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Identification of mental model and prediction of class XII high school students on the topic of convection heat transfer

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Abstract: Mental models have an important role in the learning process because learning in general can be seen as mental modeling. The purpose of this study is to identify students' mental models and identify the relationship between mental models and prediction ability on the topic of convection heat transfer. The sample of this study was 15 on 12th-grade high school students, 8 male students and 7 female students. The students came from three different schools, namely from Tasikmalaya district, Ciamis district, and Banjar City. Sampling was done by purposive sampling with the characteristics of students who have studied heat and students who have high cognitive process abilities in their respective schools. Data collection was done by semi-structured interviews with the type of questions in the form of content and prediction. Data analysis is done by constant comparative method. The results of this study show that there are no students who have a scientific mental model. Five types of mental models were found, including unclear model, convection is a continuation of conduction, convection that does not change density, convection for evaporation, and model 3. In addition, the relationship between prediction and mental model was classified as complex. This is due to students who predict without using their mental models. Knowing the diverse mental models of students, educators become more knowledgeable about the level of representation of each student. So that educators can prepare appropriate learning strategies in order to construct students' mental models.
Keywords: mental model; prediction; convection heat transfer

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Introduction

The main goal of physics education is to help students to build scientifically compatible mental models (G.-L. Chiou, 2013; Zuccarini & Malgieri, 2022; Kraus, 2023). To achieve this goal, identifying and analyzing the mental models that students have in understanding knowledge construction is a key step (Lehmann et al., 2020) . One can use a mental model to estimate and explicate novel phenomena. Additionally, the main objective of physics education is to assist students in evolving a mental model that is steady with science (Sari, 2017). Mental models are people's representations of physical phenomena or systems that are similar to the external ones in terms of construction (Bryce & Blown, 2016; Kokkonen, 2017) . Representation skills can help students understand the concepts they learn (Masrifah & Amiroh, 2023). A person who has a good mental model will have a good understanding of the material as well.

Research on mental models has factually been under the view of cognitive psychology, which aims to study how people grasp, acquire, and remember things (Priyadi et al., 2019; Rook, 2013). In order to evaluate outside data and make decisions, a person needs mental models to support their

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explanatory and predictive roles (Li et al., 2022). Through assessment, particulars about the pupils' mental models could be found (Priyadi et al., 2019). A few common methods of evaluating mental models include verbal analysis, open-ended questions, and interviews (Johnson-Laird, 2013; Priyadi et al., 2019). Mental models are derived from previously learned knowledge structures and influence newly learned information (Vosniadou & Brewer, 1992; Amalia et al., 2017; Krebs et al., 2021). The pupils' changeable levels of metal model possession suggest that they may comprehend physics ideas at varying levels, these differences ought to be the primary focus of any prior learning initiatives (Priyadi et al., 2019) .

Physics materials that are closely related to everyday life such as temperature and heat, global warming, electricity etc (Karo-Karo et al., 2021). The concept of temperature and heat is a topic that students learn from elementary school to university. Every physics student should hold the fundamental idea of heat and heat transmission as it is so important (Sari, 2017) . In high school, this topic is usually not discussed to a microscopic point of view. It is an important topic for students to learn in order to understand the topic of heat thoroughly from microscopic to macroscopic perspectives. Analysis of mental models on the topic of heat has been done by several researchers (G. Chiou & Anderson, 2010; Shepardson et al., 2011; G.-L. Chiou, 2013; Sari & Saepuzzaman, 2016) .

Heat transfer examines conduction, convection, and radiation. Even though most students comprehend the scientific principles of heat convection on a macroscopic level, they frequently struggle to put those principles into visual form. Research investigating the mental model of convection heat transfer has been conducted by (G.-L. Chiou, 2013) . The investigation was shown semi-structured interviews on 30 physics students who have established thermodynamics courses, the results showed the presence of seven mental models of students who have studied heat (1) diffusion-based convection model; (2) gradual-expanding convection; (3) Evenly distributed convection; (4) warmness-topped convection (I); (5) Warmness-topped convection (II); (6) Rim-circulated convection; (7) Fluent-cycled convection. The illustration of each model can be seen in Figure 1. In addition to the students' mental models, this study identified students' prediction ability and looked at the relationship between mental models and prediction ability. The results showed that the relationship between mental models and prediction ability was classified as complex. This is because the majority of students do not use their mental models to predict the phenomenon of conduction heat transfer.

