

# Thai High School Students' Understanding of Heat and Thermodynamics

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## ABSTRACT

This research focused on Thai students' conception involving heat and thermodynamics. Twelve Thai students were interviewed to determine the way they thought about heat energy, temperature, heat transfer, thermal properties, insulators, conductors and thermal equilibrium through everyday thermal situations. The compiled data from the interviews were used for developing a Heat and Thermodynamics Concept Questionnaire (HTCQ) which administered to 214 students from three high schools in Bangkok. The HTCQ findings revealed that most of the students lacked the understanding of heat and thermodynamics concepts. For example, at least 84% of the students lacked the understanding of absolute temperature. Most of the students defined temperature as a variable that can be measured and heat was a sensation. Only 10% of the students understood that heat is extensive quantities. The results showed that even the Thai students had a good understanding of insulators and conductors, but they could not apply their understandings to identify the appropriate materials to keep hot/cold things. This study indicated that the Thai high school students held similar alternative conceptions of heat and temperature to the western students. Many students gave the correct answers by referring their everyday experiences but they had problems with giving reasons and consistent predictions. Two fundamental ideas about the Thai students learning heat and thermodynamics were generated: 1) students' understandings are supported by the likeness between personal experiences and scientific conceptions and 2) students' alternative conceptions are reinforced by contrasting their personal experiences and scientific conceptions. This study indicates that students should be presented with heat and thermodynamics concepts along with thermal situations, and be able to identify contrasts and comparisons between them.

**Key words:** physics, alternative conception, science concept, Thai students

## INTRODUCTION

Heat and thermodynamics are the important topics of learning physics because they are fundamental concepts for modern Physics areas such as energy and mechanics and they are applicable in many fields of Physics, Chemistry

and Technology. The most importance is that these concepts can be useful for students both in daily work and life. However, many students still face some difficulties in understanding the heat and thermodynamics (Driver, 1989; Linn and Songer, 1991; Lewis and Linn, 1994; Harrison *et al.*, 1999). One of the most difficult problems encountered

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by students is the difference between heat and temperature (Erickson, 1979; Wiser and Carey, 1983; Linn and Songer, 1991). Some students are able to make correct statement such as heat and temperatures are different. However, they often admit to being unclear about their ideas. For example, temperature is a measure of the mixture of heat and cold inside an object (Erickson, 1979) and is a variable that can be measured and/or quantified whereas heat can not be. Even high school students have much difficulty with heat energy concepts and the difference between heat and thermodynamics (Kesidou and Duit, 1993).

The difficulties in learning thermodynamics are that the students frequently fail to take all parts of the interacting thermal system into a correct explanation about heat flow, and they may also ignore the surroundings (Tiberghien, 1985; Harrison *et al.*, 1999; Thomaz *et al.*, 2003; Clark and Jorde, 2004). Students do not always consider that objects in the same surroundings have the same temperature. Some researchers claimed that students lack the understanding to explain heat transfer processes. The students mention processes rather than conductions (e.g., absorption, reflection, or attraction) for describing heat transfer (Lubben *et al.*, 1998). Many students do not understand the intensive nature of temperature. Additionally, they can not predict the final temperature when two samples of water at different temperatures are mixed.

Many students are confused about insulators and conductors. For example, students thought that metal was a good insulator because metal could hold heat better than wood (very common alternative conceptions) (Newell and Ross, 1996), and that particular materials were good for keeping hot objects warm, but not good for keeping cold object cool (Lubben *et al.*, 1998). Eventhough students can make good predictions in terms of styrofoam being a better insulator than aluminium but they choose aluminium foil over styrofoam for keeping cold things cool (Lewis and

Linn, 1994). Students are more likely to express alternative conceptions when explaining real situations (Yeo and Zadnik, 2001). Deejaras (2002) had conducted a research on Thai Grade 12 students' physics application for daily life. He found that the students had a low level of accomplishment in physics dealing heat and thermodynamics.

