What do they know about Heat and Heat Conduction? A case study to excavate Pre-service Physics Teachers’ Mental Model in Heat and Heat Conduction

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Abstract. Teacher plays a crucial role in Education. Helping students construct scientifically mental model is one of obligation of Physics Education Department of Teacher Education Institute that produce physics teacher. Excavating students’ mental model is necessary to be done in physics education. This research was first to identify 23 physics students’ mental model of heat and heat conduction. A series of semi-structured interviews was conducted to excavate the students’ understanding of heat and mental models on heat conduction. The students who involved in this study come from different level from sophomore to master degree in Physics Education Department. This study adopted a constant comparison method to obtain the patterns of the participants’ responses through the students’ writing, drawing and verbal utterances. The framework for assessing mental model and the instruments were adopted and adapted from Chiou and Anderson (2010). We also compared the students’ understanding of heat and mental models on heat conduction. The result shows that Heat is treated as Intrinsic property, material substances, and caloric flow. None of students expressed heat as transfer of thermal energy. Moreover, there are two kinds of students’ fundamental component of mental model in heat conduction were found: medium and molecules. Students understanding of heat and fundamental components of mental model in heat conduction are not resulted from running mental model.

1. Introduction

One of challenges in teaching physics is to help students develop a scientifically compatible understanding of heat phenomena based on their existing ideas and beliefs [1]. Understanding that exist in someone thinking will help in describing the phenomena and process the understanding to analyze the new phenomena in the form of internal representation [2]. Internal representation that is exist in the students’ mind based on his/her understanding of a concept is called Mental Model. Mental model can be run in explain and predict the new phenomena. Moreover, the central goal in physics education is to help students construct a compatible scientifically mental model [3]

Excavating students’ mental model in certain topics, provide a constructive feedback to stakeholders of physics education particularly to probe the reasons behind misconception. This feedback is used to improve the quality of physics learning [2]. The concept of heat and heat transfer is an essential concept and all physics students should master this concept as a basic concept. Moreover, as candidate of Physics’ teachers, Students must have a scientifically understanding about
what heat is and how the mechanism of heat conduction since it is listed in the national curricula. Heat and its transfer become essential topics both in Junior High School and in Senior High School.

Mental models refer to individuals’ internal, mental representations of external, physical phenomena or systems [1] [4]. Meanwhile, Johnson-Laird [5] stated that mental models are structural analogues of the world; propositional representations are strings of symbols that correspond to natural language; and images are perceptual correlates of models from a particular point of view. Human beings understand the world by constructing mental models, i.e., working models (models that predict and explain) in their minds [6]. Someone who runs mental model, he/she will be able to predict and explain the new phenomena. Reinfried & Tempelman [7] listed mental models as constructions of knowledge and understanding that play a central role in the theory of learning of cognitive constructivism, which represents the epistemological position this study is based on.

Students’ understanding of Heat conceptions has been extensively studied since the 1970s due to the difficulties to be studied as heat represent emergent processes [1]. Most of students treated as substance rather than as a process. As listed in page 829-830, Chiou [1] comprised four patterns the students’ interpretative framework of heat as it can be found based on the past studies on misconceptions or conceptual change. The four patterns of heat conceptions are: (1). Heat is treated as an intrinsic property of a substance. Coldness is property of ice and hotness is property of wood- is an example of students response in pattern (1); (2). Heat is treated as material substance. For this pattern, hotness, which can be envisioned as a group of particles and can move from a hot object toward a cold object; the opposite of hotness particle is coldness, which can move from a cold object to a hot object; (3).Heat is treated as non material entity, caloric flow, which propagates from object at higher temperature to object at lower temperature; (4). Heat is treated as transfer of thermal energy (the total kinetic energy of all the particles in a substance) due to a temperature difference. The fourth framework represents a scientifically accepted view. The framework represents the developmental stages of peoples’ conceptions of heat, developing from naïve view toward a more scientific one.

2. Research Method

2.1 Research purpose
The aim of this study was to identify pre-service physics teachers’ mental model in heat conduction concept and investigated the relationship between the mental models’ found and students’ understanding about heat.

2.2 Research method
A series of semi-structured interviews were held to probe students’ understanding of heat and students’ mental model in heat conduction concept. The students who were involved in this study varies from sophomore to senior and some of them are Physics’ Education master students. They were first asked to allow the researcher to record along the interview. Students were given a set of questions related to heat, heat conduction, mechanism in heat conduction, examples of the phenomena related to heat conduction which they found in the daily life. They then asked to predict the heat conduction phenomena and follow up questions were then probed to strengthening the participants’ prediction and the reasons why the participants make the prediction. At the end of the interviews, the participants were given an opportunity to reflect and/or to change the answers.

There were three interview protocols: first interview protocol consisted of basic concept of heat, heat conduction, samples of phenomena heat conduction in daily life and the mechanism underlying heat conduction. The main purpose of questioning of the mechanism underlying heat conduction was to probe what happened in heat conduction based on the their existing idea. Moreover, the question whether there are students who tend to encompass the microscopic level of heat conduction, become the interestingly to be investigated.
The second interview protocol contained one interview-about-event question. The students’ were asked to predict and explain the temperature condition of two kinds rod when it was connected to the iron circular disk. The iron circular disk was heated by the flame as shown in Figure 1.

2.3 Analysis Data
The data of mental model were analyzed by constant comparison method. After that, the participants’ responses were analyzed and compared to Chiou’s framework [1]. Three rounds of data analysis were conducted to construct each participant’s mental model [3]. The first round focused to the participants drawing of phenomena; the second round focused to spatial arrangement and the last round was examining the reliability of patterns the students’ responses.

