Students’ mental model on heat convection concept and its relation with students conception on heat and temperature

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Abstract. This research depended by previous studies that only to find out the misconceptions of students without figuring out the mechanism of the misconceptions. The mechanism of misconceptions can be studied more deeply with mental models. The purpose of this study was to find students ‘mental models of heat convection and its relation with students conception on heat and temperature. The method used in this study is exploratory mixed method design that implemented in one of the high schools in Bandung. The results showed that 7 mental models of heat convection in Chiou’s study (2013), only first model (diffusion-based convection), third model (evenly distributed convection) and fifth model (warmness topped convection II) were found and model hybrid convection as a new mental model. In addition, no specific relationship between mental models and categories of students’ conceptions on heat and temperature.

1. Introduction

Senge [1] explained that to be a learning organization, schools should be able to motivate five core things of forming learning organization. E.g : (1) Systems Thinking, (2) Personal Mastery, (3) Mental Model, (4) Building a Shared Vision, and (5) Team Learning. One of them is mental model that has not been frequently applied in teaching. As educators, teachers need to reveal students’ initial information to help students’ understanding of more complex topics. The students’ initial information can be seen from students’ mental models, because mental models can be affected by previously acquired knowledge. This relates to Vosniadou & Brewer’s opinion[2] regarding mental models, beliefs and mental models emerged out from previously acquired knowledge structures, and give effect to the new knowledge. According to Chiu [3] to help students building their scientific knowledge, educators need to know the students’ mental models.

Mental models represent ideas in individuals’ mind are used to describe and explain the phenomenon. Mental models can provide important information about the origin of students’ knowledge structures (specifically and theoretically framework) Vosniadou & Brewer [2]. According to Al-Diban & Ifenthaler [4] mental models are basic cognitive constructs that describe complex learning and problem-solving processes. Mental models are important in understanding the development process of the students in learning. Arslan & Durikan [5] said mental model is the structure of daily experience and the learning process, they can reform unwittingly when needed.

The concept of heat and heat convection is an essential concept and all high school students should master this concept as a basic concept [6]. The characteristic of heat convection is dynamic interaction. Convection is the process by which heat carried from one place to another through the movement of the fluid. When the heat convection occurs, the thermal energy move along with the
heated fluid. Convection is the flow of heat transfer fluid accompanied by fluid movement [7]. Although the heating of water with a pan or hot air in the room, the process is the same. If the fluid is heated from below, the speed of the molecules increases; the density of the fluid to be reduced and pushed by the cooler fluid so that the density of the fluid cooler took place at the very bottom. Here, convection currents keep fluid to be heated [8]. It is also stated by Griffith, & Brosing [9] when heating the air inside the house, the warm air has a lower density than cold air, so the air from radiators or baseboard heaters tend to move upwards (upper house/roof). The warm air makes the air currents distribute energy around the room. Warm air move upwards along the wall near a source of heat, and the cold air moves down along the wall opposite. This is called natural convection. When the fluid is heated, for example, the air above the fire, enlarged volume of the fluid, and its density decreases. If it is associated with the Law of Archimedes, cooler fluid and its density is greater, pushing the fluid warmer and push it to the top. When the warmer fluid moves up, the cooler fluid replaced. This colder fluid will be warmer and pushed upward. Therefore, a continuous flow of heat formed during receiving heat. When the heat is moved by the displacement of gas or liquid, can be said to be heat transferred by convection. Fluid flow can be called by convection currents [7]. Convection involves the physical movement of a substance (such as water or air) from thermal contact with a system for thermal contact with other systems. Substances move brings the internal energy. You can see the rising heat energy in the form of flames and hot air over a fire in a campfire [10].

Lee’s study [11] just to find out misconception and how to eliminate these misconceptions on pre-service elementary school teachers about the concept of heat and heat transfer, this study according to Mansyur’s [12], he said that study in Indonesia for cognitive science is more dominant in the discussion of misconceptions. Most studies examined how students have misconceptions, but they not explored in more depth mechanism of the misconceptions, the actual mechanism of the misconceptions can be studied more deeply with mental models. One of the basic competencies of high school students in class X on the temperature, heat and heat convection concept is to analyze the impact of heat and heat transfer in everyday activity. Therefore this study to investigate mental models of high school students on convection heat and its relations with students conception on heat and temperature.

2. Research Method

2.1 Research purpose
The aim of this study was to identify students’ mental model on heat convection concept and investigated the relationship between the mental models’ found and students’ conception on heat and temperature.

