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Effect of Conceptual Change Oriented Instruction on Students' Understanding of Heat and Temperature Concepts

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Abstract:

This study explores the effectiveness of conceptual change oriented instruction and standard science instruction and contribution of logical thinking ability on seventh grade students' understanding of heat and temperature concepts. Misconceptions related to heat and temperature concepts were determined by related literature on this subject. Subsequently, the Heat and Temperature Concepts Test was developed. The study involved a total of 74 seventh grade students in two classes. 38 students were taught by means of conceptual change oriented instruction, and 36 students in a control group followed standard science instruction. Both groups received identical instruction and laboratory experiments, however the experimental group followed conceptual change conditions while doing experiments. Prior to instruction, students in both groups were pre-tested in order to determine their understanding of heat and temperature at the beginning of instruction. Students taught by means of conceptual change oriented instruction outperformed students who received traditionally designed instruction. Results indicated that students' logical thinking ability accounted for a significant variation in heat and temperature concepts achievement.

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One of the important findings of science education research is that students come to science classes with a wide range of preconceptions. The experiences gained by the individual form the basis of these self constructed conceptions. These conceptions are usually not consistent or partially consistent with scientific view and called *preconceptions* (Clement, 1982), alternative conceptions (Dykstra et al., 1992, Heller and Finley 1992; van den Berg and Grosheide, 1993; Petersson, 2002), *alternative frameworks* (Muthukrishna et al., 1993; Stromdahl, 2002), or *misconceptions* (Andre and Ding, 1991; Brown and Clement, 1989; Caillot and Xuan, 1993) by different authors. A misconception is more than having an incorrectly memorized fact. It originates from an inaccurate/inadequate mental structure that underlines one's thinking of a group of related concepts.

Since physics is a conceptual subject, misconceptions in physics develop at very basic levels and research in physics education has shown that students have misconceptions almost in all topics of physics such as mechanics (i.e., Clement, 1982; Minstrell, 1982; Trowbridge and McDermott, 1980, 1981; Hestenes et al., 1992), electricity (i.e., Fredette and Lochead, 1980; Cohen et al., 1983; Idar and Ganiel, 1985; Dupin and Johsua, 1987; Heller & Finley, 1992; Maloney et al., 2001), optics (i.e., Goldberg and McDermott, 1986, 1987; Feher and Rice, 1992), and thermodynamics (i.e., Ericson, 1979; Shayer and Wyllam, 1981; Bar and Travis, 1991; Athee, 1993; Ma-Naim, Bar, and Zinn, 2002).

By the time children enter school and are faced with formal instruction in science, their preconceptions are the predecessor of the concepts, principles, and theories that they will be faced with during their physics lessons. Usually these preconceptions become serious problems while learning scientific concepts. Therefore, one of the factors affecting students' learning in science is their existing knowledge prior to instruction. It is well understood in the physics community that misconceptions must be addressed if they are to be changed. If not confronted at the right time, they appear in the students' conceptual framework even up to their undergraduate level. The present study was conducted on the design and implementation of a teaching model aimed to change misconceptions on heat and temperature.

Misconceptions Related to Heat and Temperature

One problematic aspect about heat and temperature is that they present abstract, theoretical concepts. Ideas about heat and temperature are developed at a very early age and everyday experiences form the basis for these ideas. Almost all children have self explanations and constructs about heat and temperature. The most impressive findings of the research related to heat and temperature concepts have shown that these constructs are usually wrong. On the other hand cultural factors also play a role in students' understanding of heat and temperature (Lubben, Nethisaulu, and Campell, 1999). So, it is natural that students come into science classes with common and widespread misconceptions related to heat and temperature concepts.

