AN INVESTIGATION OF THE HEAT CONCEPT WITH COMPUTER MODELS

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Abstract. The purpose of this study is to investigate how students understand thermodynamic concepts such as temperature, heat and energy, and how they can enhance understanding of these concepts more easily via computer models. Students often show difficulties imagining matter molecules, temperature, heat and heat energy, some of the subjects studied at high schools in most of developed countries. Semi-structured interviews and written exams were used to explore students' ideas and their mental models. In addition, computers and computer applications are used for this purpose. With 6th grade students, computer models are compared with the traditional educational methods currently dominant in Turkey. They are considered to possess some level of developed concepts of temperature, heat, energy, and matter structure because they have already taken some fundamental courses on these topics. The implications and recommendations for pedagogy are discussed in the conclusion section of this paper.

Keywords: interactive learning environments, computers in education, simulations, secondary education

Introduction

Model concept

Every student learns best in various ways such as hands-on and touching, hearing, and seeing. Different methods and means can be used (White & Gunstone, 1992; Tunnicliffe & Reiss, 1999). Since educators employ several methods, because students are incapable of carrying out complicated experiments themselves, and applied (practical sessions) are unproductive because students tire rapidly, applied classes do not yield the desired result. Therefore, science educators utilize a variety of models in order to help students understand scientific concepts.

Prior to investigating the topic, the assets of a model should be first discussed. A model is defined as the symbolization or the visual demonstration of a phenomenon, a matter or an idea (Gilbert et al., 2000). The model is related to some characteristics of the targeted issues. From some aspects, the characteristics of the target should be established with the model (Driel & Verloop, 1999). An example could be depicting the mitochondria, the cells' power sources.

Models in science education

Different types of models can be used in science education (Ornek, 2008): (1) conceptual (mathematical, computer, physics) models; (2) mental models.

(a) Conceptual models

Computer models are primarily designed to enable phenomena in students' real world to be expressed quantitatively or visually. Different software is used to this end. This software could be models, animations or simulations (Holland, 1988). Some computer programs may ease the analysis of very complicated systems to a great extent. It can be particularly hard at times to define or analyze mathematical problems by means of computers (Chabay &

Sherwood, 1999). To this end, many commercial packages have been developed in a student-friendly manner. These mentioned packages, are usually animation or simulation programs.

By means of pictures, two- or three-dimensional animations, graphics, vector and quantitative data display, computer simulations help students to comprehend particularly complicated topics (Sherer et al., 2000). Students cannot analyze these complicated topics by computer programming (given that programming is in itself a complicated task). However, packages, flash programs or java applets can help overcome this problem. The only thing students need do is to change the parameters. In this case, students can develop a model by themselves, rather than writing a whole program from scratch. Therefore, both teachers and students can use special ready-made computer simulations conveniently in fields such as chemistry, biology and physics alike.

(b) Mental models

The concept "mental model" is attributed to the Scottish psychologist Kenneth Craik. According to Craik, concepts formulated in the mind are small-scale models of reality for predicting future events and explaining concepts (Craik, 1943). To Craik, the mental models are dynamic symbols of the outer world. Johnson-Laird (1983) developed a mental model theory and interpreted it as the various explanations of an event in the mind. Mental models are representatives of this meaning. This is not a logical structure (such as in propositions) or representation of some artificial concept (such as circles standing for sets), merely the existence of a simple object in relation to a situation. Obviously, a simple idea can be expanded and represented. However, the advantage of such an idea is its simple and natural representation of the world. Johnson-Laird demonstrated that, with the assumption that there is no capacity limit; the mind pioneer can achieve logically valid results with mental models.

Franco also defined mental models as psychological representations of reality and dreams. He contended that these occur in the human mind as human perceptions and concepts (Franco & Colinvaux, 2000). According to Gentner & Stevens (1983), mental models affect our comprehension of knowledge and perception of events associating new knowledge to prior knowledge. Other researchers defined the mental models as inner reflections of our knowledge about the world (Coll & Treagust, 2003; Gentner and Stevens, 1983; Gilbert et al., 1998, 2000; Johnson-Laird, 1983). In addition, it is known that mental models change according to people's points of view of events.

