Pre-service physics teachers’ mental models of heat conduction: a case study of the process-analogy of heat conduction

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Abstract. Identifying the students’ mental models in heat conduction forms the foundation for re-construction the introductory physics learning. In order to probe students’ mental model on heat conduction, we conducted a qualitative study. In this paper, the authors describe the process of a multiphase study aimed at inferring the pre-service physics teachers’ mental models of heat conduction. Semi-structured interviews were conducted to 31 students from two different teaching preparation institutions in West Java Province, Indonesia. They were all enrolled in Introductory Physics to elicit their understanding, explanation and prediction of heat conduction phenomena. Students’ mental models were found to be dominated by unscientifically accepted mental models. These findings led teacher educator to suggest changes in the way that thermal topics are addressed in introductory physics course.

1. Introduction

Physics is a fundamental science which study of matter, energy, and the interaction between them [1]. Learning physics promote students to increase the higher order thinking skills. Creating an exciting and sophisticated learning physics in high schools is a powerful mission to be completed by physics teachers. Teacher educators in teaching preparation institute must equip the students to have a scientifically understanding of some physics’ concept and context.

However, Physics education in college faces many challenges. One of the challenges in teaching physics is helping students develop a scientifically compatible understanding of physics phenomena based on their existing ideas and beliefs [2]. Furthermore, another challenge is that most students who are enrolled in introductory physics do not gain a valid understanding of the concepts, practices of inquiry, or mental habits used in the discipline [3].

To cope with the challenges faced by the teacher institute, continual improvement in the earlier phase of physics learning for physics teacher candidate is needed [3]. One of ways to begin the improvement in physics learning is investigating the students’ thought of some concept or phenomena. Students’ thought can be expressed by their internal representation called Mental Model. Mental models represent ideas in individual’s mind are used to describe and explain the phenomenon [4]. Researchers [5,6] refers mental model as an individual internal representation that present structural analogy of external physical phenomenon. He also explained the relationship between mental model
and target system in the components and structures. One of the main function of mental model is help someone in predict and explain of a phenomenon [2,7].

Some feedback will be gathered from investigating the students’ mental model, especially to probe the reasons behind misconception [8]. Besides that, as a Faculty, assessing the students’ knowledge by using research-based instruments and method is recommended by National Research Council [3]. Therefore, investigating the students’ mental models of particular physics concept is necessary to be conducted.

Many previous research reported that heat as one of the physics topics that most difficult to be understood [8-11]. Whereas, heat is a fundamental concept in understanding others concept related to heat such as energy, phase change, heat transfer, thermodynamic, etc. The study of heat and thermodynamics is an important part of a physics students’ education [12]. Heat is an essential topic that should be learned by students both in junior high school and senior high school [13]. Frederik mentioned there are two reasons why heat is become a topic that should be deeply research [14]: First, heat is a core topic in the introductory physics curriculum. Second, heat is also become a subject that is taught to pupils aged 13-14 years. Based on the two reasons mentioned earlier, heat is a topic that have to be mastered by Pre-service physics teachers.

In this paper we will describe the students’ mental model of heat conduction that will lead implication to construct the instructions that facilitate the transformation of students’ mental models from the naïve one to the scientifically acceptable mental models. This study also deeply revealed the relationship between students’ understanding of heat concept and students’ ideas of mechanism of heat conduction and students’ mental models of heat conduction through a phenomenon related to heat conduction.

2. Research method
This study used the qualitative research method to investigate the participants’ understanding of heat and mental models of heat conduction. For this research qualitative study, a phenomenology is appropriate to probe students’ understanding of heat and to uncover students’ mental model of heat conduction. Phenomenology utilizes rigorous data analysis techniques to determine the understanding individuals give to a specific phenomenon [15].

A series of semi-structured, generative interview questions was adapted and adopted from Chiou [2] to probe the participants’ understanding and mental models by asking them to predict and explain conduction-related phenomena. As suggested by many researchers, using this qualitative approach is a promising way to excavate people’s mental models [2,5,15].

