A qualitative research of the conceptual learning process of the heat concept

Hasan Sahin KIZILCIK* and Mustafa TAN

Gazi University, Ankara, TURKEY

***Corresponding Author's Email: hskizilcik@gazi.edu.tr**

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Abstract

The purpose of this study is to examine the process of conceptual change in which the heat concept has gone through in time and provide an analytical assessment. To this end, problem-based learning groups were formed with 13 sophomore university students. One of these students was selected and interviewed. The interviews were examined using the content analysis method, which is one of the qualitative analysis' methods. Grounded theory techniques were used to interpret the data. According to the results, the student had difficulties in distinguishing between heat and thermal energy. The student explained what heat is as "a type of energy stored in a matter" and how heat comes out as "a result of frictions which occur while particles of a matter collide with each other". It is seen that the opinions of the student are affected by common misconceptions such as "heat loss" or "the energy lost during friction turns into heat". The opinions of the student are disconnected pieces of information and her opinions change constantly throughout the process. At the end of the process, the student managed to differentiate the heat concept and thermal energy concept. In addition, she corrected her conception of heat in line with scientific theories.

Keywords: heat; qualitative analysis; misconception; conceptual learning; problem-based learning

Introduction

Scientific information is only effective when it is taught based on concepts. Previous studies show how essential it is to ensure students learn conceptually (Bodner, 1986; Nakhleh & Mitchell, 1993; Markow & Lonning, 1998; Harrison & Treagust, 2001). Conceptual learning is just as important in physics teaching as it is in other fields. Physics includes abstract concepts such as heat and temperature, which are difficult to understand and associate with other concepts (Reiner et al., 2000). Misconceptions may occur related to such abstract concepts.

According to the literature on misconceptions, the difference between heat and temperature is one of the concepts with which students of all levels have the most difficulty (Erickson & Tiberghien, 1985; Linn & Songer, 1991). Misconceptions on this subject make it more difficult to obtain scientific knowledge at every level. For this reason, it is necessary to understand reasons behind such misconceptions and then we can eliminate them.

Various examinations were designed and carried out on learning basic concepts related to thermodynamics, which is one of the important subjects of physics (Carlton, 2000; Kalem et al., 2002; Leite, 1999; Sözbilir, 2003; Taber, 2000; Warren, 1972; Wiser & Carey, 1983). Based on various studies focusing on the misconceptions regarding heat and temperature (Aydoğan et al., 2003; Eryılmaz & Sürmeli, 2002; Gümüş et al., 2003), various teaching techniques and approaches related to the subject were quantitatively compared (Başer, 2006; Başer & Geban, 2007; Gürses et al., 2002; Niaz, 2006; Olgun, 2008; Shayer & Wylam, 1981; Şenocak et al., 2003;

Tanahoung et al., 2009; Yeo & Zadnik, 2001; Zacharia et al., 2008). Although quantitative studies provide useful information about conceptual learning, they are unable to reveal the nature of learning sufficiently. Compared to quantitative studies on conceptual change in particular, qualitative studies on conceptual learning (Adawi et al., 2001; Clough & Driver, 1985; Frederic et al., 1999; Harrison et al., 1999; Jones et al., 2000; Laburu & Niaz, 2002; Lewis & Linn, 1994; Luera et al., 2005; Niaz, 2000; Paik et al., 2007; Thomas & Schwenz, 1998; Thomaz et al., 1995; Wiser & Amin, 2001) produced more effective results in terms of understanding how the basic concepts in question are learned. One of the most important results of previous studies is that students use the heat concept and temperature concept interchangeably (Niaz, 2000; Thomaz et al., 1995). To the best of our knowledge, there is no study in the literature which compares the heat concept with thermal energy.

In the conceptual change approach, the concept expresses the network of relationships that an individual constructs in his/her mind rather than a classification (Ceylan, 2008). In time, two different theories have been put forward as an alternative to the classic conceptual change approach that Posner put forward. The first of them is the ontological approach and the other one is the social/affective approach (Duit and Treagust, 2003). However, there are some common methods that are developed in accordance with the conceptual change approach, whichever the theory is based on.

The constructivist approach is largely consistent with the classical conceptual change approach. It is now known that the constructivist approach emphasizes that students are not classmates with free memory when they come to class, but they also incorporate various prior knowledge and experiences into the classroom (Smith, diSessa and Roschelle, 1993). However, unlike the classical conceptual change approach, the constructivist approach is expressed in the form of knowledge reorganization or knowledge refinement, not as a modification of learning information. Therefore, now, it is used in the literature as a remediate of the information with the effect of the constructivist approach, instead of the information change or dispelling of misconceptions which are used in the past.

Various researchers have attempted to classify types of conceptual change using different names. For example, Hewson and Hewson (1981) named them as conceptual capture and conceptual exchange, Posner et. al (1982) named them as assimilation and accommodation, Vosniadou (1994) named them as enrichment and revision, Duit and Treagust (2003) named them as weak knowledge restructuring and strong/radical knowledge restructuring. But these classifications meet in common aspects.

The conceptual change model has two major components: the conditions that need to be satisfied for a person to experience conceptual change and the person's conceptual ecology that provides the context in which the conceptual change occurs (Hewson and Thorley, 1989). According to Posner et. Al. (1982), conceptual change depends on four conditions: (i) There must be dissatisfaction with a currently held conception. (ii) The alternative conception must be intelligible. (iii) The alternative conception must appear plausible. (iv) The alternative conception must appear fruitful.

Concept maps, analogies, animations, simulations, refutation texts, conceptual change texts can be given as examples of conceptual change methods and techniques. The literature of conceptual change is quite extensive.

According to huge literature on conceptual change, for instance, conceptual change texts is one of the most used technique in conceptual change strategy after 1985. However, most of the studies on physics education which examines the success of the conceptual change texts have not varied and some of them just represent the material. In addition, some studies indicate that misconceptions of students can be continued however, they read conceptual change texts (Baser ve Began, 2007, Dilber, Karaman ve Duzgun, 2009). So, the success of this technique should be questioned.

It can be reached by a lot of studies on the other methods and techniques of conceptual change. But student-centered constructivist methods can be used to provide conceptual change. Problem-Based Learning (PBL) is one of them. If four conditions of conceptual change are provided, conceptual change can be done. The problem situations in the PBL are unstructured problems that require the student to find additional relationships between the facts and concepts in the problem, which need additional resources to learn and to understand the various solutions of the problem (Lohman and Finkelstein, 2000). In short, PBL is a method that emphasizes the meaning of the superficial interpretation (Prpic and Hadgraft, 2003). With PBL, learners logically understand related concepts and solve problems more easily by establishing links between previous knowledge and information they will learn in the learning process (Holen, 2000). In some studies, learning processes were conceptually investigated with PBL and beneficial results were obtained.

It seems that studies on the basic concepts of thermodynamics revealed various misconceptions. We can also say that students have certain problems with making connections between concepts. For this reason, it is necessary to determine what goes through students minds when thinking about the process of the change of heat. The purpose of this study is to examine the process of conceptual change over time regarding the heat concept and provide an analytical assessment. The resulting analytical assessment may be useful in determining reasons behind misconceptions related to the subject.