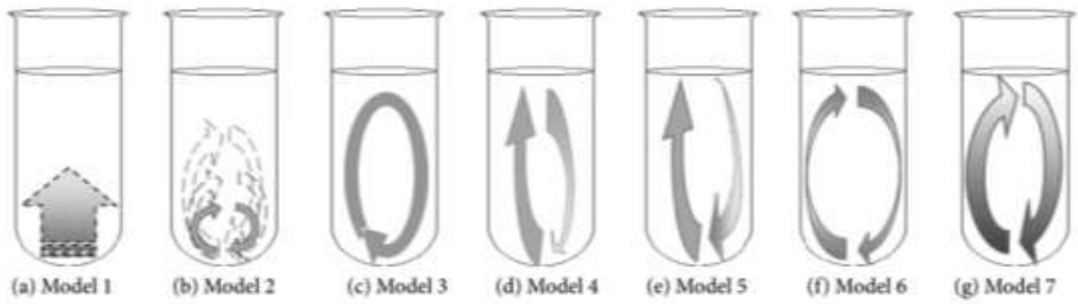


Figure 1. Illustration of Convection Mental Model (Chiou, 2013)

Other studies that refer to research G.-L. Chiou (2013) regarding the identification of mental models of heat transfer by convection, namely (Sari & Saepuzzaman, 2016). The study used a sample of physics education students in semester 3, 5, 7 and freshgraduate. The results of the study found 7 mental models owned by students (1) diffusion-based convection model; (2) gradual-expanding convection; (3) Evenly distributed convection; (4) warmness-topped convection (I); (6) Rim-circulated convection; (7) Fluent-cycled convection; and (8) Unclear Model. The new mental model found in this study is the unclear model where students are classified as having an unscientific mental model, this model is owned by one student in semester 3 and one student in semester 5. In addition, this study also identified the relationship between mental models and also students' prediction ability, the results showed that there was a complex relationship between mental models and prediction ability. This is because students do not use their mental models to predict the phenomenon of convection heat transfer.

The topic of convection heat transfer is studied by students from elementary school to university. The results of two previous studies on the identification of mental models of students who have studied heat show a variety of mental models owned. The identification of this mental model needs to be done in senior high school students. Heat transfer is an important study because of its universal application, playing a role in all sciences and technology. Heat transfer plays an important role in living and non-living things (Venkateshan, 2021). In this level, the topic is said to be a basic topic that has a lot to do with everyday life that needs to be understood by students. By knowing the mental models owned, it is hoped that in the future it can minimize students having unscientific mental models.

From the background that has been reviewed above, the researcher focuses on identifying the mental models of high school students who have learned the concept of heat. This study aims to investigate the representations that senior high school students have regarding convection heat transfer. This research is based on the importance of analyzing the mental models possessed by senior high school students who have studied convection heat transfer. This is of particular urgency as an in-depth understanding of learners' mental models can provide valuable guidance for educators in designing effective learning strategies. By understanding the variety of mental models that learners may have, educators can adjust their learning approach to overcome any difficulties or misconceptions that may arise.

Previous research conducted by G.-L. Chiou (2013) and Sari & Saepuzzaman (2016)have reviewed mental models and predictions related to the topic of convection. However, the research subjects in those cases were students at the college level. Therefore, the importance of this study lies in the different research subjects used, namely high school students. By using a different subject, this research has the potential to generate valuable new insights, as high school students have unique learning characteristics.

High school students often still have a limited understanding of the topic of convection heat transfer. Therefore, this research can help in identifying new mental model criteria that may not have been revealed before. By understanding the mental models that exist among Senior High School learners, educators can develop more effective learning approaches that suit their needs. Thus, this study has significant implications in improving the quality of learning at the senior high school level, as well as expanding our understanding of how the concept of convection heat transfer is understood and represented by learners at that level of education.

In this context, mental models refer to the understanding, mental images, and cognitive constructions that students have about the concept. This research will attempt to map the extent to which students understand, apply, and represent the phenomenon of convection heat transfer in the context of learning. This is expected to provide in-depth insight into the difficulties or misconceptions that students may have, as well as enable the development of more effective learning strategies in explaining the concept of convection heat transfer to Senior High School students.