Background

The concept of energy and heat in the science education literature

The topic of energy and students' difficulties in learning has been an intriguing research subject in science education. Many researchers have focused on how students learn energy concepts (Watts, 1983; Duit, 1984; Solomon, 1983, 1992; Trumper, 1993). The main point of this body of research pioneered some important findings by encouraging students to focus on energy as a concept that is an aspect of living organisms, to relate it to daily life and to tackle it in general along with the concept of motion (Solomon, 1992).

Yeşilyurt (2006) contributed to these studies with his research employing interviews and written exams administered to high school students in Turkey. He observed that students had some conceptual errors regarding temperature and heat. He observed that although students answered correctly how matter is heated, they had misconceptions or misunderstandings about how heat is spread. He found 60 per cent of the students understood the concepts of heat-temperature; however, they didn't have a mental model.

Liu & McKeough (2005), also, focused on the concept of energy. Their study observed students at three stages. The first stage was vector section 1 (i.e., ages 11-13), the second was vector section 2 (ages 13-15) and the third stage was vector section 3 (ages 15-19). They observed that while life experiences increased towards adolescence, accompanied by an increase in experiences regarding the concept of energy, the concepts regarding the relationship between energy resources and forms originated in vector section 1 at the first stage. They realized that once this coordination took place, students were able to conceptualize energy transfer (e.g., energy from a generation station travels to a house to run the furnace and the furnace in turn heats the house). Following the hypotheses of Liu & McKeough, students reached a bifocal way of thinking and passed to the second section of the second stage when they, at the age of 13-15, realized that the heat produced is, in fact, energy loss. Understanding the concept of energy loss, students then focused on both energy used for work and energy loss. In the third section of the third stage, adolescents at the age of 15-19 conceptualized energy for diverse systems, and they could measure the energy in a closed system. According to researchers, this stage is when the concept of energy is fully understood.

Method and material

Many researchers have investigated the effects of computer models in education and learning systems. The effect of software simulation has been studied using the curriculum that best supports student learning. 'Vacuum and Particles', a unit that explicitly addresses students' difficulties, is available in Israel (Nussbaum, 1996). A longitudinal study conducted on 1,302 middle school students showed that over 80% of the students who used 'Vacuum and Particles' experienced a conceptual change regarding the particulate nature of matter in contrast to far less change in the control group who studied 'Into the Matter.'[1)]

Research sample

The subjects of this study were teachers and 37 6th grade students (age 11-12) from the same school located in the Central Anatolian region of Turkey. Groups were randomly selected as a control group (n = 17; 4 girls and 13 boys) and an experimental group (n = 20; 6 girls and 14 boys). Only students that responded to the pre-test and the post-test were included in the study. The teachers told the experimental and control groups what they should do. Then they guided them; finally the teachers exchanged their groups.

Research design

1. First step

(a) The first chapters of the units ‘Matter’ and ‘Heat and Energy’ were taught to each group. These chapters presented concepts such as matter, properties of matter, heat energy, heat transfer and phases of matter. In addition, the concept of matter being made up of small particles was introduced; (b) A pre-exam questionnaire was administered.

First teachers taught the subjects of heat and temperature. They used classic educational methods and employed a pre-exam and semi-structured interview (Eq. A.). This classic exam was worth 70 points. Its purpose was to evaluate the students’ pre-knowledge of energy and heat energy.

Many statistics programs were used to carry out data analysis and data collection. In particular, SPSS was very useful. The SPSS program can calculate a lot of factors and tests. In this study the SPSS program was used both for data collection and data analysis. This program made it easy to calculate the t-test and F test value. In addition, the examination results of male and female students were also compared, see Table 1.

Table 1. Comparison of girls and boys pupils for control group in the pre-exam

Pupils	N	Mean	Standard Deviation	Standard Error
Girls	4	22,50	5.00	2.50
Boys	13	20,00	7.00	2.00

As shown in Table 1, the female students' mean was 22.50, while the male students' mean was 20.00. Therefore, there was no important difference between the two.