Misconceptions related to heat and temperature usually involve substance-based conceptions (Ericson, 1979, Harrison, Grayson, and Treagust, 1999). For example students thought that heat is a substance, something like air or stream (Ericson, 1979; 1980; Jara-Guerro, 1993). Students usually use heat and temperature interchangeably (Ericson & Tiberghien, 1985, Jara-Guerro, 1993). Thomaz et al (1995) found that students have a great difficulty in accepting that different objects are at the same temperature when in contact with the same surroundings for a long time. The temperature of an object is seen as a characteristic of the material from which the object is made. Common misconceptions related to heat and temperature are listed Appendix A, collected by an investigation of research related to heat and temperature concepts (Ericson, 1979; 1980; Shayer and Wyllam, 1981; Bar and Travis, 1991; Kesidou & Duit 1993; Jara-Guerro, 1993; Lewis and Linn, 1994; Harrison, Grayson, & Treagust, 1999; Jones, Carter and Rua, 2000).

Research on student' misconception has shown that they are resistant to change (Driver, 1989; Hameed, Haekling, & Garnet, 1993; Osborne & Freyberg, 1985). Even high school students have great difficulty with energy concepts, the particle model, and the distinction between heat and temperature (Kesidou & Duit, 1993). Furthermore, some students complete thermodynamic courses with many of their misconceptions unchanged (Thomaz et al., 1995; Carlton, 2000). It can be deduced that the instruction they receive left their misconceptions unaffected. Moreover, not only students but scientists also have difficulties with heat and temperature concepts. Although they may make more accurate predictions than students, they have difficulty in explaining everyday phenomena (Lewis & Linn, 1994; Tarsitani & Vicentini, 1996).

There is some research that examines misconceptions related to heat and temperature. Thomaz et al. (1995) showed that a constructivist teaching approach promotes better understanding of the phenomena of heat and temperature. Harrison, Grayson, and Treagust (1999) used an inquiry-based teaching model coupled with concept substitution strategies to restructure alternative conceptions related to heat and temperature concepts. He found that students progressively accepted greater responsibilities for his learning related to heat and temperature concepts, were willing to take cognitive risks, and become more critical and rigorous in both written and verbal problem solving. Ma-Naim, Bar, & Zinn (2002) used a conceptual change oriented approach to improve teachers' understanding of thermodynamics concepts. Their results implied that teachers in the conceptual change approach teaching model have grater gains than their control group counterparts. Another inquiry based teaching method was used by Jabot and Kautz (2003) to show the effects of the teaching and preparation of the physics teacher on the topic of thermodynamics. Their results suggested that the guided inquiry group had greater learning gains. Clark and Jorde (2004) analyzed the effect of an integrated sensory model within thermal equilibrium visualizations. They found that students in the experimental tactile group significantly outperformed their control group counterparts on posttests and delayed posttests. Findings of these researches show that instruction aimed to change students' alternative conceptions related to heat and temperature is effective.

Conceptual Change

Since misconceptions are very stable in general, traditional instruction is not sufficient to remediate them (Hestenes 1987; Dykstra et al. 1992; McDermot and Shaffer 1992; White 1992). Overcoming misconceptions is not simply adding new information to the individual's mind, but care should be taken to ensure the interaction of new knowledge with existing knowledge, provided that the new may be replaced with the existing (Hewson and Hewson 1983). Replacing the existing faulty knowledge with the scientifically sound one is one of the aims of conceptual change (Posner at al. 1982; Hewson and Hewson 1983; Novak 2002).

Assimilation and accommodation, introduced by Piaget (1950), are considered to be necessary conditions for conceptual change. Assimilation refers to the recognition of a physical or mental event fitting into an existing conception. When an event cannot be assimilated under held conceptions, then accommodation takes place. It is a change in a conception. A student must enter a state of cognitive disequilibrium for accommodation to occur. If the result of an event does not fit the student's existing conceptions, this situation disequilibrates the student with respect to his current concept. If students can assimilate the concepts presented, then there is no disequilibration and no conceptual change. Conceptual change can be achieved by disequilibration, which is the result of an unexpected event. Therefore, instruction should aim to disequilibrate students for conceptual change (Dykstra, 1992).

Different researchers have used different terms for conceptual change such as weak and "strong restructuring" (Carey 1985), "branch jumping" and "tree switching" (Thagard, 1991), "conceptual capture and conceptual exchange" (Hewson & Hewson, 1992), "differentiation and reconceptualization" (Dykstra, 1992) and enrichment and revision (Vosniadou, 1994). Each of the theoreticians has developed his own terminology, but there is common ground between the various perspectives of conceptual change. Conceptual change involves changes in students' assumptions about the world and knowing.