Method

Participants

This interview was conducted in 3 different high schools in the East Priangan area, namely Ciamis Regency, Tasikmalaya Regency, and Banjar City. Each school was represented by five Grade 12 students. Interviews were conducted with a total of 15 students face-to-face and recorded interviews using a cell phone. This research was conducted on November 23 - December 5, 2023. The length of interviews with participants averaged 30 - 45 minutes for each participant. Sampling using purposive sampling with the criteria that students have learned about the topic of temperature and heat and have high cognitive process skills from each school*, these* criteria are seen from the acquisition of rank 1-5 which is a recommendation from the physics teacher from each school. This study is qualitative research to explore the knowledge, the predictions and mental models held by participants regarding convection heat transfer. A series of interview questions were developed to explore participants' mental models by asking them to make predictions and explain phenomena related to convection heat transfer.

Research Instruments

The interviews were semi-structured. The research instrument used is an interview protocol that refers to the research of (Chiou, 2013). The interview protocol contains content knowledge, predictions, and asks for confidence regarding the answers that have been given. Content knowledge in the form of questions "what is convection?, what examples in everyday life are classified as convection heat transfer?", how does the convection heat transfer process occur?".

Figure 2. Convection phenomenon that occurs in a tube heated from below

Figure 3. Convection phenomenon that occurs in a tube heated from the middle

Figure 2 and Figure 3 are illustrations for prediction questions adapted from Chiou (2013). The figure 2 dan 3 needs to be shown to participants so that participants know the visualization of the difference in phenomena. Then the interviewer asked "Tubes 1 and 2 have the same fluid type and volume. Which one do you think will boil first? Give your reasons!". Finally, the interviewer asked "*Are you sure about your answer? Is there anything you want to change?".*

Data Analysis

Data analysis is by constant comparative method, this data analysis refers to qualitative data analysis that has been done by (G.-L. Chiou, 2013) . Data analysis focuses on exploring the mental model and predictive ability of students. First, analyzing the results of students' interviews regarding the concept of convection heat transfer that they understand is done to determine the level of modeling of each individual. Figure 4 show a framewok to distinguish between different types of models.

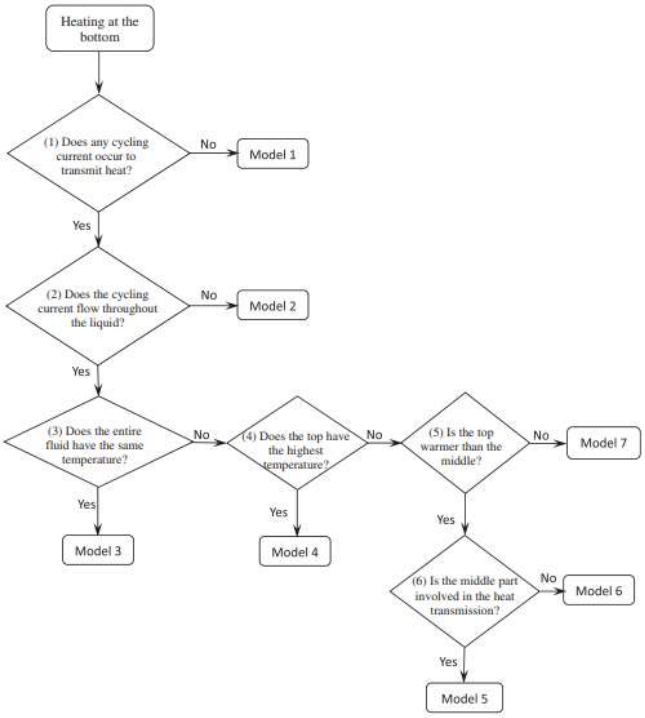


Figure 4. A framework for differentiation seven models

Results and Discussion

This section will discuss the findings of the data obtained by face-to-face interviews. The identification of students' mental models refers to research conducted by (Chiou, 2013) and (Sari & Saepuzzaman, 2016). In Chiou's research (2013) mental models were grouped into 7 models with their types, namely (1) diffusion-based convection model; (2) gradual-expanding convection; (3) Evenly distributed convection; (4) warmness-topped convection (I); (5) Warmness-topped convection (II); (6) Rim-circulated convection; (7) Fluent-cycled convection. Starting with model 1 which is classified as a nave model and ending with model 7 which is scientifically compatible. For research conducted by Sari and Saepuzaman (2016), the grouping is the same as Chiou (2013), except that a new mental model is found, namely the Unclear Model.

