situation.

From the two categories of mental models above, mental descriptive models are more widely used than exploratory. In other words, more students explain by finding or remembering the relevant variables or remembering from their memories related to the case faced by expressing them using different languages. If observed clearly, the percentage shown does not reach 100% because there are 14.29% students were included No Model. They don’t choose the answer at the first tier or give no reason at the tier-2 in the 2TOET instrument.

The descriptive mental model is that students give explanations by remembering relevant variables or remembering from the memory of their relationship [8]. Most students express it using mathematical or verbal uses. Based on the results of the analysis, it was found that the unscientific percentage of level understanding is greater than partial scientific.

The number of students included in the unscientific was 48.57%. The sample answer given by students that if the distance piston when moving upward wants to be higher than the distance between the pistons is changed to close. This is connected with the motion of piston 2 which will be faster than when the distance between the pistons is further. Students have the reasoning that the force on piston 2 is affected by the distance between the two pistons. Of course, this is not in line with Pascal’s principle...
that the thrust force on piston 2 is influenced by the cross-sectional area and external force applied to the piston 1.

Examples of student’s answer include partial scientific, that is, the smaller the cross-sectional area, the greater pressure because $P = \frac{F}{A}$, so the distance of piston 2 when moving upward is higher. Based on that answer that students already know that by making the cross-sectional area smaller than the distance of the piston 2 when moving upwards is higher. However, they ignore the Pascal principle even though it is correct in the concept of pressure that when $A_2$ changes smaller than the pressure will be greater. Students prefer to associate mathematical modelling in their explanations. When students use mathematical equations that related pressure, force, and cross-sectional area, they forget that pressure is always fixed. When the cross-section area of the piston is changed then the pressure will not change, but the force on the piston.

The exploratory mental model is that students provide explanations based on a causal relationship by giving hypotheses theoretically [8]. Examples of student’s answer in this category that if the distance between the two pistons in the hydraulic system is changed to be greater than the piston in container 2 moves up higher. The reason is that liquid particles push more pistons, resulting in greater pressure.

In this study, the mental model of the hydraulic system has been determined. The first tier at 2TOET aims to know the students' knowledge of physical quantities that affect piston spacing when moving upward. Most students revealed that the distance between the two pistons in a hydraulic system affects the piston's distance as it moves upward.

The students' mental models use in creating explanations can be eclectic and sometimes contradictory [13,17]. The results of this study are in accordance with the literature, although most of the explanations given are contradictory. Thus, it causes students to develop alternative concepts, non-scientific knowledge or things that are contrary to scientific knowledge. The reasons for this defective mental model can come from a variety of sources, such as prejudice of students who were previously studied or preferred by using their intuition.

4. Conclusion
As a result of this research, it appears that the students’ mental model about hydraulic system can find out how far students understand Pascal’s law. This result is expected to be helpful for teachers in teaching the physics concepts applied to the hydraulic system. For example, when studying Pascal's Law on the topic of static fluid. It appears that the student model associated with this hydraulic system can find out how well students understand Pascal's law. An incomplete understanding of Pascal’s law has influenced the expressed description of the hydraulic system. This case shows the extent to which students' ideas about the hydraulic system are influenced by their intuition. Therefore, in the learning process not only emphasizes Pascal’s principle intact or mathematical modelling of its concepts. However, students should be more inclined to understand what the consequences are when the fluid is in an enclosed space and is given a force.

This study provides evidence of students’ understanding of the concept of pressure on fluids that are silent in a confined space. Thus, the mental models of students gained in this study may be sources for further study. That study is the investigation of mental models, misconceptions, or learning difficulties. In addition, research on mental models of students on the same concept but with different participation, so it can be known variations of other models.

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