Use of a conceptual change learning model is one way of closing the gap between children's science and scientists' science (e.g., Hewson, 1981, Posner e al., 1982). Most of the earlier methods developed to deal with student misconceptions depend on Piagets' ideas and notions of constructivism (Gega, 1994; Hewson & Hewson, 1983; Hynd et al., 1994; Stofflett, 1994; Posner et al., 1982). These methods suggested creating dissatisfaction in the student with his alternative conception, followed by strengthening the status of the preferred scientific conception. Posner at al. (1982) suggested four conditions: (1) students must become dissatisfied with their existing conceptions (dissatisfaction); (2) the new concept must be clear and understandable for students (intelligibility) (3) the current problem should be solved by using the new concept (plausibility); (4) similar future problems can be solved by using the new concept (fruitfulness). In this study, these are referred to as "conceptual change conditions." Teachers should develop strategies in accord with conceptual change conditions in order to create cognitive conflict in students, organize instruction to diagnose errors in students' thinking, and help students translate from one mode of representation to another.

Method

Purpose

The purpose of this study was to examine the higher effectiveness of conceptual change oriented instruction (CCI) over standard science instruction (SSI) on seventh grade students' understanding of heat and temperature concepts. The specific questions that were answered by ANCOVA of this study were:

1. Is there a significant difference between effects of CCI and SSI on students' understanding of heat and temperature concepts?
2. What is the contribution of students' logical thinking ability to variation in students' understanding of heat and temperature concepts?

Subjects of the Study

The subjects of the present study consisted of 74 seventh grade students (39 boys and 35 girls) from two classes of a science course taught by the same teacher in an urban high school in Turkey. The students' native language and language of instruction was Turkish. The students' ages ranged from 12 to 13 years. Each of two instructional methods was randomly assigned to one class after individuals were already in each class. The data were obtained from 38 students in the experimental group and 36 students in the control group.

Design and Instruments

Each classroom was randomly assigned to one of the experimental instruction group (n=38) or to a traditional instruction group (n=36) that served as the control.

Heat and Temperature Concepts Test (HTCT). This test was developed by the researcher. The test consisted of 25 multiple choice questions. Each question had one correct answer and three distractors. The items used in the test were related to heat and temperature concepts. Each item measures a specific learning outcome. During the developmental stage of the test, the following procedure was followed: first, the instructional objectives of the unit thermodynamics were stated. Second, a list of students' misconceptions[1] in heat and temperature was constructed by a careful examination of related literature (e.g., Ericson, 1979; 1980; Shayer & Wylam, 1981, Ericson & Tiberghien, 1985; Thomaz et al., 1995; Chang, 1999; Harrison, Grayson, & Treagust, 1999; Leite, 1999; Carlton, 2000; Jones, Carter, & Rua, 2000; Clark & Jorde, 2004). The list of students' misconceptions used in the test is given in Appendix A. Lastly, the test items were constructed in such a manner that each distractor item brings out students' misconceptions related to heat and temperature concepts. Hence the purpose of the test was to measure students' understanding of heat and temperature concepts, all items in the test were conceptual and no quantitative calculations are needed to answer the questions. The pilot study of this test was applied to 211 eighth and ninth grade

[1] In this study the term 'misconception' was used to refer to mistaken answers given by students, student's ideas about particular situations, and students' fundamental beliefs about how the world works.

students. The reliability of the test was found to be .79. The pilot study results of analyzing the students' answers of the test were in agreement with the studies in the literature in which the students had the same misconceptions related to heat and temperature (see Appendix B for sample items).

In order to investigate the effect of treatment on students' understanding of heat and temperature concepts, HCTC was applied as a pre- and post-test to all students.