2.1. Participants
Our research participants consist of 31 sophomores from two different public-teacher-institutions in West Java Province. They were enrolled in Introductory Physics II during the academy year 2017-2018. During the previous semester, they attended Introductory Physics I, in which heat and heat transfer be a topic. When requested to participate in this study, they were attending a third semester physics course dealing with the fundamentals of electromagnetism, and voluntarily chose to participate in the interview.

2.2. Materials and data collection
Three semi-structured interview protocols were adopted and adapted from Chiou [2] to elicit the participants’ understanding of heat and mental models’ of heat conduction. The first interview protocol aimed to investigate their understanding of heat and heat conduction. In this interview, participants were asked with the questions: “Please describe your understanding of heat”, “Please describe your understanding of heat conduction”. This study will focus on the second and third phases of these interviews through which metal models were developed.

In the second phase of interview, Students were faced to Interview-about-event. In this phase, there was a series of generative questions [2,16], which were aimed to facilitate the participants to “run”
their mental models. The phenomenon related to heat conduction was delivered: “There are two different rods, metal rod and wood rod. The two rods are connected to the iron disk that has been heated by an alcohol lamp for a very long time. Can you rank temperatures of the different sections within both rods? That is, what is the ranking of the temperatures at points A, B, C, D, E, and F?”

Follow-up questions are as follow: “How did you determine the ranking of the temperatures at A, B, C, D, E, and F?” “Are temperatures at location A, B, and C (and D, E, and F) the same during different periods of the heating process? How do you know?” “Are temperatures of the two rods the same during different periods of the heating process (i.e., comparing A and D, B and E, and C and F)? How do you know?”, “How do you image the process of heat transmission in this system?”

The procedure for each generative question and its follow-up questions was adapted and adopted from Chiou & Anderson [2]. It was developed on the basis of the characteristics of mental models. The interview questions were aimed to elicit the following aspects of the participants’ mental models:

- Prediction about the changing states of the system;
- Elements involved in the target system;
- Relationships between the identified elements.

The third phase of the interview was a set of reflective questions. In this phase, several questions were posed to probe the participants’ reflections on their previous responses. The interview questions, for example, included “Do you want to change any of your answer to the questions? Why?”, “Do you feel confident about your answer?”, etc. The participants’ responses to these questions were used to make sure that the participants had provided affirmative answers and satisfactory responses for future analyses [5].

2.3. Data analysis
Determining participants’ mental models of heat conduction, this research adopted grounded theory both in analyzing and interpreting the data [2]. Constant comparison method was used to categorization the students’ response into the form of students’ mental models of heat conduction. The steps that were used by Chiou [2] in searching the patterns of the participants’ mental model of heat conduction were mainly used in this study. We compared the students’ response to Chiou’s findings, both in ontological belief, process analogies, final state prediction and students’ mental models of Heat Conduction. Nevertheless, we also accommodated the students’ response which is excluding Chiou’s finding into new categories.

Students were required to predict the final state of the phenomenon related to heat conduction as shown in Figure 1, and then they were asked to explain stepwise in thermal states in each point both in aluminum rod and wooden rod in every stage of heating process. The participants’ response in interview was audiotted. The first step to interpret the data is transcribed the recorded audio into text, and the text together with the participants’ writing and drawing formed the materials to be analyzed.

3. Results and discussion
3.1. Students’ mental models of heat conduction
This section presents the students’ mental models of heat conduction. Students’ mental models combine students’ ontological beliefs and process analogies of heat conduction. In this paper, we would like to presents The Process Analogies of Heat Conduction as one of the element of mental models. Table 1 shows Students’ process analogies of Heat Conduction. Based on the students’ explanations in response to the interview questions, students’ expressed the process of stepwise of heat conduction in metal rod and the process of analogies of heat conduction were identified in Table 1. We can see that there are ten process analogies. Among these ten process analogies, four of them are fundamental analogies, and the other six are dual analogies. Five of the ten process analogies are adopted from five process analogies of Chiou [1]: Marching, Flooding, and Gradient as fundamental analogies; Gradient-marching and Gradient-Flooding as dual analogies. The other five process analogies are new process analogies of heat conduction found in this study. These other five process analogies are: Stacking as fundamental analogies; Gradient-stacking, Marching-Flooding, Marching-
Melting, and Stacking-Flooding as dual analogies. Different to other fundamental analogies from Chiou [1], Stacking analogy is a new analogy in which heat conduction proceeds in a gradually increasing fashion. If we see in detail, this analogy is inversely proportional to gradient analogy. In this analogy, in the first phase of heating, heat is stacked in point B, and in the last phase of heating, heat is gradually stacked in point C (in the end of the rod). Therefore, based on this analogy, point C will be the highest temperature compare to other points (A and B). There is only one student who is in this analogy of heat conduction.