2. Second step

(a) The chapter, 'Heating and Cooling, and Heat Transfer' was taught for six class periods to the control and experimental groups. The students were taken lessons in the laboratory for three hours. Computerized simulation was only used the experimental group; for this purpose a heat and energy simulation was taken from the website;[2)] (b) A post-exam questionnaire was administered; (c) 17 students from the experimental group and 20 students from the control group were interviewed.

In the second stage, teachers explained the concepts and the lesson. At this point the computer simulations with the interactive program, shown in Fig. 1, were used. These were applied to post-exam. This, therefore, facilitated a comparison of the students' success. Then, a post-exam and a semi-structured interview were conducted with the students, (Eq. B.). This exam was worth 60 points. Also, ANOVA was applied and F and t values were calculated through the SPSS program.

Fig. 1. An interactive programme about heat

The SPSS program was used in the same way as in the first step. Results were examined to see whether there was any difference between female and male students in terms of success (see Table 2). The number of female students in experimental group was less than that of male students.

Table 2. Comparison of gurls and boys pupils for experimental group in the pre-exam

Pupils	N	Mean	Standard Deviation	Standard Error
Girls	6	20,83	4,91	2,00
Boys	14	20,35	3.07	0,82

As seen in Table 2 the scores of female and male students were found to be nearly the same. The female students' mean was 20.83, while male students' mean was 20.35. Standard deviation and mean were very important in showing that there was no difference. The standard deviations of female and male students were 4.91 and 3.07, respectively. Thus no difference was found.

Curricular components included: (a) The chapter 'Heating and Cooling, Expansion and Contraction, Heat transfer' from 'Matter and Molecules'; (b) The software simulation from the yteach Internet site; (c) Interactive software that compares the simulation with particles.

'Heating and Cooling, Heat Transfer, Heat and Temperature': The development of 'Matter and Molecules' involved two cycles of research and development. It led to significant improvement in student learning although some difficulties remained (Lee et al., 1993). This unit takes account of students' prior knowledge, provides a wide variety of macroscopic experiences accompanied by molecular explanations and systematically guides student interpretation of their experiences.

Computerized simulation: 'yteach internet site'[3)] consists of interactive software programs. This site includes 155 animations about Energy Resource and Energy Transfer in Key Stage 3. In addition, it includes animation of solids, liquids and gases and interactive programs. It shows 'particles' in the three phases of matter, and shows their constant motion and the interaction among them. In the interactions programs on this site, students are able to observe and track an individual particle in a variety of conditions (temperature, phases of matter, etc). In addition, students can modify parameters such as temperature and amount and observe the consequences of doing so. Students can make predictions and then observe what happens to the particles during heating, heat and temperature and contraction. Using the simulation, teachers can demonstrate various phenomena and provide (or ask students to provide) microscopic explanations. All particles in the simulation are round and seem identical, regardless of how the matter structure. In addition, particles of all substances appear as individual atoms and never as molecules. Upon observation, we noticed that the teachers in our study did not differ greatly in the way they implemented computerized simulations. The three lessons that were selected were very structured which contributed to minimizing the differences. Each of the three lessons was accompanied by computerized worksheets that included questions guiding students' observations. Occasionally, students received feedback on their responses.

Comparison software: middle and high school students tend to see models as an actual copy of reality and not as conceptual representations (Grosslight et al., 1991). Involving students in considering which aspects of the actual phenomena are represented by the model and which are not may address this potential pitfall (Thagard, 1992; Harrison & Treagust, 1996; Gilbert et al., 1998; Justi & Gilbert 2002; Stern & Roseman 2004). With this in mind, comparison software was developed and used in our study. This interactive software (in the yteach site) attended to the differences between particles and their representation, in terms of size, velocity, shape, number of particles in a cubic centimeter and dimensions (the simulation is two-dimensional whereas particles are not).