There are many students' difficulties in learning of heat and thermodynamics from many research studies in western countries, but rarely research done in Thailand. It seems unclear that the western students' understanding and their difficulties in learning heat and thermodynamics are similar to or different from the Thai students'. Therefore, this study aimed to investigate Thai high school students' conceptions, alternative conceptions dealing with heat and thermodynamics in the existing teaching and learning of heat and thermodynamics. Specifically, the research sought to address the following research questions:

1. What scientific conceptions do high school students hold for heat and thermodynamics?
2. What alternative conceptions do high school students hold for heat and thermodynamics?

## METHODOLOGY

This research is a survey research based on an interpretive paradigm. The interpretation in this study sought to determine students' answers and responses to a purposive questionnaire. The study employed a combination of qualitative and quantitative methods which allowed a deeper understanding of the way students thought of scientific concepts and the reasons of holding conceptions through thermal situations.

### Sample

The participants were 214 high school students from six classes in three high schools in Bangkok who had completed learning the heat and thermodynamics concepts in the 2004 academic year.

## Research instrument

This study attempted to determine students' understanding of heat and thermodynamics on the large scale. Heat and Thermodynamics Concept Questionnaire (HTCQ) was constructed by following the steps of constructional process of the multiple choice questionnaires which were suggested by Robbins (1998). The HTCQ consisted of one open-ended and nineteen multiple-choice questions, which were developed from both interview data and the literature review. They are described as following:

*Step 1: Stating of purpose;* this questionnaire used for investigating students' alternative conceptions of heat and thermodynamics. Most of questions are situated in everyday contexts;

*Step 2: Defining relevant variables;* the test specification was prepared in consistent with the IPST physics textbooks and learning objectives;

*Step 3: Developing questions;* review the previous research studies focusing on students' alternative conceptions. Twenty open-ended questions were adapted from the literature and generated by the first researcher. These questions were used for interviewing students. The content validity of the interview questions was checked by three experts (one scientist, two science educators). The purpose of each interview question is listed as below.

- Question 2 was original from Yeo and Zadnik (2001) and Question 4, which was an open-ended question, was adapted from Lewis and Linn (1994) which sought students' conception of absolute zero temperature and the differences between heat and temperature respectively.

- Question 3 was generated by the first researcher and Question 15 was adapted from Harrison *et al.* (1999) which aimed to assess students' understanding of the factors of heat energy.

- Question 5 was original from Yeo and Zadnik (2001), Question 6 was adapted from

Thomaz *et al.* (2003) and Question 7 was generated by the first researcher which aimed to investigate students' understanding of heat transfer which emphasized the process of heat transfer.

- Question 8 was generated by the first researcher and Question 9 and 10 were adapted from Lewis and Linn (1994) which looked at students' conception of conductors and insulators.

- Question 11, 12 and 13 were generated by the first researcher which aimed to investigate students' understanding of temperature and phase change.

- Question 14 and 16 were adapted from Lewis and Linn (1994) which looked at students' understanding of thermal equilibrium.

- Question 17 was original from Yeo and Zadnik (2001) and Question 18 was generated by the first researcher which aimed to investigate students' understanding of heat exchange.

- Question 19 and 20 were generated by the first researcher which aimed to investigate students' understanding of the second law of thermodynamics.

*Step 4: Constructing questionnaire;* the questions were brought to interview 12 high school students who had learned heat and thermodynamics in the 2004 academic year. The students were from two different schools, 6 students from each school. They were considerably chosen by their physics teachers; two low achievement students, two students average achievement and two high achievement students in physics subjects. The interviews took approximately 30-45 minutes for each student which were recorded and later transcribed by the researchers. The interview data was analyzed into four categories; Sound Understanding, Partial Understanding, Partial Understanding with Alternative Conceptions and Specific Alternative Conceptions. The analysis of the interview results by the researchers was reviewed by three experts. Then students' answers in the categories were used for creating multiple-choices of each question in the HTCQ;

*Step 5: Pretesting;* two pretests were conducted. The first pretest, the researcher gave to experts (two scientists and five educators) to critique and to offer suggestions. Once this had been done, the researcher made the necessary change and conducted the questionnaire pretest again with one class (39 students) at a high school in Bangkok. Once, the second pretest was completed, the researcher improved the questionnaire by adjusting the necessary change and rearranging questions.