Logical Thinking Ability Test (LTAT). The test was originally developed by Tobin and Capie (1981). Prior to the experimental study, the test was administered to all students to determine and control their reasoning ability at the beginning of treatment. This instrument is composed of 10 items and 5 subscales consisting of factors that relate to identifying and controlling variables, and to proportional, correlational, probabilistic, and combinatorial reasoning. The reliability of this test was found as .81.

Treatment

Duration of the study was approximately 4 weeks. A total of 74 students were enrolled in two science classes of the same teacher in an urban high school. There were two modes of treatment in this study. The control group received Standard Science Instruction (SSI). The experimental group was taught by means of Conceptual Change Oriented Instruction (CCI) that met conceptual change conditions.

Both groups received identical standard science instruction in teaching hours (2 hours per week) that used teacher-directed strategy. In this paper standard science instruction refers to the following teaching strategy. The teacher followed lecture and discussion method to teach concepts in thermodynamics. The students studied the physics textbook on their own before the class hour. The teacher structured the entire class as a unit, wrote notes on the board about the definition of concepts, and solved a number of quantitative problems. The main principle was that knowledge resides with the teacher and that it is teacher's responsibility to transfer knowledge to students. When the teacher finished her explanation, some concepts were discussed through teacher directed questions. The teacher solved some problems in their textbook on the board. The classroom typically consisted of the teacher presenting the "right way" to solve problems.

Both groups has two hourly laboratory sessions per week. Both groups did the same experiments. The difference between the two modes of instruction is that, the experimental group did their experiments by following conceptual change conditions. Since this is the only difference between the two modes of instruction, it is believed that this study explores the effectiveness of conceptual change conditions on students' understanding of heat and temperature concepts.

To explore the difference between the two types of instruction, here is an example. The first experiment was "Estimating Temperature with Sensation." In this experiment students were provided with three bowls containing water at different temperatures: 0 ^{o}C (yellow bowl), 25 ^{o}C (green bowl), and 40 ^{o}C (brown bowl). In the control group, they were asked to place one hand in the yellow bowl and the other hand in the brown bowl. They were asked which one is "hot" and "cold". After a minute they were asked to place the cold hand in the brown bowl and described the temperature as being hot. Next the hot hand is placed in the brown bowl and this time the temperature is described as being cool. Then they were asked to write a report for the experiment. The author read reports written by students. This is a typical standard laboratory session as suggested by most of lab manuals of the textbooks.

In the experimental group the same experiment was done with conceptually conflicingt situations and questions. To activate students' misconceptions about determining temperature with sensation, students were given the following situation: On a cold winter day, a child in the room washes his hand with water flowing from the tap. She said that the water is very cold. Another child just come from outside, washed his hand with the same water flowing through the same tap. She said that the water is considered to be lukewarm. The students were asked to discuss who was correct about the temperature of water flowing through the tap. This situation created a conceptual conflict in their mind about determining temperature through sensation. Then to get a correct conclusion, they were motivated to do the experiment "Estimating Temperature with Sensation" as described above. After the experiment they were asked to measure temperatures with a thermometer. The students were asked to think about determining temperature with sensation. This satisfied the first stage of conceptual change conditions, that is, students were dissatisfied with their existing conception. Next, students were asked to estimate temperatures of the wooden and iron part of their desk by touching them. This time most students said that although the iron part of the desk felt colder than the wooden part, saying iron part is cooler might not be correct. This is because they have understood that sensation is not reliable for determining temperature. Then students were asked to measure temperatures of each part. They saw that both of them were at the same temperature. Students were told that what you sense when touching an object is the energy transferring between your finger and the object. It was not the temperature. It was explained that temperatures of objects that had been at the same place for a long time were the same, although one might feel that their temperatures were different. This was clear (new conception is intelligible) for most of the students and solved current problem (new conception is plausible). The new conception may be used to explain similar situations that students may encounter. For example they would understand why sitting on a stone feels colder than sitting on a stool.

Results

In order to investigate the effect of treatment on the dependent variable and control the students' previous learning with respect to heat and temperature concepts and their logical thinking ability before the treatment, all of the subjects were administered two pre-tests (HTCT and LTA). Data related to pre- and post-test is presented in Table-1. It was found that there was no significant difference between CCI group and SSI group in terms of achievement ($t=0.70$, $p>0.05$) and logical thinking abilities ($t=0.20$, $p>0.05$) before the treatment.