In this study, we used PBL to provide the conceptual change in heat concept. We discuss how a student learns heat concept in PBL process and what happened in the students' mind in the process. Interviews were made with the Socratic method to ensure that four conditions of conceptual change were achieved. Researchers in this study used classical conceptual change models.

Method

The action research technique and the grounded theory, which are one of the qualitative research techniques, were used in this study. For the purpose of the study, an attempt was made to create a mental model for the learning process of the heat concept. To this end, it is aimed to provide an analytical generalization, which is defined as the attempt to reach certain results or hypotheses with a limited number of participants or sources of information (Altunışık et al., 2002).

Participant

Problem Based Learning (PBL) groups were formed in the study with the participation of voluntary sophomore students studying to become physics teachers at a public university. The purposive sampling method was employed to achieve this. One of the inclusion criteria was not taking a course including subjects on thermodynamics during their university education. So, students didn't take the same course in thermodynamics. They have different backgrounds on heat concept. It's important to have rich data.

The same problem was given to the groups and the PBL process was run for five weeks. A student (Nickname: Ekin) in one of these groups was selected to examine throughout the process. The selection made in terms of providing richest data. Opinions of the selected student related to the heat concept were examined throughout the five-week PBL process.

PBL Process

A problem which "warming up problems of a ski resort in a mounted position" was given to the PBL group. The group members tried to solve the problem for five weeks. First of all, they distinguished the problem to four sub-problems. They set a week to solve each sub-problem. Accordingly, they examined the advantages and disadvantages of geographical location, examining the heat production source, insulation techniques, and the heating system, respectively.

They started to study by investigating factors such as the average temperature, the highest and lowest temperatures, wind and pressure of the region in the first week. At the same time, they studied the concepts of temperature and pressure. In the second week, they examined the energy sources in the region. Ekin particularly emphasized geothermal energy. At the same time, she tried to learn the concept of heat. She focused on the relationship between heat and thermal energy. Participants studied insulation techniques in the third week. Meanwhile, they focused on the concept of "heat loss". In the last week, he tried to synthesize their thoughts on the planning heating system. They made suggestions for the problem by making presentations in the fifth week.

Throughout the process, they researched concepts such as temperature, pressure, heat, thermal energy, heat loss by using the internet and printed publications. They compared the contradictory information they had obtained and questioned the reliability of this information. For this reason, Ekin changed her thoughts on the concepts throughout the process.

Data Collection Method

Semi-structured interviews were held with the student throughout the PBL process. The purpose of these interviews is to reveal the knowledge and opinions of the student about the heat concept and other related concepts. To this end, direct questions about heat concept were asked to the student, as well as indirect questions about heat transfer, change of state, and expansion were asked to reveal her opinions about the heat concept. Five interviews were held with the student throughout the process in total. In the first interview, general opinions of the student on heat were revealed. In the second interview, opinions of the student on the heat concept were revealed through the example of heat transfer additively. In the third interview, the example of expansion was added. In the fourth interview, the example of change of state was added. The fifth interview included a comprehensive summary of all opinions of the student on the heat concept directly and based on various examples.

The data collection process continued throughout the teaching process carried out using the PBL method. Table I shows the PBL process and at which stage of the process the data was collected.

Table I. Activity implementation schedule related to the conceptual data obtained from Ekin

Week	Date	Time	Process
Briefing Week	24th Feb.	16:30	Briefing
	25th Feb.	13:30	Analysis of Problem Session
First Week	2nd March	14:00	First Interview
	3rd March	16:30	Sub-Problem Session
	4th March	13:30	Sub-Problem Session
Second Week	5th March	12:30	Second Interview
	10th March	16:30	Sub-Problem Session
	11th March	13:30	Sub-Problem Session
Third Week	15th March	13:30	Sub-Problem Session
		16:00	Third Interview
	18th March	13:30	Sub-Problem Session
Fourth Week	22nd March	09:30	Fourth Interview
		13:30	Sub-Problem Session
	25th Mart	13:30	Sub-Problem Session
Fifth Week	29th Mart	09:30	Fifth Interview
		13:30	Final Session
	1st April	13:30	Presentations
	2nd April	16:30	Assessment

As shown in Table I, the process took about five weeks to complete. Session dates and hours were decided by consulting with the participants. Weekly interview dates and hours were decided by consulting with Ekin.

Data Analysis

The interviews with the student were transcribed and then the data was examined using the content analysis method. Propositions asserted by the student related to the heat concept were individually extracted from dialogs and each proposition was taken as a code. The related codes were assigned to the same group.

Firstly, interviews with the student were examined individually. Then, all interviews were examined holistically. The following stages were followed to this end.

- Transcribing the interviews.
- Obtaining codes using the transcription of the interviews.
- Assigning codes to groups.
- Detecting relations between codes and code groups.
- Interpreting the interviews by using excerpts from the interviews.
- Determining relations between opinions of the student.
- Detecting the process of conceptual change.

When analyzing the interviews, the codes repeated concurrently or consecutively during the interview process were determined in order to detect relations between codes and code groups. Then, excerpts from the dialog at that time were examined to find whether there was a logical connection between these codes. Relations were determined using this approach. An example to interview excerpts used to determine codes can be seen below:

Interviewer: $Q = m.c.\Delta T$. What do you understand from this equation? What does it mean? So, what value do you calculate using $Q = m.c.\Delta T$?
Ekin: It is actually heated change. (Q09) For example, ΔT is what we use to calculate the thermal energy between the initial state and the final state by the final temperature minus the initial temperature.
Interviewer: So, you think that it is heated change. Is that correct?
Ekin: Yes, heat change. (Q09) Since we calculate it, for instance, ice must have heat at the beginning. (Q04) Because we subtract the initial value from the final value.
(First Interview)

The codes in this excerpt are Q09 (There is a concept called heat change) and Q04 (Matter stores heat / Matter has heat). Using this approach, it was examined whether or not there was a logical relation between consecutively detected codes. Repeat frequency and the persistence level of the student's opinion related to a given code were also considered. Persistence level is determined using her precision of words. Charts were created using these variables. In these charts, other codes were proportioned according to the most frequently repeated code.

After determining relations between codes, all relations in the interview were examined taking temporal order as well and a general interpretation was made for each interview. Resulting relations were assessed by categories and generally based on temporal change. It was thus described how the conceptual construct in the mind of the student changed throughout the process.

Findings

Findings obtained from the interviews with the student (Ekin) were used to describe how the students understood the heat concept. However, the definition of heat, the relationship of heat within matter, and the relationship between heat and other concepts frequently changed within five weeks. Conflicting opinions were observed even in the same interview. In case of conflicting opinions, we considered which one Ekin repeated more and her persistence. This is defined as "balance of dominance" by researchers. The intersection of two conflicting ideas is given as "dominance" in charts. In these charts, other codes were proportioned according to the most frequently repeated code.

In this section, the change in Ekin's opinions over time was examined under four categories: (1) general opinions about heat, (2) opinions about the relationship between the heat concept and temperature concept, (3) opinions about the relationship between the heat concept and thermal energy concept, and (4) opinions about the quantitative aspect of heat. These were examined separately.

Analytical Assessment of Ekin's General Opinions about Heat

Ekin's general opinions about heat are examined under two sub-categories. The first one is the relationship between heat and matter and the second one is the definition of heat. The following codes can be used to demonstrate opinions asserted by Ekin regarding the relationship of heat with matters.

a. Matters does not store heat.

b. Matters stores heat or possesses heat.

c. There is a concept called heat change.

d. Matter only stores heat when it is not at thermal balance.

