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Determination of Factors Related to Students' Understandings of Heat, Temperature and Internal Energy Concepts

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Abstract

The purpose of this research is to investigate the relationships between high school students' learning approaches and logical thinking abilities and their understandings of heat, temperature and internal energy concepts. Learning Approach Questionnaire, Test of Logical Thinking and Three-Tier Heat, Temperature and Internal Energy Test were used as data collection tools in this research. All data collection tools were administered to 120 Anatolian High School students. The data collected through these tools were analyzed using descriptive statistics and stepwise multiple regression analysis. According to the results of this research, the variable that best predicts high school students' understandings of heat, temperature and internal energy is their logical thinking abilities. Students' logical thinking abilities and their orientations toward meaningful and rote learning predict 41% of the variance of their understanding scores concerning heat, temperature and internal energy. Results of the research indicate the importance of students' logical thinking abilities and their orientations towards meaningful learning on their understandings of heat, temperature and internal energy concepts.

Keywords: learning approach, reasoning ability, heat, temperature, internal energy

1. Introduction

Students' learning approaches are one of the important variables that affects the quality and permanence of learning (Senemoğlu, 2011). The learning approaches of students who prefer to memorize while learning is defined as surface or rote learning approach whereas the learning approaches of students who prefer to establish relationships between the newly learned concepts and previously learned concepts as deep or meaningful learning approach (Tekkaya & Yenilmez, 2006).

Meaningful learning takes place when individuals pay attention to new information within active cognitive processes, organize that information and link this information with their previous information. Ausubel (2000) emphasizes that the important factor affecting learning in this process is students' existing knowledge. Moreover, he points out that meaningful learning will take place when students relate new knowledge or ideas with their existing knowledge (Ausubel, 2000). On the other hand, rote learning involves only addition of new knowledge to the memory. Although an effort may be made in rote learning to link new knowledge with the old knowledge, understanding of the knowledge does not take place because there are deficiencies in the relation of knowledge (Keengwe, Onchwari, Wachira, 2008). In other words, in rote learning, new knowledge is incorporated into the existing cognitive structure as it is, that is in an arbitrarily manner that will not be meaningful (Novak, 1993). In addition, the knowledge remains in individuals' memories for a brief period due to this arbitrary and verbatim link between the old and the new knowledge (Ausubel, 2000). Moreover, it is even possible that they cannot handle this knowledge effectively when they need it (Ausubel, 2000). Taking into consideration these reasons, it is emphasized that while they are teaching concepts related to science, science teachers need to create environments where students can form meaningful understanding (Cavallo, 1996; Mayer, 2002).

Studies in the field of science teaching have focused on investigation of factors affecting the quality of students' learning. One of the areas where students suffer the greatest difficulty in learning science is Physics because Physics is a course that students generally regard as being hard, complex and abstract (Ornek, Robinson, & Haugan, 2008). Teaching Physics concepts by relating them with students' previous knowledge or contexts encountered in daily life will help to increase the quality of students' learning of Physics. On the other hand, one of the factors that make students' learning of Physics difficult concerns physics misconceptions. Misconceptions signify ideas and understanding individuals' minds which they have in connection with a concept or phenomenon which is quite different from the scientific definition of that concept or phenomenon (Eryılmaz & Sürmeli, 2002). Novak (2002) argues that it is not possible to eliminate incorrect knowledge structures that have formed in misconceptions through the rote learning approach, because these incorrect knowledge structures will cause students to make erroneous relations while forming new knowledge, thereby lead to a decrease in the quality of learning. In addition, it is maintained that students who adopt rote learning orientation may have more misconceptions in science (BouJaoude, 1992). Therefore, accurate teaching of Physics concepts will be possible only by establishing meaningful relations between new concepts and existing concepts and eliminating contradictions that may lead to misconceptions.