Semi-structured personal interviews were designed to probe beyond students' initial responses. The interviews lasted approximately 60-65 minutes. A total of 37 students – 20 from the experimental group and 17 from the control group - were interviewed at the end of instruction. Those interviewed were chosen according to their score and responses to the post-test. The questionnaires that received the lowest scores typically included unanswered questions or responses that clearly indicated that the student did not understand anything in those lessons.

Results and discussion

The results are as follows (Tables 3 and 4):

Table 3. Average scores of pre-tests according to groups (95 % Confidence)

Pre-test	Experimental Group		Control Group	
Total Score	Mean	Standard Deviation	Mean	Standard Deviation
70	20,50	3,60	18,82	6,25

t-test value: 1,018; p: 0,083; F-value: 3,18

Table 4. Average scores of post-tests according to groups (95 % Confidence)

Post-test	Experimental Group		Control Group	
Total Score	Mean	Standard Deviation	Mean	Standard Deviation
60	45,50	5,60	31,76	12.86

t-test value: 4,33; p: 0,005; F-value: 8,99

Students in both groups did not display any significant difference until starting the study. So they were at the same level (Table 3). There were no significant gender related differences found in the first step (Stern et al., 2008).

The scoring system considered the total number of elements that were included in each answer. Each question was awarded 10 points in the pre-exam and post-exam, but sometimes, students didn’t answer fully. In such cases, teachers gave half points or less to students’ drawings. If students did not know anything, they were not given any points. All the students in the experimental and control groups improved their understanding of heat, heat energy and heat-temperature. The improvement was more substantial in the experimental group than in the control group.

Whereas the students in the experimental group improved their scores by 20,50 points on average, students in the control group gained only 18,82 points. There was no notable difference between these two groups. Furthermore, the students in the experimental group scored significantly higher in the post-exam than the students in the control group. The pre-exam scores of students in both groups were found to be significantly different from the post-exam scores using repeated measures ANOVA (F= 8,99, p= 0,005), indicating that both groups improved their scores (Table 4). However, their pre-exam results were not found to be significantly different as shown in Table 3 (F= 3,18, p= 0,083). In particular, their t values did not show any difference as seen in Table 3 (t= 1,018). Overall, a statistically significant variance was not found between the pre-exam scores of the control and experimental groups. However, both groups significantly improved their scores, though the improvement in the experimental group was significantly higher. Although the p value was 0,005 as shown in Table 4, we thought that the success of experimental group was significantly higher than that of control group. Also the experimental groups' mean score (45,50) was significantly higher than that of the control group (31,76). These results suggest that the use of computerized simulation improved understanding of energy, heat energy and heat-temperature among 6th graders, as was evidenced by their improved ability to apply this abstract idea where they answered the post-exam questions.

Interview analysis

During the interviews, students had the opportunity to clarify and elaborate on their own written responses and to apply energy, heat energy and heat-temperature in additional contexts. Generally, the ideas expressed by the students during the interviews concurred with the ideas that they had expressed in writing. As following (S: Student, I: Interviewer):

I: Which of the following amounts of heat are bigger – in a big bucket or in a glass?

S: A glass

I: Why?

S: Because the grains of matter in glass are closer than those in a big bucket.

I: If the matter amount is small, are grains (molecules or atoms) closer? Can you draw it for me?

S: Yes.

I: Please, repeat it again on the computer

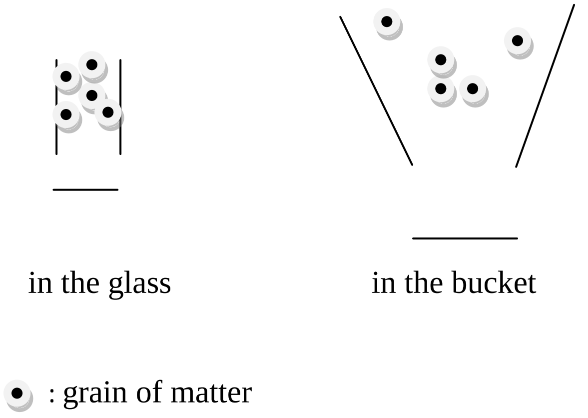

Fig. 2. The drawings of control group on paint program of what they imagined in their minds

Fig. 2 shows what the control group imagined when they used paint program to draw their answer to the interview's question. The control group had some misconception following these exams because they had been taught using classical educational methods.