These four propositions asserted by Ekin show the relationship between heat and matter in her mind. The first two propositions (a and b) conflict with each other. The last proposition (d) can be accepted as an interim proposition which supports both propositions to a certain degree. The third proposition (c) is the proposition where the heat change concept was asserted. This new concept supports the proposition that heat is stored by matter. Figure 1 shows how the dominance of these propositions changed throughout five weeks.

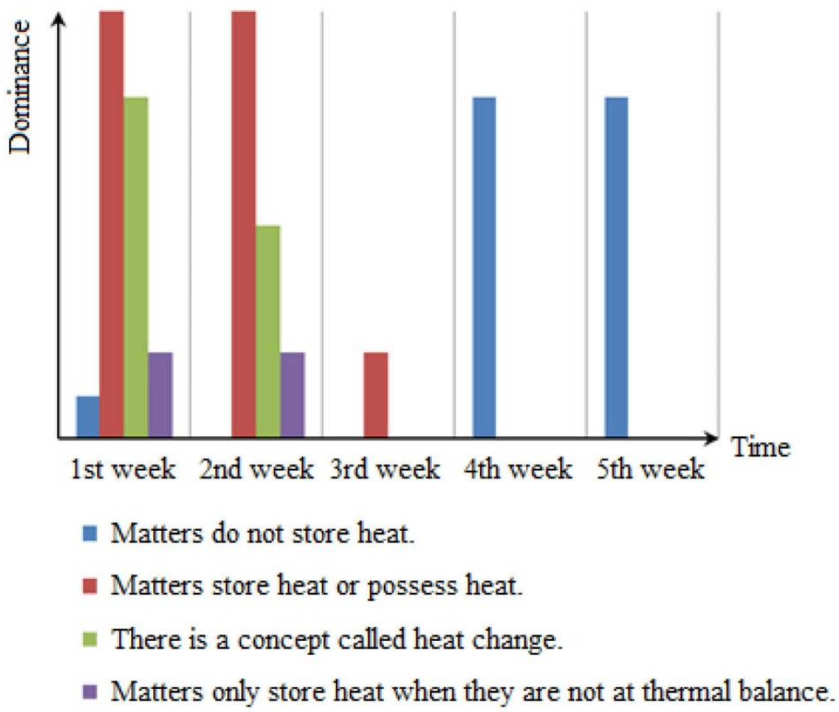


Figure 1. Temporal change in Ekin's opinions about the relationship between heat and matter

Ekin's opinions about the relationship between heat and matter changed during the five- week process. As shown in Figure 1, all propositions were asserted in the first week. In other words, Ekin had all these opinions more or less in the first week. However, the most dominant was the idea that heat is stored in matters. It is followed by the idea that the heat change concept is a real concept. She mentioned the idea that matter does not store heat but she did not dwell on it. The idea that matter stores heat only when there is no thermal balance is at its peak in the first weak. It disappeared after the third week.

The ideas that matter does not store heat and idea that matter stores heat are inversely proportional naturally. The third week and the fourth week can be seen as the breaking point in this sense. Because the idea that matter does not store heat disappeared in the second week and while the same idea had not formed yet in the third week again, the conflicting idea, the idea that matter stores heat was considerably reduced in the fourth week.

Another important finding is the decrease and disappearance of the idea of heat change in parallel with the idea that matter stores heat. So, it can be said that the idea of heat change is based on the idea that matter stores heat. Ekin had the idea that matter possesses heat or store heat, thus the idea that the quantity of the stored heat changes in cases such as temperature change. These two propositions explain and support each other.

The proposition that matter stores heat only when it is not at thermal balance might be a proposition asserted as a result of the indecision between matters storing and not storing heat. It might also be a result of misinterpreting $Q = m.c.\Delta T$, which is used to calculate the quantity of heat transfer. As expected, the idea that matter does not store heat became more dominant while the idea that matter stores heat lost its dominance and gradually disappeared. The following dialog can be shown as an example:

Interviewer: $Q = m.c.\Delta T$. What do you understand from this equation? What does it mean? So, what value do you calculate using $Q = m.c.\Delta T$?
Ekin: It is actually heated change. For example, ΔT is what we use to calculate the thermal energy between the initial state and the final state by the final temperature minus the initial temperature.

Interviewer: So, you think that it is heated change. Is that correct?
Ekin: Yes, heat change. Since we calculate it, for instance, ice must have heat at the beginning. Because we subtract the initial value from the final value.
(First Interview)

In the fourth week, the idea that matter does not store heat became dominant. The other three propositions disappeared. As a conclusion, we can say that the idea that matter stores heat creates a suitable environment for the idea of heat change and the idea of heat storage. When the idea that matter stores heat lost its dominance, these other related propositions disappeared as well.

Another aspect which we addressed is the definition of heat. Ekin asserted five propositions related to the definition of heat, which are as follows:

a. Heat is a type of energy.

b. Heat is the transferred energy due to the difference in temperature.

c. Heat is the energy, which comes out due to friction or collision.

d. Heat is the total kinetic energy of matter's particles.

e. Heat is the mean kinetic energy of matter's particles.

Ekin's first proposition (a) describes the dimension of heat. However, it does not only have a dimensional approach, it also asserts that heat is a type of energy. The second proposition (b) is the most compatible with scientific theories. The third proposition (c) describes heat as the energy which comes out as a result of a mechanical phenomenon. The fourth proposition and the fifth proposition (d and e) are very similar, yet there is a difference between the two in terms of the effect of mass. Figure 2 shows how the dominance of these propositions changed throughout five weeks.