2.2 Research method
This research method is mixed methods (both quantitative and qualitative). The study design used in the study is exploratory design. "Exploratory mixed methods design emphasizes qualitative data than quantitative data and quantitative data to build qualitative data" [13]. In this study, the first is collecting quantitative data followed by collecting qualitative data, the results of quantitative data is intended to help the results of qualitative data.

2.3 Participant
In quantitative data, 28 participants were students of class XI IPA at high schools in Bandung. Then in the qualitative data, 30% of 28 students were selected to be the subjects of mental model identification.

2.4 Instrument
Collecting data used tests and interviews. The instrument test used is a three-tier test about temperature and heat concept. The first tier contains 5 options, namely A, B, C, D, and E, this tier
using instruments Thermal Evaluation Concept [14] [15] as many as 30 questions that are adopted and adapted in the numbers 1 to 15, 17 to 27, and 29 to 32. As for the two other questions made by the researcher is at number 16 and 28, each question has been validated by experts and physical education specialists as much as three experts. To test the students' conceptions researchers added two others tier, which are: second tier contains the reason of students choice on first tier, and third tier is confidence index (if the student is sure to choice and reason). The level of confidence in the three-tier test provides an opportunity to assess the nature and strength of their misconceptions [16].

Interview’s instrument is adopted and adapted from Chiou [3]. Three rounds of interviews were conducted to investigate not only the understanding of the students but also their mental model of heat convection. Each student spends an average of 30 to 60 minutes per student to complete the three stages of the interview. The first phase aims to investigate students' understanding of heat convection as well as some basic scientific concepts about temperature, heat and heat convection. Student responses in this interview was expected to provide a foundation and a framework to guide the interpretation of their mental models. In a second phase, some generative questions designed to investigate the students' mental models about heat convection. Then, follow-up questions were given to investigate how students simulate the process of heat convection. In the third phase, several questions were posed to probe the participants' reflections on their previous responses.

2.5 Analysis Data
Quantitative data analysis conducted in accordance with the table category analysis answers three tier test [17]. There are four categories will we find ; scientific knowledge, error, lack of knowledge and misconceptions. It is from the analysis of the answers to each question. Researchers summing the results of the analysis of each question on the fourth categories of each student. The results of the analysis can be categorized based on the categories of students' conceptions in Table 1. The results of the analysis of quantitative data associated with mental models of qualitative data analysis later.

| No | The categories of students' conception | Types of answers |
|----|----------------------------------------|--------------------|
| 1  | Dominantscientific knowledge          | Scientific knowledge 51%-100% from all the answers |
| 2  | Dominantlack of knowledge             | Lack of knowledge 51%-100% from all the answers |
| 3  | Dominant misconception                 | Misconception 51%-100% from all the answers |
| 4  | Misconception and lack of knowledge are equal | Misconception and lack of knowledge 48%-52% from all the answers |

Qualitative data analysis using the constant comparison method. Then analyze the results of interviews and compared with the results in Chiou [3]. 3 phases of interviews were analyzed to find out the students' mental models. The first phase is from the image of each student about the heat convection. Then, the focus is placed on the explanation of the temperature difference of the fluid as a result of convection currents. Then the last phase of testing is the reliability of each category of students. 2 deal physics lecturer from mental models that formed was tested by calculating Kappa coefficient. Kappa coefficient calculation is calculated using 2x2 contingency tables [18].

3. Result and Discussion

3.1. Student’ Conception on heat and temperature
Based on table 1, there are 4 categories based on students' answers: dominant scientific knowledge, dominant lack of knowledge, dominant misconception, and misconceptions and lack of knowledge are equal. 30% students of each category in the picture 1 are 4 students dominant lack of knowledge (IY, SSA, AZ, and MZA), 5 students dominant misconceptions (FMA, RMR, PAB, NRS, and BA) and 1 students misconceptions and lack of knowledge are qual (CNP). No students were included in dominant scientific knowledge, then only 10 students were investigated in mental models.

3.2. Students’ Mental Model
From 7 mental model in Chiou’s study [3] which scientific accepted is model 7. However in this study, there was no student in model 7. 3 mental models by Chiou, G. L [3] and 1 mental models that the new findings. Categorizing the mental model of heat convection reliability was examined by calculating the Kappa coefficient, which was 1, showing excellent agreement between the two experts.