Mental Model of Convection Heat Transfer

The findings from this interview found 5 groups of mental models. Of the mental models found, no students have model 7 or the scientific model. Model 3 is owned by 4 students, unclear model is owned by 1 learner. There is a new discovery in this research, namely students who think that convection is a continuation of conduction, this model is owned by 3 students. Furthermore, convection is a result of energy transfer only owned by water bubbles that does not involve a change in the volume of the water, this model is owned by 4 students. Another model found is Convection occurs for evaporation to occur, this model is owned by 3 students.

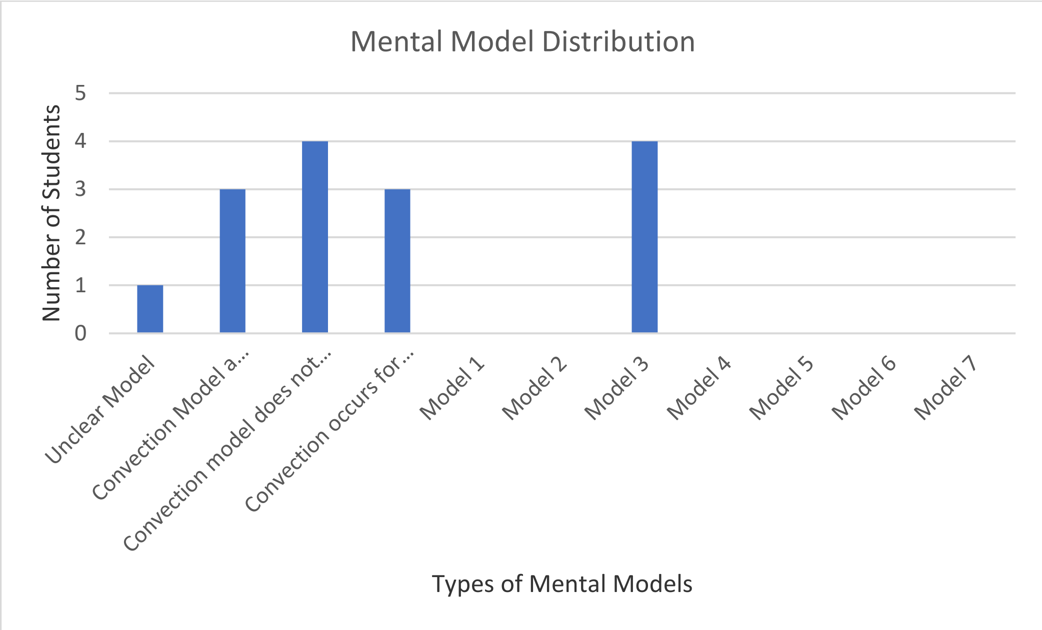


Figure 5. Distribution of Mental Models

The following table provides an explanation of each mental model categories :

Table 1. Description of Categories Mental Models

Categories	Description
Unclear Model	Students have no representation of convection
Convection a continuation of Conduction	This model is formed in students who assume that boiling water is the effect of conduction that occurs in the pan used.
Convection that is not followed by density change	This model is formed by students who assume that the bubbles moving upwards are a result of heat transfer alone without involving changes in particle density.
Convection for evaporation	This model is formed in students who assume that water particles will move towards cooler areas and eventually the particles will become vapor.
Model 1	Heat transmission resembles diffusion, where heat transfer from hotter to cooler areas without the movement of flow. The highest temperature occurs near the heat source and drops slowly with distance from the source.
Model 2	Initially, there are only small lap currents at the bottom of the liquid, which then develop and extend gradually to the water surface. The temperature inside the cycle region remains stable, while the temperature outside the region remains unchanged.
Model 3	Once heating starts at the bottom of the liquid, the spin current immediately spreads throughout the liquid, evenly distributing the heat from the heat source. As a result, the temperature becomes uniform throughout the liquid.
Model 4	Once heating starts at the bottom of the liquid, the spin current immediately starts flowing upwards, absorbing heat without releasing it. When it reaches the top, the current sinks and releases heat as it descends to the bottom. As a result, the upper liquid has the highest temperature.
Model 5	The cyclical current flows immediately after heating begins at the bottom of the liquid, absorbing heat without releasing it as it rises upwards. Upon reaching the top, the current begins to descend and releases heat as it returns to the bottom. The heat remains concentrated at the bottom, so the liquid there has the highest temperature, while the upper liquid has the second highest temperature.
Model 6	The cycling current immediately flows along the periphery of the container once heating starts at the bottom of the liquid; the center is not involved. The cycling current absorbs heat from the bottom, rises to the top, then drops back down. In each