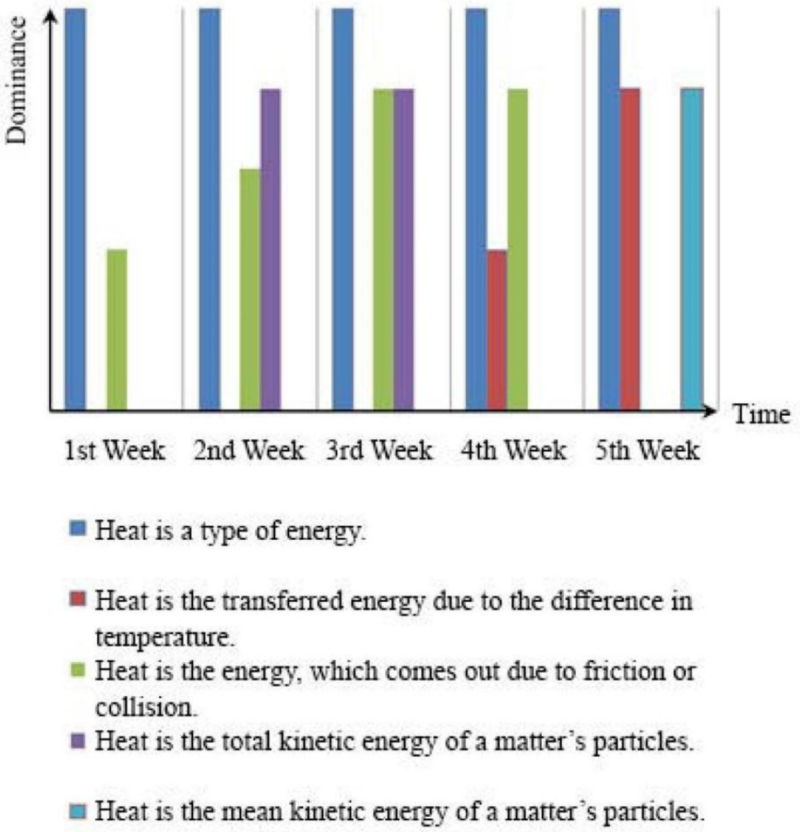


Figure 2. Temporal change in Ekin's opinions about the definition of heat

From the first interview until the last one, Ekin kept her idea that heat is a type of energy. In the first interview, she asserted collisions and frictions, i.e. mechanical phenomenon, as the reason behind the heat. She stated during interviews that her knowledge of "energy lost due to friction turns into heat" led to this idea. Ekin presented an example by rubbing her hands. She thought that it is how heat occurred and stored by matters. Her idea may be supported by false information, false definitions, or indirect expressions in some resources that she reached. This idea continued growing until the fourth week. In the fifth week, the idea disappeared with the increased dominance of other definitions. Ekin changed her ideas when she gained more knowledge about the type of molecular collisions, which she had thought to be the cause of friction. Her idea that heat is released as a result of friction disappeared when she found out that these collisions are perfectly elastic collisions. Ekin's following statements can be given as an example:

Interviewer: What do you think heat is?
Ekin: Heat is a type of energy.
...
Ekin: For example, matter does not have a heat when it is stable (Q70) but energies turn into each other and heat loss occurs.
Interviewer: So, there is a heat which matter stores and it gets lost? Is that what you mean? Ekin: Yes. For example, an energy loss occurs due to friction.
Interviewer: For example, your notebook... Does it have heat?
Ekin: I think it does.
(First Interview)

Ekin: Molecules, atoms in an object constantly vibrate. They are in motion. Heat is released when they touch one another. They produce a kinetic energy. The sum of this kinetic energy is referred to as heat. However, all molecules, not just a single one. This shows that matter has heat.
(Second Interview)

Ekin: After all, there is friction. Through friction, particles transfer heat. For example, when we put two objects next to each other, their atoms vibrate and energy transfer occurs due to vibration.
Interviewer: So, do you say that it happens through friction?
Ekin: Yes. And they collide. There is vibration. (Rubs her hands) For example, my hands got warm. It's friction...
Interviewer: They rub against each other when they vibrate. Heat is released at this time. Is that true? Do they collide with each other?
Ekin: They do it when they vibrate.
(Third Interview)

Interviewer: Can you tell me what kind of collisions these are?
Ekin: Perfectly elastic collisions.
Interviewer: What about kinetic energy in perfectly elastic collisions?
Ekin: Conserves. Oh... So it is not about friction. Then friction must be not involved in the occurrence of heat. They collide and they transfer their energy to each other. I thought there was friction during vibration. But there is not.
(Fifth Interview)

In the second and third week, Ekin strongly asserted the idea that the total kinetic energy of the particles of matter causes heat in addition to the proposition of mechanical phenomenon. This idea disappeared after the third week, in which the dominance of the idea that heat is stored within matter weakened. At this point, there might have been a connection between the idea that heat is stored in matter and the idea that the total kinetic energy of the particles of a matter causes heat. Because Ekin might have felt the need to explain how heat is stored in matter, which she had advocated since the first week, she might have asserted the total kinetic energy of particles idea in the second week. However, when she gave up on the idea that heat is stored in matter and the idea that heat is a type of energy which is not stored in matter got stronger in the fourth week, the idea that heat is the total kinetic energy of particles disappeared as well. Ekin's following statements can be given as an example:

Ekin: Now at least I can explain to you what heat and temperature are as concepts and when you asked me the last time, when you said, "Does this notebook have heat?", I was not sure. But it does. Now, I am sure.
(Second Interview)

Ekin: Now, I still define heat as the total kinetic energy of a matter. I mean, we refer to the total kinetic energy of particles as heat.
(Third Interview)

In the third week, when the idea that heat is not stored in matter became dominant, Ekin started to define heat as a transferring energy. This idea became even stronger in the final week. However, the idea that heat is the mean kinetic energy of particles appeared strongly in the final week. The emergence of this proposition is surprising. Because it was asserted at a time when the idea that heat is not stored in the matter was dominant. The emergence of this idea might be related to the temperature concept. This is addressed in the section involving the analytical assessment of the relationship between heat and temperature. Ekin's following statements can be given as an example:

Ekin: Now, I changed my mind about the heat a little bit. I used to define heat as the mean kinetic energy of particles. In a way, this is the definition of temperature. Also, this is why I told you that all matter has heat, but they do not. It must be understood as such: There must be a temperature difference. And there must be a transfer for

heat to exist.
Interviewer: So?
Ekin: So, when you asked, "Does a notebook have heat?" and "Can you measure its heat?", I said, "Yes, I can." I meant that I could calculate it given its mass and specific heat. However, this matter does not actually have heat.
(Fourth Interview)

Ekin: Heat is actually a transfer. I mean, it is a transfer occurring between two or more bodies of matter with different temperatures.
(Fifth Interview)

The third week, important changes occurred in Ekin's conception of heat. Examining the transcription of the third week's session, it was seen that her study of basic concepts related to heat and heat transfer improved. Ekin's study in this week might have caused her to re-shape the heat concept in her mind, correctly or incorrectly.

Analytical Assessment of Ekin's Opinions about the Relationship Between Heat and Temperature Concepts

Ekin's opinions about the relationship between heat and temperature concepts were mainly examined in terms of the cause and effect relation between heat and temperature. Ekin essentially asserted four propositions related to the cause and effect relation between heat and temperature:

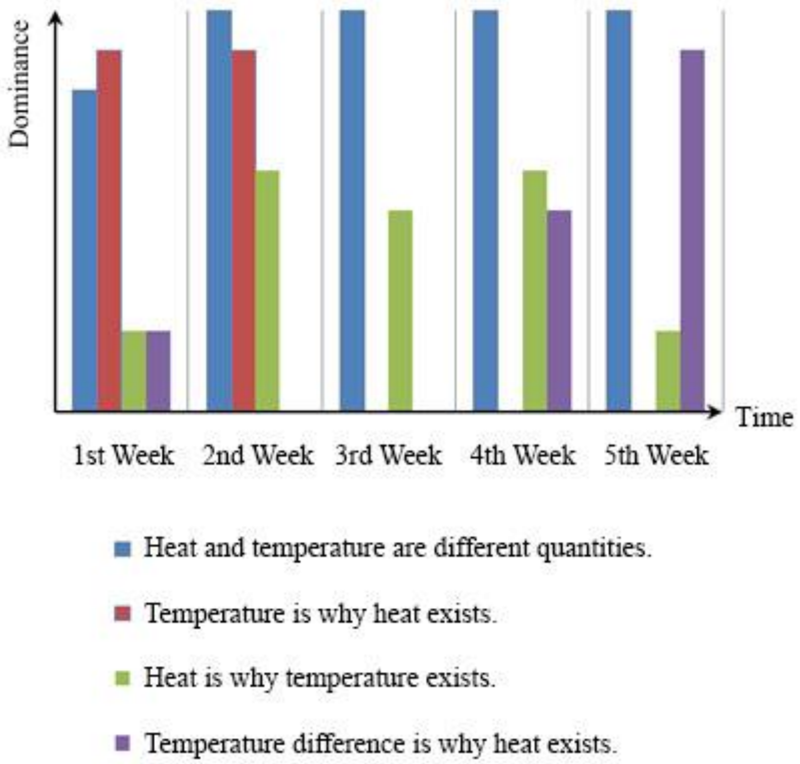
a. Heat and temperature are different quantities.

b. Temperature is why heat exists. / Heat increases because temperature increases.

c. Heat is why temperature exists. / Temperature increases because heat increases.

d. The temperature difference is why heat exists. / There is no heat if there is no temperature difference.