### **Data collection and data analysis**

The HTCQ was administered to the sample. They could take approximately 45 minutes to complete this questionnaire. The questionnaire data was interpreted using a combination of qualitative and quantitative methods. In the quantitative analysis the number of students' responses in each category were calculated and reported as percentages.

## **RESEARCH FINDINGS**

This study identified eight main concepts of heat and thermodynamics that the students found problems with: heat energy, temperature, heat transfer, thermal properties, insulators, conductors and thermal equilibrium. The total scores of the heat and thermodynamics concept questionnaire were 20 marks. The results of 214 high school students collected by using the HTCQ indicated that 167 students (80%) received 0-5 marks and 47 students (20%) received 6-9 marks. Obviously, no one could obtain scores higher than 50% of the HTCQ's full scores. From the result, it seems like most of the students lacked the understanding of heat and thermodynamics concepts. The details of students' responses in each concept of heat and thermodynamics were described as below.

### **Heat and temperature**

Students were provided a situation that

someone talked to students that 'I saw physicists make super-conductor magnets, which were at a temperature of  $-300^{\circ}\text{C}$ '. They were asked whether they believed in this situation or not. Fourteen percent of students did not believe in this sentence because they held correct understanding that a lowest temperature is at  $-273.15^{\circ}\text{C}$ , while 31% of students believed in this sentence because they understood that the lowest and highest temperatures had no limit. Twenty one percent of students thought that  $-168^{\circ}\text{C}$  of liquid nitrogen was the lowest temperature. Hence, at least 84% of students still lacked the understanding of absolute temperature.

To seek students' conceptions of heat and temperature, students were asked to explain the terms of heat and temperature. Students' responses were classified as presented in the Table 1.

Nearly one third (30%) of the students could express some distinctions between heat and temperature. For example, "heat was an amount of energy and temperature was the measure of heat energy". Most of the students could express the single thermal distinction. For example, "heat was high temperature (16%) or a hot thing (17%) or sensation (14%)." or "Temperature was measured in degree or can be high and low". From the open-ended question, 12% of the students identified that there was no difference between heat and temperature. They gave several reasons to support their answers, such as "if a thing was hot with heat, it would have a high temperature", "high temperature made heat", "heat depended on the changing of temperature and time", or "both heat and temperature used the same unit; that was the degree."

### **Heat energy**

To assess students' understanding of heat energy, the students were asked to compare the amount of heat energy of two objects at different temperatures to specify the factors of heat energy. Two objects are made of the same material but have different mass. Only 10% of the students held

**Table 1** Students' understanding of the Words Heat and Temperature (n = 214)

Heat		Temperature	
Categories of response	% of students	Categories of response	% of students
Energy	30	Amount of heat energy	6
Hot thing	17	Measure or unit of heat	8
High temperature	16	Degree	39
Sensation	14	Heat	12
Heat is in the object	10	Temperature is the changing of air or surroundings	7
Amount of heat	6	Temperature can be high and low or hot and cold	24
Heat depends on time and is the changing of temperature per time	5	Temperature comes from the changing of heat or energy	5

correct understanding that heat energy is depended on not only specific heat capacity and temperature, but also the mass of the objects (Heat as intensity). While 57% of the students thought that the object that had higher temperature would have more heat energy and 24 % of the students thought that heat energy is depended on the specific heat capacity of objects only.

By changing the situation, students were asked to compare the amount of heat energy of two objects at 0°C in the freezer. The objects are made of the same material but have different sizes. The results showed that 23% of the students held correct understanding that heat energy is depended on not only specific heat capacity, but also the mass of the objects. However, 20% of the students thought that two objects that had different sizes (both were the same materials at 0°C) would have the same heat energy because both of them were in the same state. Twenty nine percent of the students thought that heat energy is depended on the specific heat capacity of objects, so that if both of them were made from the same material, they would have the same heat energy. Interestingly, 12% of the students still thought that specific heat capacity depended on the size of objects.