3.2.1. Model hybrid convection
In hybrid convection model, when heated, the molecules enlarged so its density decreases, then move up gradually and not back down. Liquid at the top have the highest temperature than other parts of the
liquid. For example, when students BA in the interview about mechanism of heat transfer on tube I, he replied:

BA: When heated, volume increases, its density decreases, thus evaporate and move up

There are four students in this model BA, MZA, RMR, and SSA. MZA has a similar thought with BA, MZA and BA thought that evaporation occurs after reaching top of liquid. However, RMR thought after reaches the top, boiling occurs.

3.2.2. Model 1: Diffusion-based convection

Characteristics of the model 1 is diffusion mechanism that occurs when heating. Only one student is included in the model 1, he is FMA. When the interview about mechanism of heat transfer on tube I, he replied:

FMA: The first, heated at the bottom and move upward gradually
R: Why does it move up?
FMA: Because of heat at the bottom

In this model, students ignore the liquid as a heat carrier. The highest temperature in the liquid is bottom of the tube and gradually decreases to the top of the tube.

3.2.3. Model 3: Evenly distributed convection

In model 3, students assume that the heat changes molecules near a heat source becomes larger so its density decreases and moves upward and then immediately turned down and so on, and the temperature in the liquid is the same. As shown in snippet interviews between researchers and AZ:

Q: Describe the process of heat transfer that occurs in the tube!
AZ: Because the heat from here (bottom) spread up, (drawing current convection) going around so continue.
Q: What about the temperature in different parts of the water when convection occurs? (e.g. bottom = A, the middle = B, the top = C)
AZ: A = B = C

However, CNP had different ideas, she thought the current convection from bottom of the tube to the top of the tube, it happens continuously until boiling and then after boiling evaporation. CNP also thought that the temperature in each part of the liquid on the top tube has a high temperature and gradually decreases to the bottom of the tube.

3.2.4. Model 5: Warmness-topped convection (II)

There are three students in model 5, they are IY, NRS, and PAB. They thought that the bottom of the liquid had the highest temperature and gradually decreases upward. When asked about the mechanism of heat transfer when heated at the bottom, IY answers that because it is heated, the volume of molecules in the bottom of liquid enlarged so its density decreases \( \rho = \frac{m}{V} \), then the molecules are moving up to the top and moving down to the bottom so that make the convection current. When the molecule moves up to the top, the top displace the molecules move. NRS have the same answer with IY, but PAB has a different answer to both. PAB thought that when the molecule at above of liquid, its density enlarged because of boil. From the top, spread straight down. Later, all parts of the liquid will be hot.

![Image](a. Model Hybrid) ![Image](b. Model 1) ![Image](c. Model 3) ![Image](d. Model 5)

**Figure 3.** Drawings of students in each mental model
3.3. Relationship between students Mental Model and Student’ Conception

Table 2. Relationship between students mental model and students’ conception

| Mental Model | Dominant Lack of Knowledge | Dominant Misconception | Misconception and Lack of Knowledge equal | Total |
|--------------|---------------------------|------------------------|------------------------------------------|-------|
| Model X: Hybrid convection | MZA, SSA | BA, RMR | - | 4 |
| Model 1: Diffusion-based convection | - | FMA | - | 1 |
| Model 3: Evenly distributed convection | AZ | - | CNP | 2 |
| Model 5: Warmness-topped convection (II) | IY | NRS, PAB | - | 3 |
| Total | 4 | 5 | 1 | 10 |

From Table 2, students in dominant lack of knowledge category has a different mental model, there are model hybrid, model 3 and model 5. And students in dominant misconceptions has a different mental models too, there are model 1, model hybrid and also model 5. And the latter, students misconceptions and lack of knowledge are equal has model 3. This result proving that no specific relation between mental models and students conception.

4. Conclusion

From 7 mental models about heat convection in Chiou [3], model 1 (diffusion-based convection), model 3 (evenly distributed convection) and model 5 (warmness topped convection II) that found in this study, and new mental model as a hybrid convection model. Among the four mental models no mental models in scientific accepted.

No specific relationship between mental models and categories of students’ conceptions. Students are included in dominant lack of knowledge have mental models ranging from a hybrid convection model, model 3 (evenly distributed convection) and model 5 (warmness topped convection II). While students are included in dominant misconceptions have a varies model, they are in model 1, hybrid convection model and also model 5 (warmness topped convection II). And the last of students belonging to the category 4 has a model 3 (evenly distributed convection).

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