In terms of the first proposition (a), Ekin sometimes implied heat and temperature are the same and sometimes implied they are not. The dominance balance between the two ideas was considered in this study. Ekin sometimes asserted temperature as the reason behind heat's existence, sometimes asserted temperature difference as the reason behind heat's existence, and sometimes asserted heat as the reason behind temperature's existence. The last proposition (d) is the most compatible with scientific theories. Figure 3 shows how the dominance of these propositions changed throughout five weeks.


Dominance
Time
1st Week
2nd Week
3rd Week
4th Week
5th Week
Heat and temperature are different quantities.
Temperature is why heat exists.
Heat is why temperature exists.
Temperature difference is why heat exists.

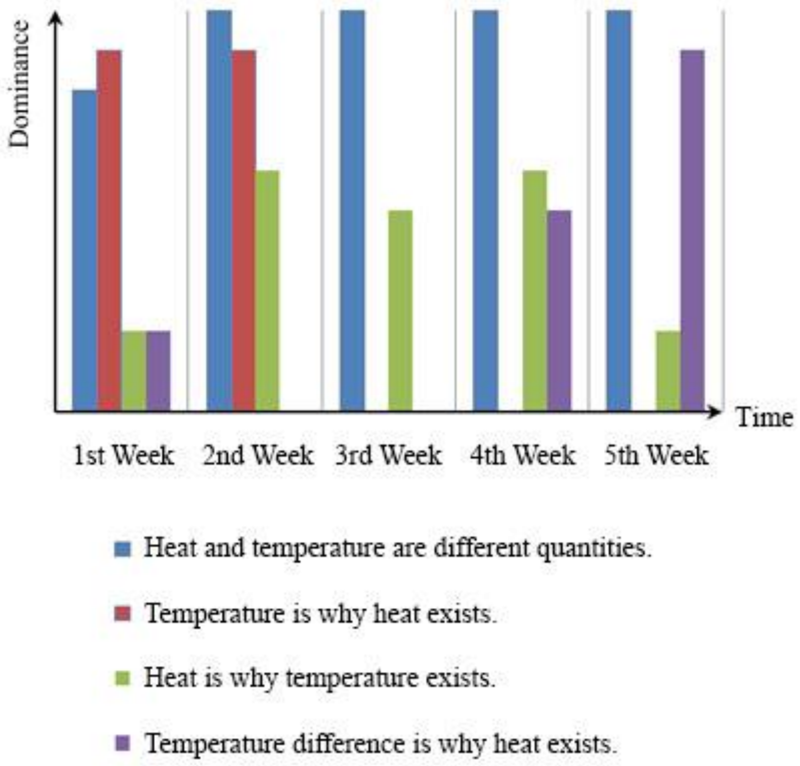


Figure 3. Temporal change in Ekin's opinions about the relationship between heat and temperature

While Ekin doubted that heat and temperature might be different concepts in the first week. Its reason might be wrong using these terms interchangeably. But she had a strong stance in the following weeks and was convinced these are separate concepts.

For the first two weeks, Ekin had the idea that heat exists due to temperature. It is important to remember that during this time Ekin also had the idea that heat is a type of energy which can be stored within matter and temperature is a quantity which is always seen in matter. In the first week, Ekin usually defined heat as energy arising from collisions and frictions. Also, Ekin thought that the average kinetic energy of particles is temperature and the total kinetic energy of particles is heat. Thus, we can say that she thought that the temperature of matter is its particles' motion energy and this energy is collected and stored as heat, thus heat is a quantity dependent on temperature. However, she seems to have given up these ideas after the third week. This can be observed in Ekin's following words:

Ekin: I think there is temperature as long as there is heat. Heat depends on the quantity of a body. For example, when you put your finger in a glass of water at 25 °C, it feels warm. If we add some more water at the same temperature, the temperature is the same, but the heat has increased because its mass has increased. (Third Interview)

Ekin's idea that heat exists due to temperature changed constantly, but it was always there. At first glance, it is interesting that this proposition which conflicts with the second proposition (b), a quite dominant proposition for the first two weeks, always existed. $Q = m.c.\Delta T$ might be effective in this case. Because in this equation, heat and temperature seem related. The symbol "Δ", which shows the difference, is interpreted as the absolute zero and sometimes as the freezing temperature of water at 1 atm pressure (0℃) by Ekin. For this reason, the idea that if there is no temperature, there is no heat might be possible. Small fluctuations in the dominance of this idea might be a result of times of indecisiveness regarding the fitness between her idea and the equation.

Although Ekin mentioned the relationship between temperature difference and heat in the first week, she gave up this idea in following weeks. In the fourth week, the idea that heat cannot exist without temperature difference became dominant. It is important to note that the dominance of ideas that matter does not store heat, the energy transferred is referred to as heat, the temperature is not energy, yet a quantity related to the kinetic energy of particles increased after the fourth week. When the heat concept started to become clear in Ekin's mind, its relationship with temperature started to become clear as well. Although Ekin's ideas about the definition of the temperature concept followed a more complicated route, the determining factors might be her ideas about temperature's relationship with heat and whether the temperature is a type of energy or indicator. The main problem related to heat, the problem of whether it can be stored in matter or not, seems to have played a key role in the relationship between heat and temperature.

It seems that Ekin did some of her own study about heat transfer in the third week. The fact that she researched what happens during heat transfer might have influenced

Ekin's thoughts about the relationship between heat and temperature because the fact that heat transfer occurs in cases where there is a temperature difference is emphasized in sources which she cited. While Ekin had difficulties making the connection between heat and temperature, her study might have helped her achieve this task.

Analytical Assessment of Ekin's Opinions about the Relationship Between Heat and Thermal Energy Concepts

Ekin's opinions about the relationship between the heat and thermal energy concepts are essentially based on describing thermal energy through heat. Ekin essentially asserted three propositions about the relationship between heat and thermal energy:

a. Heat and thermal energy are different concepts.

b. Heat and thermal energy are directly proportional.

c. Thermal energy is about water's heat and a building's getting warmer.

In terms of the first proposition (a), Ekin sometimes implied that heat and thermal energy are similar and sometimes implied that they are separate concepts. The dominance balance between the two ideas is considered. The second proposition (b) and the third proposition (c) show the relationship between these concepts. Figure 4 shows how the dominance of these propositions changed throughout five weeks.