	cycle, the current does not affect the center of the liquid; it only moves around the periphery of the container. As a result, the bottom has the highest temperature, the top second, while the temperature of the center remains stable.
Model 7	The cyclical current flows immediately after heating begins at the bottom of the liquid. The cyclical current absorbs heat from the bottom of the liquid and rises upwards, releasing heat along its journey. Upon reaching the top, the current begins to descend again, absorbing heat from the surroundings. As a result, the liquid at the bottom has the highest temperature, while the temperature gradually decreases towards the top.

Of the 11 mental models that have been found from these findings and previous research can be classified for mental models unclear model, convection a continuation of conduction, convection that is not followed by density change, convection for evaporation is an unscientific mental model and for model 7 is a mental model that is close to a scientific mental model (Sari and Saepuzaman, 2015). Unscientific mental model occurs because students have a wrong basic conception.

Here are some excerpts of interviews with students from each mental model representative :

Unclear Model

Unclear model is found in S9 students who are not able to explain the process of convection. When the interviewer asked about the convection process:

I : What do you know about convection?
S9 : Heat transfer that occurs in the fluid
I : Can you give an example?
S9 : Heating water
I : What is the process of the water boiling?
S9 : I don't know about the process, but when it boils, there will be evaporation.

The learner only knew the general definition and example of convection without knowing what he meant. Learners who have this mental model have no conceptual basis at all regarding convection heat transfer.

Convection is a Continuation of Conduction

This model is formed in students who assume that boiling water is an effect of conduction that occurs in the pot used. They assume that only conduction has an effect on convection. The following is a conversation with one of the students:

I : What do you know about convection?
S6 : The occurrence of boiling water
I : What is the process of convection in boiling water?
S6 : What is heated under the pot, the pot will be hot. As the heat spreads to the top of the pot, the water will get hotter too.
I : Are there any other factors that make water boil?
S6 : No, because what makes the water boil is just the rim of the pot heating up.

Students who have this model are S6, S7, and S14. Learners are still affected by their knowledge on the topic of conduction so that they assume that convection only occurs due to a hot container so that the water becomes hot.

Convection That is Not Followed by Density Change

This model is formed in students who assume that the bubbles that move upwards as a result of heat transfer alone do not involve any increase or decrease in the volume of water due to heating. The following is the result of an interview with one of the students:

I : What do you know about convection?
S8 : The same heat transfer of the substance moves. For example, like heating water, the particles that are heated initially at the bottom will move to an area with a lower temperature above the cold particles will be encouraged to move to a hotter area. The cycle occurs continuously.

I : Are there any other factors that cause the particles to move as described?
S8 : As far as I know, it's only because of the temperature difference.

Students believe that particles can move upwards only as a result of heat transfer because heat moves from higher temperatures to lower temperatures or vice versa. Students who have this model are S1, S2, S8, S14.

Convection for Evaporation

This model is formed in students who assume that water particles will move towards colder areas and eventually the particles will become vapor. They assume that the temperature at the bottom and then moving upwards has the same temperature. The following is the result of an interview with one of the students:

I : Can you explain what you mean?
S10 : Suppose this is a pot, then this water is heated by fire. This water will have bubbles, the water was cold and then heated to heat, then there is a reaction to appear bubbles.
I Where does the heat come first?
S10 : the one below
I : Why does the top water also boil?
S10 : From bottom to top because the heat transfers from high temperature to low temperature, the temperature below and the temperature above will be the same.
I : If it's above that, what about the particles?
S10 : It will evaporate, it will continue like that from the bottom heated and then evaporate.

Students who have this model are S10, S12, S13. Learners who have this understanding assume that the particles in the water move upwards directly into vapor. This happens because learners may have limited or inappropriate prior experience with the concepts of evaporation and convection. They may have seen water boiling on a stove and witnessed steam rising into the air, and this may affect their understanding of the phase change process from water to steam.