Heat, temperature and internal energy (HTIE), which are among the most frequently confronted concepts of Physics in daily life, are perceived to be difficult by students and various misconceptions are known to exist with regard to these concepts (Gurcay & Gulbas, 2015; Gurcay & Gulbas, 2016). The most common misconceptions among concepts of Thermodynamics involve the misconceptions 'Heat and temperature are the same' and 'Temperature is a measure of heat' (Eryılmaz, 2010). These misconceptions reveal that the fact that heat and temperature are different concepts is not adequately understood by individuals. In addition to this, there are studies stating that like the concepts of 'heat and temperature', the concepts of 'heat and internal energy' are also mistaken for one another (Harrison, Grayson & Treagust, 1999); it is also sometimes believed that 'heat and internal energy are the same' (Gurcay & Gulbas, 2016) and it is thought that 'internal energy is the amount of heat possessed by an object' (Warren, 1972; Gurcay & Gulbas, 2015). It is suggested that three-tier tests, which are argued to be one of the most effective ways of identifying these misconceptions, be used in this regard (Gurcay & Gulbas, 2015).

Various studies have emphasized that students' reasoning abilities may be a key factor in their understandings of science concepts (Lawson, 1985; Cavallo, 1996). Formal reasoning ability is a skill that enables students to employ reasoning concerning a problem or a situation within the cause and effect relationship and arrive at a conclusion by making the most appropriate decisions. Lawson et al. (2000) state that formal reasoning, which involves skills such as control of variables, proportional, probabilistic, correlational, and combinatorial reasoning in the adolescence period. In addition, Lawson et al. (2000) emphasized that these skills were effective in the process when students were forming science concepts because the more developed students' logical thinking ability is, the more complex their mental schemas become (Adey & Shayer, 1990). However, Lawson and Thompson (1988) argued that students' reasoning abilities were significantly correlated with the misconceptions they had. Based on this, some researchers maintained that developing students' logical thinking abilities would increase the quality of their learning science learning (Lawson, 1985; Valadines, 1997). Valanides (1997) emphasized that teachers should benefit from approaches that require the use of inquiry skills such as learning cycle to improve their students' formal reasoning abilities. As a consequence of developing students' reasoning abilities, logical relationships which they will establish between evidences and misconceptions will enable students to have fewer misconceptions.

Some studies stated that students' orientations towards learning and reasoning abilities were also effective on their levels of understanding topics of genetics (Cavallo, 1996; Kılıç & Sağlam, 2014). Although some studies conducted on elementary school (Baser & Geban, 2007) determined that students' reasoning abilities had a positive effect on their understandings of concepts of heat and temperature, there are no studies conducted to determine what kind of an effect they have on high school students' understandings of HTIE concepts. Moreover, when studies on physics education were examined, it was found that there were no studies investigating the relationship between students' learning orientations, reasoning abilities and their understandings of HTIE concepts. Investigation of variables related with students' understandings of HTIE concepts gains significance specifically due to the fact that subjects of HTIE concepts are perceived by students to be difficult (Meltzer, 2004) and that they are known to have many misconceptions in this regard (Wiser, 1995). Therefore, the purpose of this study is to determine to what extent high school students' reasoning abilities, their orientations towards meaningful and rote learning predict their understandings of concepts of HTIE.

2. Methodology

The research aims to investigate the relationship between students' understandings of HTIE concepts, learning orientations and reasoning abilities. Since the purpose of the study is to describe an existing situation about the sample, survey model was used (Fraenkel & Wallen, 2009).

2.1 Study Group

This study was carried out with 120 Anatolian High School students. 66 were attending 11^{th} grade and 54 were attending 12^{th} grade. 54.2% (65) of the study group consisted of male students while 45.8% (55) consisted of female students. Students' socioeconomically status are generally at a medium level. The age range of the students participating in the study varies between 16 and 18. Students in Turkey are selected to Anatolian High Schools through a central examination. Therefore, students at Anatolian High Schools are relatively more successful compared with the students attending other high schools.

This study was conducted on students who had learned the concepts of HTIE previously. The concepts of HTIE are included as the first subject in the curriculum of high school 11th grade Physics course. Therefore, 11th and 12th grade students who had learned the concepts of HTIE took part in the study. Hence, purposive sampling was used in the study.

2.2 Data Collection Tools

Data were collected through Learning Approach Questionnaire, Test of Logical Thinking and Three-Tier Heat, Temperature and Internal Energy Conceptual Test.