First new process dual analogy is Gradient-Stacking. This analogy combines the gradient analogy and the stacking analogy. In this conception, at the beginning stage of heat conduction, heat conduction proceeds as the progression of a gradient analogy. That is, the quantity of heat in an object gradually declines in proportion to the distance between a specific location and the heat source. Afterward, heat conduction continues as a stacking analogy in which heat is stacked in point C, the edge of the rod. Therefore, C is the highest temperature. The second new process dual analogy is Marching-Flooding. In this analogy, at the beginning stage of heat conduction, heat conduction proceeds as a step-by-step march. After entering an object, heat steps ahead unitarily and regularly toward the other end while a region swept by the marching heat reach thermal equilibrium immediately.

In the last stage of heating, heat conduction then continues as the flooding analogy in which the transmitted heat is immediately and evenly spread throughout the object and it reach thermal equilibrium throughout the rod. The third new process dual analogy is Marching-Melting. In this analogy, heat first proceeds in marching analogy for a transient phase and then continues in melting in the last phase of heating. There is one only student who is in this analogy. She thought that after heating-process, the aluminum rod is started to melt. The fourth new process of dual analogy is Stacking-Flooding. In this analogy, heat first proceeds in stacking analogy for a transient phase in which heat conduction proceeds in a gradually increasing fashion and then continues in flooding analogy. Therefore, in the last phase of heating, all part of the rod reaches thermal equilibrium.

3.2. Implication to learning of introductory of physics
The findings of this research can offer some suggestions for reforming the learning related to the heat concept, Introductory of Physics Learning. Heat and Thermodynamics are the subject in Introductory of Physics. The weight of this part is The Laws of Thermodynamics. Heat transfer, especially the mechanism of heat conduction is rare to be learned deeply. Whereas, in high school both in Junior high school (7th-9th grade) and Senior high school (10th-12th), Heat transfer is a topic that must be learned in detail.

With respect to instructional practice, when teaching heat conduction, for instance, teachers should first provide guidance for students how to observe the effect of heat in solid e.g. metal both from macroscopic and microscopic view. Teachers also should provide the model of the atoms or molecules in solid or in matter when it is being heated. Through the model of the state of the atoms or molecules, students can be more comprehend of the meaning of temperature, hot and cold, heat, and heat transfer. The meaningful learning can be achieved when teachers require the students to observe the phenomena that they are familiar with. Furthermore, they show the microscopic state of the matters. So, Physics teachers must provide the model of the microscopic state of the matters. Model based learning is now relevant and necessary with Physics learning.
4. Conclusion

Based on the results and discussion, it can be concluded that there are several new process-analogy of heat conduction. The new process analogy as one of students’ mental model, reinforces the fact that there are many variations of the student's mental model in heat conduction. The findings in this study show more differences than the analogy process that Chiou found. This encouraged us to create a new