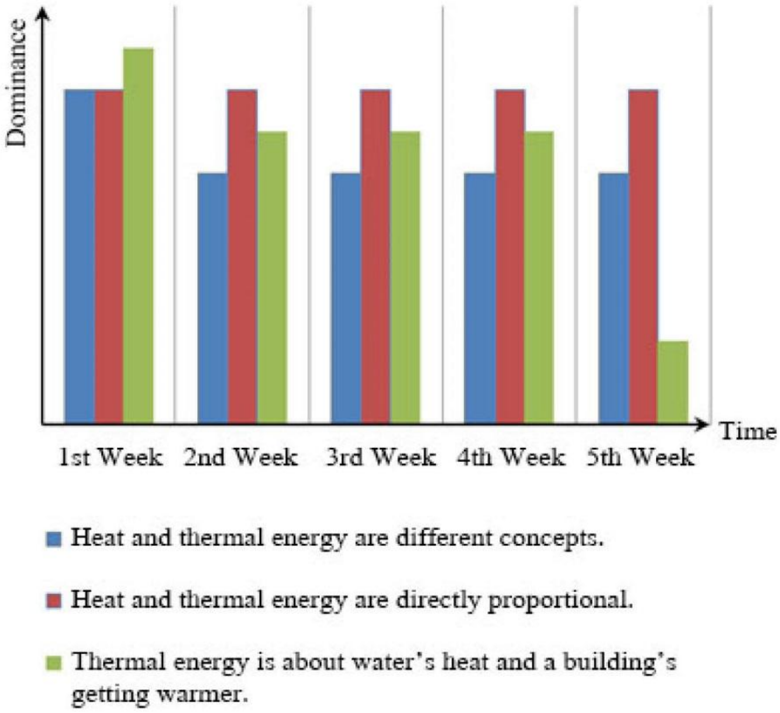


Figure 4. Temporal change in Ekin's opinions about the relationship between heat and thermal energy

Initially, Ekin thought that thermal energy is a sub-type of heat. She described thermal energy as a type of heat which can be applied in real life. She thought that it's related to water. It seems that the use of the term "thermal energy" for the energy of hot springs and geysers in everyday life can be effective. This is confirmed by Ekin's following words:

Interviewer: How is thermal energy is different from heat?
Ekin: I can say that thermal energy is a type of heat which we can apply to real life. For example, hot springs... as far as I know hot springs allow your muscles to relax. Thermal energy is a type of heat which we can use to apply to real life. It occurs with water's heat.
Interviewer: Can we not mention thermal energy without water?
Ekin: I mean... For example, there are varieties of thermal energy. Geothermal, hydrothermal... I know those. For example, hydrothermal is about water.
(First Interview)

In the next interview, Ekin's ideas about the relationship between heat and thermal energy did not change much. Ekin expressed her ideas in the first two weeks. Then she did not assert any new ideas and repeated the same ideas in the following weeks. However, the dominance of all three propositions is high. The fact that Ekin's definition of thermal energy was not clear until the final week might have had an impact on this. She thought that the concepts of heat and thermal energy had to be different, yet did not have a certain idea about what thermal energy is. Thus, she had difficulties with understanding the relationship between the two concepts. In the final week, Ekin asserted a thermal energy definition which is very different from her heat definition and independent from the water.

Analytic Assessment of Ekin's Opinions about Heat's Quantitative Aspect

Ekin's opinions about heat's quantitative aspect can be examined under three aspects: The measurement of heat, calculability of heat's value, and how to calculate heat's value.

Ekin's ideas about the measurement of heat can be briefly summarized as follows:
a. The unit of heat is the calorie.
b. The unit of heat is degree centigrade.
c. Heat is measured by a calorimeter.

Among these three propositions asserted by Ekin, the first two (a and b) are about heat's unit of measurement and the third (c) is about the device used to measure heat. In the first week, Ekin confused the unit of heat due to incorrect uses in everyday life. However, she later corrected her mistakes. She asserted that "degree centigrade" is unit of heat due to expression "body heat" that is a common misconception in everyday life. But, she later decided that heat's unit is "calorie". Ekin said that heat could be measured by calorimeter in the first week and did not change her opinion in the following weeks.

For the second aspect, Ekin's ideas about heat's calculability can be briefly summarized as follows:
a. Heat can be calculated.
b. Heat can only be calculated during heat transfer.
c. Heat can only be calculated during the change of state.
d. Heat can only be calculated for certain matter / pure matter.

The first proposition (a) asserted by Ekin can be seen that "Heat cannot be calculated" sometimes. The dominance was determined considering positive and negative statements. The second proposition (b) asserted heat could only be calculated during heat transfer and the third (c) asserted heat could only be calculated during the change of state. The last proposition (d) asserted heat could only be calculated certain matter which stores. Ekin thought these bodies of matter had to be pure. While Ekin's first proposition (a) is not wrong, the second and third propositions (b, and c) are the most coherent to scientific theories. Figure 5 shows how the dominance of these propositions changed throughout five weeks.

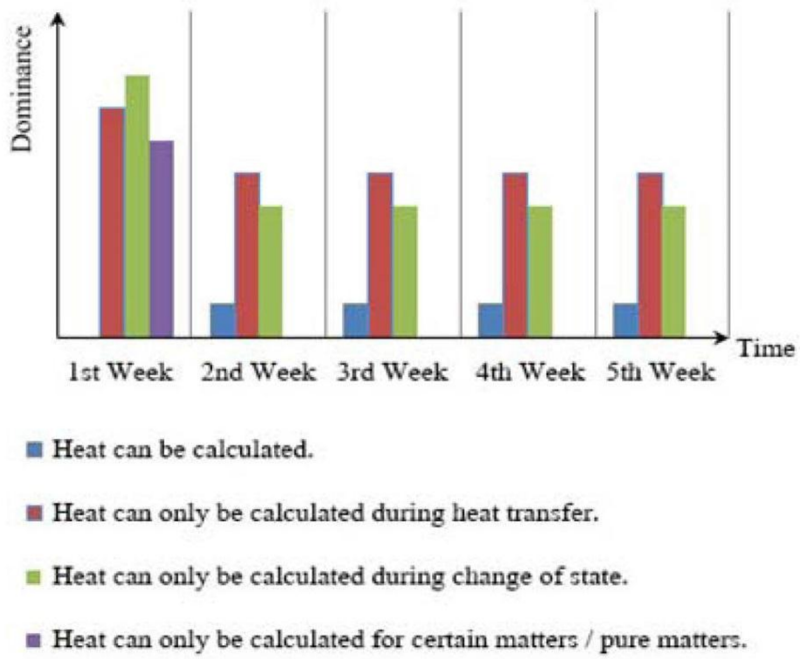


Figure 5. Temporal change in Ekin's opinions about heat's calculability

When directed questions about the calculability of heat in the first week, Ekin thought about examples, suggesting that heat could be calculated for matter changing state or exchanging heat and also only for pure matter. Because she thought that the specific heat of impure matter cannot be known. It can be said that Ekin probably thought based on $Q = m.c.\Delta T$ for heat transfer and $Q = m.L$ for the change of state. This can be observed in Ekin's following words:

Ekin: Maybe we cannot calculate it because we do not know the matter's specific heat or because the matter is not pure.
(First Interview)

Ekin: I mean, when you ask me to calculate its heat, I need to know its mass, specific heat, and temperature to do that.
(Second Interview)

Ekin thought matter can store heat in the first few weeks. However, she had difficulties with calculating the value of heat stored in matter. For this reason, she asserted that we cannot calculate the heat stored by the matter. It is interesting that while Ekin advocated that matter can store heat in the first week, but when she was asked to calculate this heat, she tried to do so firstly and then asserted it could not be calculated, and then could only be calculated for pure matter. However, she once again thought about calculability of heat stored in a matter without heat transfer and change of state. This is most likely because of the idea that matter can store heat. Ekin did not assert a different idea in the following interviews. However, she changed her definition of heat in the following interviews and replaced her idea of heat stored in matter with the idea that heat can be calculated during heat transfer. This is explained in the aspect about how to calculate heat's value.