### Heat transfer

To investigate the students'

understanding of heat transfer which emphasized the process of heat transfer and thermal properties of materials, students were asked to predict the temperatures of metal and plastic chairs which are in the same room. Nearly 30% of the students thought that the metal objects feel colder than the plastic objects because they were heavier, 7% of the students thought that temperature was a property of a particular material or object, 24% of the students thought that metal had less heat to lose than plastic. Another 20% of the students tried to explain that metal objects are colder than the plastic ones because they could absorb heat more than plastics did. Just only 8% of the students held correct understanding that really materials both metal and plastic chairs were in the same surroundings. They were at the same temperature.

By changing the situation, the students were asked to predict the temperature of aluminium and wood strips which were put in the truck in the hot day. Forty three percent of the students thought that metal was hotter than wood because metal held heat better than wood did and 29% of the students thought that the metal could radiate heat better than wood did. However, 20 % of the students held correct understanding that the metal could conduct heat energy from their hands faster than wood did.

### Insulators

To seek students' understanding of good insulator and good conductors, students were asked to arrange materials from a good insulator to a good conductor; glass, ceramics, wood, metal, styrofoam and paper. After that, students' ability to use their understanding of conductors and insulators at an application level was identified. Students were asked to choose the best materials from glass, ceramics, wood, metal, styrofoam and paper which is suitable for keeping thing cool and keeping thing warm. Only 6.5% of the student held correct understanding that styrofoam could be used for keeping hot thing warm and keeping cold thing cool. While more than 63% of the students thought that each material was good for keeping hot objects warm but could not keep cold objects cool. At least 71% of the students thought that metals could attract, hold, or absorb heat or cold so that wrapping by using metal would be excellent for keeping hot thing warm and cold thing cool.

These findings showed that some students had a good understand that which material was a good insulator or a good conductor such as styrofoam being a better insulator, but they could not apply their understanding.

### Temperature and phase change

To investigate subjects' conceptions of temperature and phase change, each the student was asked to give a reason why a pressure cooker can cook faster than a normal cooker. Only 13% of the students held correct understanding the boiling point of water can be above 100°C. A half of the students thought that the high pressure made the molecules of gas getting smaller. Then, the small molecules helped heat in the pressure cooker to spread easier. Twelve percent of the students thought that the high pressure could generate extra heat and 19% of the students thought that the pressure cooker spread the heat more evenly through the food.

The students were provided a situation: equal amounts of water and oil (both are at the

same temperature) are heated by identical gas in the same time. When asked which liquid had higher temperature after 5 minutes, 22% of the student could give the correct answer and explanation. They thought that oil has higher temperature than water because the specific heat capacity of oil is lower than water. Nearly, 44% of the students could give the correct prediction but their explanations could not support their answers. They thought that the factors of temperature change were the density and boiling point of oil and water. Sixteen percent of the students identified that if they are put oil and water on the fire at the same time then they would receive the same amount of heat energy. They did not see that the water received more heat than alcohol to change the temperature.

### Thermal equilibrium

The students were provided a situation that they have stored two pieces of ice, which make of the same material but had different sizes, in the freezer for an hour. Students were asked to compare the temperatures of two pieces of ice and gave reasons to support their answers. Only 19 % of the students could give the correct prediction and explanation that both of them had the same temperature because both of them exchanged heat with the freezer until they were the same temperature with the surroundings. Over half of the students could give the correct prediction but their explanations could not support their answers. They thought that two pieces of ice would reach the same temperature because two pieces of ice made of the same material (16%) and two pieces of ice were in the same state (36%). While 28 % of the students gave the incorrect answer that the temperature of the big ice cube was higher than small one because it could contain more cold than small one.

The students were asked to explain the situation why the wrapped dolls in blankets never warm up. Twelve percent of the students held correct understanding that both the dolls and

blankets have no heat energy resources and are at the same temperature. About 57% of students identified that the wrapped dolls in blankets never warm up because the blankets were made of material which did not hold heat well; 13 % thought that blankets were poor conductors and 5% thought that the blankets used were probably poor insulators.