		PRE				POST	
		HTCT		LTA		HTCT	
Group	N	M	SD	M	SD	M	SD
CCI	38	12.94	3.30	3.86	0.99	16.05	3.79
SSI	36	13.50	3.46	3.91	1.05	19.60	3.85

Table 1: Means(M) and Standard Deviations (SD) of pre- and post- test results of Heat and Temperature Concepts Test (HTCT) and Logical Thinking Ability Test (LTA)

After treatment, the effects of the two modes of instructions on students' understanding of heat and temperature concepts were determined by means of analysis of covariances (ANCOVA) by controlling the effect of students' logical thinking ability as a covariate. The summary of analysis is given in Table 2. The analysis shows that the post-test mean scores of CCI group and SSI group with respect to the achievement related to heat and temperature concepts were significantly different. CCI group scored significantly higher than SSI group ($\overline{X}_{CCI} = 19.60, \overline{X}_{SSI} = 16.05$).

Source	Sum of squares	df	Mean square	F	*p*
Covariate (Logical Thinking Ability)	571.68	1	571.68	84.69	0.00*
Treatment	250.59	1	250.59	37.12	0.00*
Error	479.28	71	6.75		

* $p < 0.05$

Table-2: ANCOVA Summary (Group vs. Achievement)

The misconceptions reflected by the distracters of the heat and temperature test items are the common misconceptions in a particular thermodynamic topic. The post-test average percentage of correct responses of the experimental group was 78.4% and that of the control group was 64.2%. When the proportion of correct responses and misconceptions determined by the item analysis for the experimental and control groups was examined, remarkable differences between the two groups in favour of the experimental on several items were indicated. For example, 84.2% of the students who received CCI abandon the idea that temperature can flow one substance to another. However, 41.7% of the students in SSI still thought that temperature flows from hot substance to cold substance. In a question students were asked which material should be used to keep a cola pan as cold as possible for a period of time. 50.0% of the students in the SSI group still thought that aluminum foil is the best material to keep substances cold. On the contrary, only one student chose aluminum foil in the CCI group. The rest of the students in CCI group selected wool fabric for this question. On the other hand, almost all students in both group selected wool fabric for keeping materials as hot as possible for a period of time (2 students in SSI group and 1 student in CCI group made the wrong choice) in the pre-test, whereas 58.1% of all students (both in CCI and SSI) gave correct answer for this question in the post-test.

Another common misconception held by students was that heating always means increasing the temperature (87.8 % of all students in the pre-test). In the experimental group only 3 students (0.08%) made the wrong choice in the question measuring this item. However, 33% of the students (12 students) in the control group still held this misconception.

The results (Table 2) showed that the contribution of students' logical thinking ability to the variation in their achievement related to heat and temperature concepts was significant. Consequently, it can be said that the logical thinking ability accounted for a significant variation in achievement related to heat and temperature concepts.

Discussion and Implications

This study has examined the relative effectiveness of conceptual change oriented instruction as opposed to the standard science instruction in heat and temperature related science topics. Results revealed that conceptual change oriented instruction caused a significantly better acquisition of scientific concepts related to heat and temperature than the standard science instruction. Thus, the conceptual change oriented instruction described in this study appeared to be successful in changing students many misconceptions related to fundamental ideas about heat and temperature. It can be said that the main difference between the control and experimental group instruction is the focus on students' misconceptions. So, if students are drawing on common misconceptions to make sense of new phenomena, the teachers can use this as a tool when designing their instruction.