The third aspect is about how to calculate heat's value. Ekin thought the aspect firstly as heat stored in matter and then only as heat. Ideas asserted by Ekin on this aspect can be summarized as follows:

a. Heat's value has no limit.

b. Heat's value cannot be negative.

c. $Q = m.c.\Delta T$ gives heat that enters or leaves.

d. $Q = m.c.\Delta T$ gives heat change.

e. $Q = m.c.\Delta T$ gives heat stored by matters (reference point is 0 ℃).

f. Mass and type of matter are indicative factors when calculating the heat that is stored by matter.

The first proposition (a) asserted by Ekin is that the heat stored in the matter has no limit. The second one (b) asserts that this heat cannot have a negative value. The last proposition (f) asserts that the heat stored in the matter is related to its mass and type of matter. Also, there are three different statements regarding what $Q = m.c.\Delta T$ gives. Figure 6 shows how the dominance of these propositions changed throughout five weeks.

Conclusion and Discussion

Ekin's ideas about heat frequently changed throughout the process. Although she asserted the idea that heat is not stored in matter in the first interview, some of her statements asserted the opposite. Considering the idea of "heat loss", which is mentioned especially in basic physics courses and secondary education curriculum, and also mentioned by Ekin during interviews as well, it was found that she actually thought that matter stored heat. In reality, Ekin considered heat as a type of energy which can be stored, however, she didn't realize this in the first place. The misconception that matter stores heat is quite common. This misconception was observed in some previous studies as well (Jara-Guerrero, 1993).

The fact that some say the equation $Q = m.c.\Delta T$ does not give heat, but "heat change" supports this. In reality, Ekin thought that heat was a type of energy stored in matter, the quantity of this energy changed through heat transfer, this change was calculated with the equation given above, in other words, the final heat minus the initial heat. This led to the idea that "ΔT", the temperature difference, in the equation was "ΔQ", the heat change. Here, $Q = m.c.\Delta T$ is actually perceived as,

$$Q_{final} - Q_{initial} = \Delta Q = m.c.T_{final} - m.c.T_{initial} = m.c.\ \Delta T$$

Ekin thought that Q represented the total energy stored by the body of matter. In support of this, Ekin used this equation to calculate the heat stored by the body. She accepted the initial temperature as water's freezing temperature at 1 at pressure, 0°C. Kesidou and Duit (1993) found that students believed that temperature did not exist at 0°C. This finding is consistent with ours. However, when Ekin was reminded that not ΔQ, but Q is used in the equation, she suspected something was wrong, but her idea did not change at that moment.

Also, Ekin was sometimes influenced by the use of heat and temperature interchangeably because of misuses in everyday life. This may indicate that Ekin had difficulties with scientific thinking and mastering scientific concepts. Misconceptions involving the idea that heat and temperature are the same things are seen in the literature at every level (Arnold & Millar, 1996; Aydoğan et al., 2003; Başer, 2006; Erickson, 1980; Erickson & Tiberghien, 1985; Eryılmaz & Sürmeli, 2002; Harrison, 1996; Jara-Guerrero, 1993; Kesidou & Duit, 1993; Krajcik, 1991; Linn & Songer, 1988; Streveler et al., 2008). Jara-Guerrero (1993) observed that while students assert that heat and temperature are different concepts, they can still use them interchangeably. A similar situation can be seen here as well. Some studies show that this is due to misuses in everyday life (Driver, 1989; Campanario, 2002; Hameed et al. 1993; Harrison et al. 1999; Kolari & Savander-Ranne, 2000; Osborne & Freyberg, 1985; White, 1992). Because students hear many nouns, verbs, and adjectives related to heat and temperature (for example: heat, temperature, overheat, hot, cold, thermal, thermic, warm, freeze, warmth, to get hot, etc.) every day (Erickson & Tiberghien, 1985; Luera et al., 2005; Tiberghien, 1980). Thus, scientific terms may be confused with everyday uses.

In later weeks, Ekin described heat as a type of energy stored in matter. She even described it as the total energy arising from the motion of particles of matter. However, it is important that she emphasized the phenomenon of friction to when defining heat since the first week. It is believed that Ekin might have been influenced by frequently repeated misconceptions especially in secondary education institutions such as "the energy lost due to friction turns into heat". Because she frequently described heat as a type of energy arising from the friction caused by the vibration of particles due to their temperature. This idea is consistent with some studies on misconceptions in this area. In parallel with this finding, some studies show that students had the idea that the motion of particles is referred to as heat (Erickson, 1980; Kesidou & Duit, 1993).

Ekin had two main thoughts about heat which supported each other: "Heat is the total kinetic energy of particles" and "Heat occurs with friction due to collisions during vibration". One of these describe how heat occurs and the other described what heat is. Among the two, the idea that "heat is the total kinetic energy of particles" is close to the definition of thermal energy. The characteristic of the thermal energy concept is attributed to the heat concept and this led to the idea of heat change. Also, storage of heat was found to be related to this. The other idea may be a result of "energy lost during friction turns into heat" and "heat loss".

In the fourth week, Ekin stated that heat was not stored in matter and defined heat as the energy entered and left due to the temperature difference, which is not adequate but closer to scientific theories. This was observed in other studies as well (Taber, 2000). It can be said that the change in Ekin's ideas is a result of the information which she acquired in sessions with the PBL group. This change seems to have triggered many other changes. For example, the relationship between heat and other concepts and the thermal energy concept seem to have been the most highly affected ideas. It can also be said that this idea brought an end to the idea of "heat change". Summary of Ekin's main opinions for heat in time can be seen in Table II.

Table II. Summary of Ekin's main opinions for heat in the time

Week	What is Heat	How Emerges Heat?
1	A type of energy that sores in matter	Because of friction of particles
2	The total energy of matter's particles	Because of friction of particles
3	The total energy of matter's particles	Because of friction of particles
4	Transferred energy when there is not thermal equilibrium	If there is not thermal equilibrium
5	Transferred energy when there is not thermal equilibrium	If there is not thermal equilibrium

Although weaker in terms of dominance, the idea related to friction between particles was alive at this stage. It can be said that this idea was dependent on the definition of heat, while it also had independent components. Although one of the two heat-related misconceptions mentioned above, the idea that "heat is the total energy of particles", disappeared, the idea that "heat is the energy released due to friction", which was found to be connected with this, did not disappear completely. This made it necessary to address the idea that "heat is the energy released due to friction".

It can be said that this misconception is based on the idea that "the energy lost during friction turns into heat" and the idea of "heat loss". It is supported by Ekin's statements. There was also the idea that frictions become equal at the time of thermal equilibrium and differentiate when there is no thermal equilibrium. The fact that this idea lost its dominance when Ekin started to assert that there is a perfectly elastic collision between particles and the energy that is conversed explains this situation.