### Heat exchange

The students were asked to predict the final temperature of two samples which have different temperature after mixing. Thirty percent of the students could predict the final temperature when two samples at different temperatures were mixed. About 70% of them could not predict the final temperature. However, most of them understood that the final temperature cannot be higher than the temperature of two samples before mixing.

The students were provided a situation that one container of water and a half of container of alcohol, which are at the same temperature, are brought into contact. Only 8% of the students held correct understanding that both of water and alcohol lose the same amount of heat because water and alcohol were at the same temperature. While 41% of the students thought that water would lose the greatest amount of heat because water contained more heat energy than alcohol and alcohol was colder than water. Forty six percent thought that alcohol would lose the greatest amount of heat because the specific heat capacity of alcohol was lower than water and alcohol was colder than water.

### The second law of thermodynamics

When the same amount of water at 60°C and alcohol at 20°C were brought into contact, 22% of the students held correct understanding that heat travels from water to alcohol until both water and alcohol are at the same temperature. While 35% of the students thought that water would lose heat energy to alcohol until

both water and alcohol had the same amount of energy; 14% thought that alcohol would heat up to 40°C and the water would cool down to 20°C because the specific heat capacity of the alcohol was lower than the specific heat capacity of water; and 22% thought that the temperature from water transferred to alcohol until both water and alcohol were at 40°C.

By changing the situation, the students dealt with the thermal interaction of a cup of coffee and the room around it. A cup of coffee at room temperature is left in the room for awhile. They were asked whether, at the end of the interaction a cup of coffee may reach the temperature higher than the room temperature. Twenty two percent of the students held correct understanding that it was impossible because the surroundings did not give heat energy back to the coffee after they were at the same temperature. They could understand that heat transferred by itself only from a warmer to a colder body. Fifty eight percent of the students could give the correct prediction that it was impossible that coffee had become warm but their explanation could not support their answer. While 40% of the students thought that it was possible thought coffee had become warm because temperature differences might occur by themselves (6%) or the surroundings could gain heat energy from coffee while coffee could gain heat energy from the surroundings to become warm (17%). The students did not think that all real processes take place by themselves in only one direction.

## DISCUSSION

The findings revealed that most of the students held alternative conceptions of heat and thermodynamics. Many students were confused of the concepts of heat and temperature and could not explain the differences between heat and temperature. Some students still regarded that the words "heat" and "temperature" were the same things. This finding was likely similar to the work by Kesidou and Duit (1993) which pointed out

students' difficulties in distinctions between heat and temperature in the extensive–intensive framework. Additionally, many students held alternative conceptions that heat is depended on the temperature of the object only because they viewed that higher temperature objects would have more heat energy.

An unclear intensive property caused some students thought that specific heat capacity depended on the size of objects only. Heat capacity and specific heat capacity were often poorly differentiated in student's mind as reported by van Roon *et al.* (1994). Many students could not predict the final temperature when two samples at different temperatures are mixed. However, most of them understand that the final temperature cannot be higher than the temperature of two samples before mixing. Students could use the formulae,  $Q=mc\Delta t$ , to find out the amount of heat energy. However, they did not consider the value of specific heat capacity as a factor of temperature changing of the object. Sometimes, many students could give the correct answers but their reasons could not support their answers. This finding identified that the students were able to use formulae and solve the theoretical or mathematical problems, but they did not understand concepts underlying the formulae. Students could make sense with the concrete situation, closely with their life experiences, but they could not link what they had learned in physics classrooms with their experiences.

One of the most important concepts that many students held alternative conceptions was thermal equilibrium. Many of them could state the concept of thermal equilibrium correctly. However, they did not always consider that objects in the same surroundings have the same temperature, when they were given new situations, as reported by Tiberghien (1985), Thomaz *et al.* (2003) and Clark and Jorde (2004). These research studies discussed that confusion is reinforced by the contrast between the cold sensation generated by touching a good conductor such as metal e.g. a

pan and the warm sensation by touching an insulator. In contrast with Thai context, many Thai students held the alternative conceptions of thermal equilibrium which caused by the hot sensation generated by touching a good conductor and the warm sensation by touching an insulator in the hot day. By these results, it is indicated that the students have learned the by memorizing the concept without the fundamental understanding and they faced problem with transferring thermal equilibrium concept because their personal experiences were resisted with the scientific concepts.