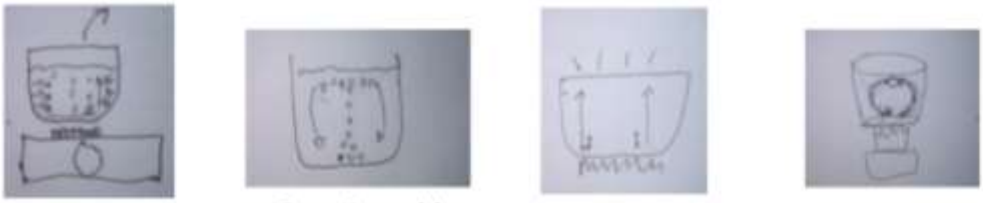
Model 3

This model is based on the reference model Chiou (2013)This model assumes that the flow of the water cycle starts when heating from below and then the heat is distributed to each part of the water and the parts have the same temperature. The following is the result of an interview with one of the students:

I : How is convection related to boiling water?
S3 : When water is heated, there will be heat transfer where hot particles will move to cooler areas. For a long time the one above will move to the hot area, continuously repeating like that.
I : You mentioned that the bottom area heats up first, will the particles moving up have the same temperature as the bottom?
S3 : Yes, but it happens in some time, because it will reach thermal equilibrium. In the beginning, the lower particles were hot first.

Students who have this model are S3, S4, S5, S15. Participants who have model 3 may believe that when heating starts, convection currents will quickly spread throughout the liquid. They may also believe that convection currents will even out the distribution of heat energy within the liquid, causing the liquid temperature to become uniform throughout the system. Thus, in their view, model 3 includes three alternative conceptions related to the causal or spatial relationships between different components or parts in a convection system (Chiou, 2013).

The following is a visualization made by students about convection:



Convection Model a continuation of conduction

Convection model does not involve changes in water volume

Convection for evaporation

Model 3

Figure 6. Visualization of Learner Convection

From the results previously presented, it shows that almost all students still have a non-scientific mental model. Students have an internal representation of the topic of convection only to the extent of knowing the theory conveyed in learning without knowing the meaning of the definition and theory. As is known from the students' answers regarding the definition of convection, one of them said *"the process of heat transfer that occurs due to particle transfer"* from the question after being asked further about *"what do you mean by particle transfer in convection?"*. Students have not been able to answer the question scientifically. This happens because students assume that this heat flows spontaneously without involving particle movement due to changes in density in water molecules that already have an increase in temperature.

Students Prediction

It was found that 6 students predicted that tube 1 boiled first, 4 students who predicted that tube 2 boiled first, and 5 students who predicted the same time. Table 2 show the distribution of students' predictions.

Table 2. Distribution of Predicted Students

Students Code	Gender	Tube 1	Tube 2	Same
S1	L	1		
S2	P		1	
S3	L			1
S4	L			1
S5	L			1
S6	L		1	
S7	L	1		
S8	P		1	
S9	P	1		
S10	L			1
S11	L	1		
S12	P		1	
S13	P	1		
S14	P	1		
S15	P			1

From the distribution it is known that S1, S7, S9, S11, S13, S14 predict that tube 1 will boil first. Students S2, S6, S8, S12 predict that tube 2 will boil first. Students S3, S4, S5, S10, S15 predicted that the time would be the same. The correct prediction is that tube 2 will boil first. The 4 students who predicted correctly gave reasons that did not use their mental models. Students tend to guess their predictions. Here are the reasons the four students chose tube 2.

Table 3. Reasons for Learner Prediction to Chose Tube 2

Student Code	Description
S2	Tube 2, because it is closer to the air. The boiling becomes faster. Tube 1 has a lot of water so it takes a long time to boil.
S6	Tube 2, right from the center is heated, bubbles will appear, because the distance is close, it will boil faster because the heated place is close to the surface.
S8	Because tube 2 has a large surface to be heated than tube one which is below, so it will make hot water faster.
S12	Tube 2, because it is closer to the surface so the bubbles quickly reach the top.

The explanations given by the four students tended to rely on reasoning because the distance between the heat source and the surface was closer so the boiling would be faster. The results of previous research Chiou (2013), Sari and Saepuzaman (2015) support this finding that some participants in the study assumed that tube 2 boils faster due to less water at the top than the water under the fire so that convection currents occur and make the water boil quickly, so it is not only high school students who assume that it turns out that college students also exist. Chiou (2013) explains that the most appropriate explanation for the prediction is the rapid boiling of tube 2 due to convection and conduction. So that in this study students still do not have scientific explanation skills.