Conceptual change methods that were built upon constructivism can be used to take students' misconceptions into account when designing instruction. The method of dealing with misconceptions was to use strategies of conceptual change designed to promote the acquisition of new concepts as a consequences of the exchange and differentiation of the existing concepts and the integration of new concepts with existing concepts. The conceptual change approach offered a set of guidelines to help students gain experience in grasping the concepts. These guidelines provided special learning environments such as identifying common misconceptions about heat and temperature, activating students' misconceptions by presenting simple qualitative examples, presenting descriptive evidence in class that the typical misconceptions are incorrect, providing a scientifically correct explanation of the situation, and giving students the opportunity to practise the correct explanation by using questions. It would also appear that a reason for the poor progress of the students in the standard science instruction group in acquiring scientific concepts lies with the continued presence of the alternative concepts in their conceptual framework. The improved achievement to remove misconceptions related to heat and temperature apparently resulting from the conceptual change approach emphasis, is consistent with the result of similar studies in this area (e.g., Guzetti et al., 1993; Hynd et. al., 1994; Wang & Andre, 1991; Sungur et al., 2001; Diakidoy et al. 2003). The more established misconceptions are likely to be more useful to the individual and therefore more difficult to eliminate. The instructional strategy has to be designed in such a way that the individual is convinced that the scientifically sound concept is more useful than the existing alternative conception. Well-designed conceptual change approach to science instruction represents an alternative approach which encourages students to alter preconceptions and is based on the constructivist approach. It means that the alternative conceptions can be reduced even if not completely eliminated in the course of instruction. The nature of the conceptual change approach can enable the students to progress at their own pace and to encourage students to use their thinking ability. Science educators must become more involved in developing and designing the optimum conceptual change instruction and teachers must be informed about the usage and importance of conceptual change conditions, and they must plan the instructional activities accordingly. Addressing the question of how to teach science is central in any science teacher program. Teachers have had difficulty understanding constructivism and its role in classroom practice (Clements, 1997; Peterman, 1993). Teaching for conceptual change should be the particular focus of some courses related to teaching methods and teaching practice in teacher education programs. This facilitates prospective teachers' learning to teach for conceptual change (Marion et al., 1999).

Although the results indicated a significantly greater acquisition of scientific concepts in the group who received the conceptual change oriented instruction than in the group who received the standard science instruction, it must be pointed out that the students utilizing the conceptual change oriented instruction still did not have an excellent understanding of the scientific concepts after instruction. There is therefore room for improvement in effecting conceptual change from existing alternative concepts to scientific concepts.

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Appendix A: List of Common Student Misconceptions Probed by HTCT

1. Heat and temperature are the same.
2. Temperature depends on size (or mass of substance).
3. Temperature of a substance is related to amount of air in it
4. Temperature can flow from one substance to another.
5. Temperature of a substance depends on the material that itnis made of.
6. Temperature is a measure of heat.
7. Temperature is a measure of hotness or coldness.
8. There are two kinds of heat, cold and warm.
9. Hotness or coldness are characteristics of subjects
10. Heat is a physical substance (Choleric point of view).
11. Heat is the energy of a hot substance
12. Time required for heating and cooling does not depend on volume or mass
13. Liquids are cooler than solids in the same surroundings
14. Among the same subjects to be heated, absorption of heat depends on size (or mass) of the subject
15. Materials have specific breakpoints to heat
16. When two liquids are mixed, temperature of the mixture is the sum of temperatures of liquids
17. Woolen materials are best for keeping subjects hot, not for keeping subjects cold and aluminum foil is the best material for keeping subjects cold
18. Heating always means increasing temperature
19. Temperature at phase change is the maximum temperature that a substance can have.

Appendix B: Example items from heat and temperature concepts test

500 gram of iron ball, 250 gram of iron ball and 250 gram of wool are in the same room for a long time. Which of the following is/are true for the temperatures?
A) Temperature of wool is highest
B) Temperature of 250 gram of wood block and 250 gram of wool are the same
C) Temperatures of wood blocks are the same and lower than wool.
D) Temperature of 500 gram of iron ball is highest.

A wood block of 550 gram and an iron boll of 500 gram are under the sunlight for an hour in a hot summer day. Which of the following can be said about these objects?
A) Their temperatures are the same.
B) Temperature of the iron ball is higher than the wood block.
C) Temperature of the wood block is higher than the iron block.
D) Both have the same internal energy.