Two lecturers who have expertise in thermal physics were asked to recode the participants’ understanding of heat and mental models in heat conduction. The inter-coder reliability was calculated by Kappa coefficient which was 0.86 (p<0.05) and this was showing an excellent agreement between coders.

3. Result and Discussion

3.1. Students’ understanding of heat
Based on the four patterns of students’ interpretative frameworks of heat that stated by Chiou [1], The pre-service physics teachers’ conceptions of heat can be seen in Fig. 2. As can be seen that there was only one student who treated heat as property intrinsic. He/she explained that heat is a form of energy. It can be converted to others form. Heat is a property of object, likewise the potential energy. He/she agreed that heat is owned by person, ballpoint, etc. He/she did not notice the temperature difference.

Furthermore, none of students answered that heat is an energy that exist as transfer of thermal energy due to the temperature difference. Most of students (more than 70%), treated heat as Caloric flow. Students’ responses are homogeny that heat as Energy that is move due to the temperature difference. If they continued to be asked about the energy itself, they failed to explain in detail about the Energy. Its responses are closest to the definition written in high school text book of Physics.

In the other hand, there are two students who treated heat as combination of others framework. First student, combine the framework of intrinsic property and caloric flow. He/she explained that heat is energy that transferred due to the temperature difference when it is connected/touched each other. In addition, in the last part, he/she explained that heat is owned by each substance. The higher the temperature, the more heat is contained and vice versa. Second student, He/she expressed heat as combination of fourth framework and third framework. He/she stated that heat is transfer of average kinetic energy from the particle with high energy toward particle with low energy, whereas average kinetic energy is a definition for temperature. He/she pretended as having a scientifically understanding about heat due to the use of energy term. But, he/she could not determine the difference between temperature and heat.
3.2. Students’ mental model in heat conduction

Heat conduction is a dynamic process of how heat is transferred through the solid substance. Students’ fundamental components of mental model in Heat Conduction were found as described in Figure 2.

There are two kinds of students’ fundamental components of mental model in heat conduction based on the interviews. First component mental model is Molecules. Students, who chose molecules as a fundamental component mental model in heat conduction, explain the underlying mechanism of heat conduction as: “heat conduction proceeds as molecular collisions”. For Example, Student A01 mentioned that heat conduction as impact of molecular collision:

I : Please describe the mechanism of heat conduction!
A01 : The mechanism ya? Ooo… when the metal is being heated… the particles in the metal… moving faster…
I : What kind of moving?
A01 : Hmmm… The particles arrangement in metal is dense, so when it is heated, the particles will be vibrated. As hotter, then they more vibrate… they collide each other and influence the next particles to vibrate, so the energy propagates
The second fundamental component of mental model in heat conduction is Medium. Most of students who chose this component, explain the heat conduction as process of heat transfer when the medium did not move with the heat. There is one student who additionally explained that in heat conduction involved the temperature difference, from the higher temperature toward lower temperature. He/she did not explain much more about the mechanism in microscopic or in molecular. Another student, A12 who is in this category, stated that heat conduction is process of energy transfer without medium (heat is directly propagates from one object toward another object without mediator).

I: Please describe the mechanism of heat conduction!
A12: The process? … Process in which energy transfer directly…
I: Directly? Could you explain?
A12: Directly transfer is without mediator, for example …. Eee…. From the flame, flame directly touch the pan…. Flame is hot, it has an energy, directly touch the pan…
I: Emh… OK… so it is directly energy… is there any limitation for your answer?
A12: No..
I: So, each energy that directly transfer, it is called heat conduction?
A12: Yes mam…. For example, iron… in ironing… it is conduction

The results show that the fundamental component of mental model in heat conduction is majority of medium. All participants firstly answer that heat conduction is heat transfer in medium. Some students additionally explain with interaction molecular, but others only explain in medium. These findings are different with Chiou’s finding [1], that he found that there are three kinds of fundamental component in heat conduction, i.e. Heat particles, Caloric flows, and Molecules.

4. The Relationship of fundamental component of mental model in heat conduction and students’ understanding of heat
Ideally, students who have a scientifically understanding of heat, they should also have a scientifically accepted of mental model in heat conduction. Table 1 shows the relationship between students’ conception of heat and Fundamental components mental model in heat conduction.

| Students’ conceptions of heat | Fundamental components of mental model in Heat Conduction |
|------------------------------|----------------------------------------------------------|
|                              | Medium | Molecules |
| Intrinsic Property           | -      | 1         |
| Material Substances          | 1      | 1         |
| Caloric Flow                 | 6      | 10        |
| Transfer of Thermal Energy   | -      | -         |
| Hybrid                       | 2      | -         |

They did not run their mental model to explain heat, they were just memorized the sentences of definition about heat. It is worth noticing that students in high level, they should have a better understanding of heat from the microscopic view, that heat is transfer of energy thermal due to the temperature difference. What kind of thermal energy, they should involve the total kinetic energy of all particles, such as atoms and molecules, in a substance.

5. Conclusion
Based on this finding, we can conclude that students’ understanding of heat is still dominated by the definition written in the textbook. None of students chose Heat as transfer of thermal energy. The participants’ fundamental components of mental model in heat conduction were medium and
molecules. Students’ understanding of heat and heat conduction is not a result from running mental model, otherwise their thinking is still fragmented. This finding led us to improve the quality of learning especially in delivering heat concept as a dynamic and essential concept.

6. References

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