Relationship between Mental Models and Prediction

The following graph presents the relationship between students' mental models and predictions:

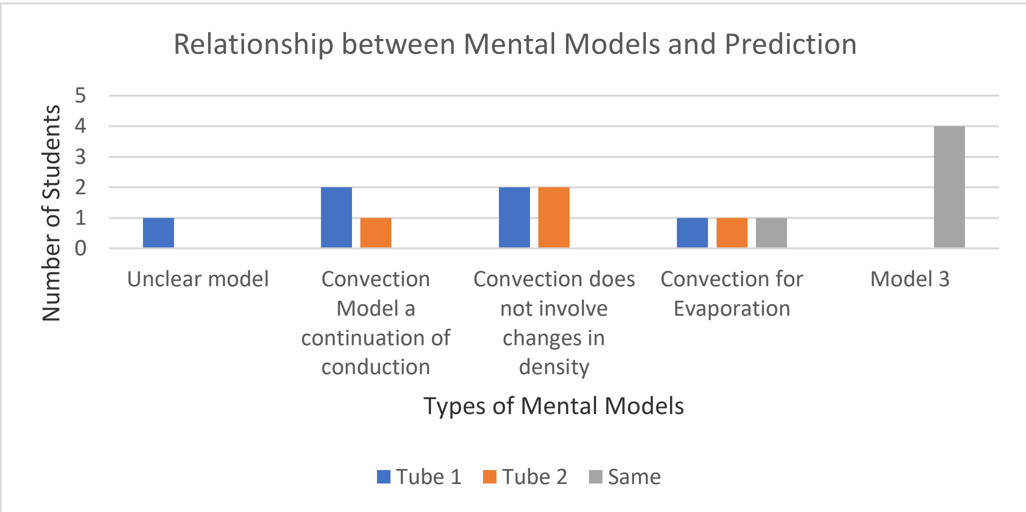


Figure 7. Relationship between Mental Model and Prediction

Ideally, students who have a good mental model will use their mental model to explain the prediction of a phenomenon (Sari & Saepuzzaman, 2016; Dauer et al., 2019). Students who have unclear models predict that tube 1 will boil. Students who think convection is a continuation of conduction 2 predict tube 1 will boil first and 1 predicts tube 2. Students who thought that convection does not involve a change in water volume 2 predicted tube 1 and 2 predicted tube 2. Students who had model convection for evaporation, 1 predicted tube 1, 1 predicted tube 2, and 1 predicted the same time. All students who had Model 3 predicted that the water in the tube would boil in the same time, this was also found in the research of Sari & Saepuzzaman (2016). This relationship can be considered a complex relationship (G.-L. Chiou, 2013; Sari & Saepuzzaman, 2016). This is because students' predictions are not based on their mental models and understanding. The predictions mentioned and explained by learners lead to guessed predictions. None of the learners had a mental model that was close to scientific so they did not use their mental modeling ability to answer the prediction and explain the prediction. This happens because learners do not have a good concept of heat transfer so their mental model and prediction skills are still low.

From a series of research that have been conducted, there are several things that can be developed by future research to be further developed. This research emphasized on qualitative research in future research should be combined with quantitative research to measure the criteria of participants' mental models. Furthermore, this research only discusses one topic of heat transfer, namely convection in the next research, it is best to add other topics of heat transfer, namely conduction and radiation.

From all of these findings, it shows that the mental models owned by students are not scientific so that they are not able to predict a phenomenon from the topic of convection. This finding also shows that the modeling ability of students is still low. To excel in physics studies, it's vital for students to grasp fundamental concepts so they can effectively tackle problems. To enhance students' conceptual understanding, teaching materials should be clear and accessible (Wahyuni et al., 2024). In addition, it is important that modeling is included in learning, so that students can know the visualization of a phenomenon. The existence of visualization makes students better understand a phenomenon and can form a scientific mental model.

Conclusion

Based on the findings in this study, of the 15 students who came from 3 different regions, there were 5 types of mental models found unclear model, convection is a continuation of conduction, convection that does not involve densiy change, convection for evaporation, and model 3. No students were found to have a scientific mental model. Predictions given by students are not based on their mental models and understanding, they only explain according to practical thoughts (guesses). So that to improve the mental model of students can be done learning that encourages to construct mental models and understanding of students on the topic of heat. By understanding the varied mental models held by students, educators gain insight into the extent of each student's representation. This equips educators to tailor learning strategies accordingly, facilitating the construction of students' mental models.

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