During the PBL process, she did not conduct any research on the concept of heat in first week. For this reason, at the end of the first week, she had her previous misconceptions about the concept of heat. While the second week, she began to examine the heat sources. She examined the geothermal energy more thoroughly. Therefore, she handled some information about the concepts of heat and thermal energy. The information she acquired led her to think that thermal energy and heat are the same concepts. She focused to examine geothermal energy. So, she thinks that there were a relationship between thermal energy and water. When she examined the concept of "heat loss" in the third week, she realized that her thought was not true and she changed her mind in the fourth week. The thoughts of "how energy emerges" and "what energy is" shaped to be in harmony.

During the PBL process, participants are only diverted by the teacher. Participants take responsibility for their own learning. They do this when solving the problem. For this reason, when solving the problem, the teacher has relatively less control over the progress of their research. It may not go in the right direction. The participant can reach conflicting and misleading conclusions initially, such as the case of Ekin. If they don't question the reliability of the information which they acquire, their research may lead to incorrect results.

Beginning in the first week, Ekin asserted that temperature is the reason behind heat's and thermal energy's existence. This might be due to the fact that Ekin understood temperature the best among these three concepts (heat, temperature and thermal energy). Although she is not able to define temperature precisely, she is able to describe what it is and what it is not. She also thinks that particles in the matter move and this is related to temperature. The fact that Ekin had the idea that heat is a type of energy stored in a matter because of particles and that she asserted thermal energy is related heat might be the reason why she made this association. Relationships between these three concepts remained this way until she managed to define the concepts of heat and thermal energy on a scientific basis. Streveler et al. (2003) stated that students do not understand the relationship between heat and energy and the relationship between temperature and energy. According to them, students' failure to make the connection lead to many misconceptions related to heat and temperature.

Throughout the process, Ekin never mentioned the relationship between temperature and thermal energy, $E = 3(1/2.k.T)$. However, she mentioned the idea that "particles of hot matter are more active". The connection she made between the motion of particles and temperature and heat allowed her to make a similar connection between temperature and heat. She thought that heat is the total kinetic energy of particles and that temperature is an indicator related to the mean kinetic energy of particles. In other words, she made a connection between heat and temperature, which should have been made between thermal energy and temperature. This is especially evident in her idea that "the temperature does not change, but the heat increases when the matter's mass increases". In short, she confused the concepts of heat and thermal energy.

By changing her definition of heat in the fourth week, her idea about the relationship between heat and temperature changed as well. While at first, she made a connection between heat and temperature, which should have been made between temperature and thermal energy, and asserted that temperature is the source of heat, later she associated heat with "temperature difference". In other words, she asserted that there had to be a temperature difference to talk about heat. This is consistent with scientific theories.

In conceptual learning, some researchers think that some factors must change. Kalem et. al. (2002) think that some changes are needed in curricula and Leite (1999) thinks that some changes are needed in textbooks in order to teach heat and temperature concepts more effectively. But most of the researchers focus on conceptual changes and how much simplifications are needed for concepts to be learned.

Carlton (2000), in his paper; acknowledges the difficult nature of the concepts involved for most learners; points out that pupils are likely to come to lessons with their own alternative ideas in place; stresses the importance of making learners' existing ideas explicit, and using them as a starting point for constructing scientific understanding; attempts to tease out a level of presentation that is both simple enough for pupils to understand and adapt, and yet is scientifically valid. With Carlton, Taber (2000) would agree that it is sensible to teach about heat and temperature without introducing the complication of work done by changes in volume. This can be learned about later as an additional factor that does not fundamentally change the concepts of heat and temperature. However, he does not accept Carlton's approach to defining heat as the energy that has been transferred, and temperature as a measure of the concentration of heat energy. Although this leads to a simpler scheme, it also leads to logical inconsistency, and the potential for much confusion later.

During the interviews with Ekin, we examined her concept acquisition and imprinting process, as well as changes in her conceptual construct. One of the characteristics observed in Ekin was that while she provided some memorized information, she had not internalized the information in question. These were as if she memorized then as commonly used sayings. Sometimes these cliched statements such as "temperature is not a type of energy" worked, but more often than not these statements were not supported with any actual knowledge. Sometimes Ekin's answers could not go beyond being intuitive. Studies show that many students, similar to Ekin, have a readiness based on experience and intuition (Clough & Driver, 1985; Erickson, 1979; Erickson & Tiberghien, 1985; Rogan, 1988; Tiberghien, 1980). However, Ekin gave up her intuitive answers and memorized sayings, and adopted a more inquiring approach. The study conducted by Harrison et al. (1999) supports this idea. Results of their study show that students have increased responsibility for their own learning, are able to take mental risks, become more decisive in the solution of written and verbal problems, and learn how to criticize themselves throughout the process of a conceptual change.

Another characteristic observed in Ekin is that her conceptual knowledge was disconnected. Her memorized sayings and pieces of thought and information resembled independent isles. She had difficulty making connections, switching between pieces of information, and using a specific piece of knowledge in another situation. It is impossible for the student to understand the subject with this type of disconnected knowledge. This may be because she stored the information in her mind without internalizing and without associating them with her own experiences and everyday life. This prevents students from constructing their knowledge (Mäntylä, 2006).

Throughout the process, the researchers sensed that Ekin experienced flashbacks. While her idea on a certain subject seemed to have changed, she came back to her previous thoughts in the next interview. Although she made progress in general, it was in the form of a process of change with ups and downs. Also, similar to some other studies (Jara-Guerrero, 1993; Kesidou & Duit,1993; Lewis & Linn, 1994), it is found in this study that the student had certain misconceptions or incomplete information related to certain concepts. The fact that some misconceptions remained even after the PBL process shows that these misconceptions are more resistant to conceptual change (Carlton, 2000; Hewson & Hewson, 1991; Thomaz et al., 1995). According to Lewis and Linn (1994), even scientists may have such misconceptions. This is also supported by other studies (Leura, Otto, & Zewitz, 2005; Lewis & Linn, 1994).

Scientific theories define thermal energy and heat as different concepts. However, it is seen that these two concepts are sometimes used interchangeably by students. In order to prevent this misconception, the thermal energy concept should be given more emphasis in the curriculum. It may also be beneficial to teach it before the heat concept. Because students may have a gap in the total kinetic energy of particles. They can need to define it. If they don't know anything about thermal energy, they can define it as heat, the dimension of which is energy. Otherwise, this can allow students to understand the heat concept better and prevent certain misconceptions such as the idea that heat is a type of energy stored in matter. The relationships between temperature and thermal energy should be given in detail, beginning with the equation $E = 3(1/2.k.T)$. Also, the temperature measured in Kelvin should be dwelt on more.

Particularly in physics courses, the idea that "the energy lost due to friction turns into heat" should be abandoned. It should suffice to say that the kinetic energy lost turns into another type of energy. However, insistently saying that it turns into heat makes it more difficult for students to understand the heat concept. A similar case applies to "heat loss" as well.

Misconceptions about heat may be related to misconceptions about other concepts. Misconceptions related to vibration, energy, momentum and general mechanical concepts may prevent students from understanding concepts related to heat and temperature. For this reason, eliminating misconceptions related to the former may be effective in eliminating misconceptions related to the latter.

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