The findings showed that students understood the meaning of good insulator and conductor materials. However, they still held the alternation conception that a material, which was good for keeping hot objects warm, could not keep cold objects cool as the reported by Lewis and Linn (1994). This view might come out from their experiences of keeping hot water by using thermos which made of metal (outside). Additionally, Thai students had difficulties in concepts of insulators similar to Western students. Both of them thought that particular materials were good for keeping hot objects warm and cold objects cool.

The difficulty in learning thermodynamics was that the student did not understand the heat flows because of the difference of the temperature of objects. They thought that heat exchange would occur until every object had the same amount of heat energy. As worked by Kesidou and Duit (1993), students held alternative conceptions that it is possible thought that coffee had become warm because temperature differences might occur by themselves. These students did not think that all real processes take place by themselves in only one direction. In contrast, Thai students answered by refer their everyday experiences. Thus, half of them could give the correct answer that it was impossible that the objects had become warmer when they were at the same temperature of the surroundings. However, Thai students still had problems with

description to produce detailed and consistent predictions about all the features of the system.

This study recognized the fact that Thai students had difficulties in understanding of heat and thermodynamics similar to Western-students. Thai students also had problems with descriptions to produce detailed and consistent predictions about all the features of the system. This study indicated two fundamental ideas about Thai student understanding of heat and thermodynamics as following:

1) Students' understandings were supported by the likeness between personal experiences and scientific conceptions.

Students' understandings about thermal situations came from their everyday experiences (Arnold and Millar, 1994). Several students could give the correct answer, such as the second law of thermodynamics, by referring to their everyday experiences. Students could understand the scientific concepts instinctively whenever the concepts absolutely made sense to their life experiences. However, students still face problems in giving scientific reasons and consistent predictions.

2) Students' alternative conceptions were reinforced by the contrast between personal experiences and scientific conceptions.

Students held certain intuitive thinking about everyday experiences for heat and thermodynamics concepts. For example, the concept of thermal equilibrium did not make sense to students' experiences in the term of sensation. Thus, students' understanding was grounded in everyday experience which was perhaps the one reason of students' alternative conceptions of heat and thermodynamics. Importantly, it seemed to be especially resistant to change this understanding (Driver, 1989).

## IMPLICATIONS AND SUGGESTIONS FOR TEACHING AND LEARNING

From the fundamental ideas, it is

recommended that teachers could teach heat and thermodynamics concepts along with thermal situations or students' experiences and then identify contrasts and comparisons between them until students clearly understand that how the concept describe that situations. Thus, an understanding of students' prior knowledge is useful in providing appropriate situations and effective pedagogies as well. Multi-contexts should be used to introduce and explain heat and thermodynamics concepts, so students can be better understand the concept and see how the concepts are transferred and applied. The new approach should address students' prior knowledge of heat and thermodynamics. The students already have the ideas of thermal situation before they get into the classroom. The new learning approach should more emphasis on helping students to build scientific thought and analysis up from there.

Additionally, to develop students' understanding of the differences of heat and temperature, teachers should help students to recognize that mass is also an important factor of heat energy. The terms of intensive and extensive quantities should be explained to students. These terms will help students clearer identify the differences of heat and temperature. This idea is similar to the work by Kesidou and Duit (1993) when the extensive-intensive framework were used as criterions to pointed out students' difficulties in distinctions between heat and temperature. Perhaps, intensive and extensive quantities could help students to understand the difference between heat capacity and specific heat capacity.

One of the findings from this study is that sometimes, students explained an event by using wrong concept principle. Apparently, using formulae did not come along with developing conceptual understanding and emitted encouraging transferring the concepts. Even though students were able to using formulae and solving the theoretical or mathematical problems, but they did not understand concepts underlying the formulae.

Hence, teaching should give more emphases on 1) develop student's conceptual understanding before solving theoretical or mathematical problems and 2) encourage students to express their ideas by using the technical terms and concepts with an event consistently in order to improve student's transfer of heat and thermodynamics concepts.

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