### Table 1. The process analogies of heat conduction.

| Analogy       | Description                                                                                                                                  | Progress of State change | Students in This Process Analogy |
|---------------|-----------------------------------------------------------------------------------------------------------------------------------------------|--------------------------|----------------------------------|
| Marching      | Heat conduction proceeds as a step-by-step march. After entering an object, heat steps ahead unitarily and regularly toward the other end. While a region swept by the marching heat reach thermal equilibrium immediately with the anterior region, the region beyond the marching heat remains thermally unaffected. | (i) A=B=C (ii) A>B=C (iii) A=B>C | S5 (1)                          |
| Flooding      | Heat conduction proceeds as a gradual rising flood. After entering an object, heat is instantaneously and evenly distributed throughout the object. The temperature of the whole object increases at a constant rate till thermal equilibrium is reached. | (i) A=B=C (ii) A=B=C (iii) A=B>C | S2, S19, S20 (3)                |
| Gradient      | Heat conduction proceeds in a gradient fashion. After entering an object, heat rushes forward dispersedly, and the amount of transmitted heat gradually declines along the object. Temperatures at different regions of the object increase in inverse proportion to the distance between the region and the heat source. | (i) A=B=C (ii) A>B>C (iii) A>B>C | S4, S6, S21, S25, S28, S31 (6)  |
| Stacking      | Heat conduction proceeds as a step-by-step stacking. After entering an object, heat steps toward the other end and stack in each point. In the first phase of heating, heat stack in central point of rod. In the second phase of heating, all heat particles stack in the end of rod. The highest temperature is reached by the end of the rod. | (i) A=B=C (ii) A<B>C (iii) A<B>C | S7 (1)                          |
| Gradient-marching | Heat first proceeds in gradient analogy for a transient phase and then continues in marching analogy                                           |                          | - (0)                           |
| Gradient-Flooding | Heat first proceeds in gradient analogy for a transient phase and then continues in flooding analogy                                         |                          | S9, S12, S13, S14, S15, S18, S22, S23, S24, S26, S27, S30 (12) |
| Gradient-Stacking | Heat first proceeds in gradient analogy for a transient phase and then continues in stacking analogy                                      | (i) A=B=C (ii) A>B>C (iii) A>B>C | S3 (1)                          |
| Marching-Stacking | Heat first proceeds in marching analogy for a transient phase and then continues in stacking analogy                                      | (i) A=B=C (ii) A>B>C (iii) A>B>C | S8, S11, S16, S17 (4)           |
| Flooding      | Heat conduction proceeds in different analogies at different stage.                                                                           |                          | S29 (1)                          |
| Marching-Melting | Heat first proceeds in marching analogy for a transient phase and then continues in melting                                                |                          | S1 (1), S10 (2)                 |
| Stacking      | Heat conduction proceeds in different analogies at different stage.                                                                           |                          |                                  |
approach in teaching the concepts of heat and heat conduction. Model-based instruction is an alternative to the instruction model that facilitates the construction of a scientific mental model.

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References
[1] Tipler P A and Mosca G 2004 Physics for Scientists and Engineers, 5th Edition, Extended (New York: WH Freeman and Company)
[2] Chiou G L and Anderson O R 2010 Sci. Educ. 94 825
[3] National Research Council 2013 Changing World-Challenges and Opportunities in Undergraduate Physics Education (Washington DC: The National Academic Press)
[4] Amalia R, Sari I M, and Sinaga P 2017 J. of Physics: Conf. Series 812 012092
[5] Chiou G L 2013 Phys. Rev. Spec. Topics-Phys. Education Research 9
[6] Greca I M and Moreira M A 2002 Sci. Educ. 86 106
[7] Greca I M and Moreira M A 2000 Int. J. Sci. Educ. 22 1
[8] Sari I M and Rusdiana D 2017 J. of Physics: Conf. Series 812 012090
[9] Redish E F (1994) American J. of Physics 62 796
[10] Sari I M and Saepuzaman D 2016 Proc. Int. Conf. on Innovation in Engineering and Education (ICIEVE) Published by: Atlantis Press doi: 10.2991/icieve-15.2016.48
[11] Yeo S and Zadnik M 2001 The Physics Teacher 39
[12] Pathare S R and Pradhan H C Physics Education 45
[13] The Ministry of Education and Culture 2013 (Republik Indonesia)
[14] Frederik I, Valk T V D, Leite L, and Thoren I 1999 European Journal of Teacher Education 22 1
[15] Lindell R S 2001 Enhancing College Students’ Understanding of Lunar Phases (Nebraska: University of Nebraska)
[16] Vosniadou S and Brewer W F 1995 Cognitive Science 18 123