However, the experience of the experimental group was very different from the control group. See the interview below:

I: Which of the following heats the 'fastest' - air, water or key?

S: Is key made of a metal?

I: Yes.

S: OK: key.

I: Why?

S: Because, the grains of a key are closer than those of the others.

I: Can you put the following in order?

S: Yes.

I: Please, repeat it again, draw it on the computer.

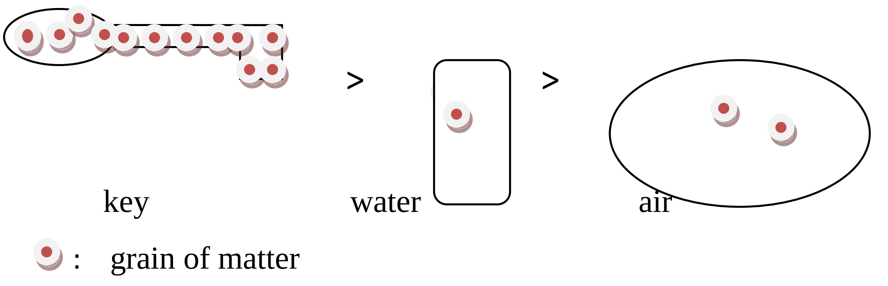

Fig. 3. The drawings of experiment group on paint program of what they imagined in their minds

Fig. 3 shows what the experimental group imagined when they used paint program to draw their answer to the interview's questions. During the interview process, it was discovered that experimental group was more successful than the control group after having received computerized education.

Conclusion

In the study described in this paper, students who were provided with a molecular software simulation demonstrated significantly better understanding of the particulate model of matter than students who were not provided with this simulation. These results suggest that computerized simulation improved the understanding of the particulate nature of matter among our 6th graders. These findings are in accord with previous research, which showed that dynamic molecular animations, rather than static illustrations, could be powerful tools in promoting the learning of chemistry and physics concepts (Wu et al., 2001; Dori et al., 2003; Dori & Belcher, 2005).

Whereas this may seem encouraging, the achievements of both groups were very low. The average post-exam scores were approximately 46 for the experimental group and 32 for the control group. There were only 37 students available at the school (17 from the control group and 20 from the experimental group). The teachers reported that weeks later, the students from the experimental group explicitly referred to the computerized simulation several times, suggesting that these students may have retained ideas concerning matter, molecules and their motion, heat, the difference between heat and temperature better than the control group. In addition, the average score of the experimental group was higher than that of control group in the post-exam, although there was no notable difference between these two groups. Computerized education is not common in Turkey. In my opinion, students in the experimental group may have indeed remembered the unusual experience of working with interactive software but that this experience did not necessarily confer better learning in the long run.

Since the computerized simulation used in the study was not intended to be the only teaching tool but rather supplementary material, it is unlikely that this or any other supplementary software alone will be sufficient to promote meaningful learning. Computerized simulation is but one instructional strategy, and many studies conducted over the past few decades clearly show that the learning of abstract ideas in science requires the use of sound and diverse instructional strategies. Among these are the role of prior knowledge, the use of relevant phenomena for making scientific ideas plausible, conditions that facilitate the transfer of knowledge and the importance of guiding students' interpretation of their learning experiences (e.g., Lee et al., 1993; Smith et al., 1993; Kesidou & Roseman 2002). 'yTeach', a popular Internet site, was used in this study during the majority of curricular time devoted to the heat and heat energy and other issues. Whereas interactive programs and class activities from this site - a research-based unit that prescribes sound pedagogical strategies used in our study - teachers were not aware of the rationale for these strategies and only one chapter from this material was used throughout instruction. In conclusion, computerized education is better than classic educational methods.

NOTES

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