2.2.1 Learning Approach Questionnaire

Learning Approach Questionnaire (LAQ) was developed by Cavallo (1996) to determine whether students preferred rote learning or meaningful learning as their learning orientation. The questionnaire was adapted to Turkish by Yenilmez (2006). LAQ has two sub-dimensions, namely meaningful learning and rote learning, and 22 items. Each sub-dimension consists of 11 items. Each item contains a 4-point likert type response range in the form of 'Never True', 'Seldom True', 'Frequently True' and 'Always True'. Minimum and maximum scores that could be obtained from each sub-dimension of the questionnaire varies between 11 and 44. Students receiving high scores from the rote learning sub-dimension of the questionnaire are more inclined to prefer rote learning whereas students receiving high scores from meaningful learning sub-dimension tend to prefer meaningful learning. It was stated that the Cronbach Alpha reliability coefficient for the meaningful learning sub-dimension of the original LAQ was .81 whereas it was .76 for the rote learning sub-dimension (Cavallo et al., 2004). The Cronbach Alpha reliability coefficient of the questionnaire adapted to Turkish was reported to be .78 for the meaningful learning sub-dimension and .62 for the rote learning sub-dimension Yenilmez (2006). In this research, Cronbach Alpha reliability coefficient was found to be .82 for the meaningful learning sub-dimension and .66 for the rote learning sub-dimension.

2.2.2 Test of Logical Thinking Ability

Test of Logical Thinking Ability (TOLT) was developed by Tobin and Capie (1981) to measure students' formal reasoning ability levels. The TOLT was adapted to Turkish by Geban, Aşkar and Özkan (1992). This test consists of ten questions and measures five logical inference abilities. These abilities involve controlling variables, proportional, correlational, probabilistic, and combinational reasoning. The 1st and 2nd questions of the test measure proportioning ability, the 3rd and 4th questions measure ability of defining and controlling variables, the 5th and 6th questions measure ability of calculating probabilities, the 7th and the 8th questions measure the ability of making correlations and the 9th and 10th questions measure the ability of combining.

The first 8 items of the test are composed of two-tiers. In the first tier of the items, one needs to choose an answer from among the choices whereas in the second tier one needs to write explanation for the answer or choose an answer from among the choices. Students' answers are taken to be correct answer, only if both tiers of the items are answered correctly. Students need to answer both tiers correctly in order to be able to receive 1 from the two-tier items. Moreover, in order to get 1, from the 9th and 10th questions, students need to list all of the possible combinations. Minimum and maximum scores that could be received from the whole test vary between 0 and 10. Student scores between 0 and 3 are categorized as low level, while scores between 4 and 6 are regarded as medium level, and those between 7 and 10 are considered to be high level formal reasoning ability (Oliva, 2003). Cronbach Alpha reliability coefficient for the original TOLT was determined to be .85 (Tobin & Capie, 1981). The reliability coefficient of the TOLT adapted to Turkish, on the other hand, was reported to be .77 (Geban et al., 1992). In this research, Cronbach Alpha reliability coefficient was calculated to be .71.

2.2.3 Three-tier Heat, Temperature and Internal Energy Test

Three-tier Heat, Temperature and Internal Energy Test (HTIET) is a three-tier diagnostic test developed to determine high school students' conceptual understandings of HTIE (Gurcay & Gulbas, 2015). Three-tier HTIET involves 12 three-tier questions, namely 4 three-tier questions related to each of the concepts of HTIE. The range of the scores that could be received from the test containing three-tier questions varies between 0 and 12. In order to get 1 score from a tree-tier question, students need to respond correctly to the question asked in the first tier, then in the second tier to the question about the reason for the response given and then to the question about whether or not they are sure about the responses they have given to the first two questions in the third tier.

The correct answer expected of students with regard to questions about heat is the response 'heat is energy that is transferred due to a difference in temperature' but potential misconception answer expected to be given by students is 'the heat of an object depends on the size of the material of which it is made'. Concerning questions about temperature, students are supposed to give the correct response, which is that 'when two objects made of the same material but are of different size are left in the same environment for long enough, their ultimate temperatures will be equal' whereas the expected misconception response is 'temperature of an object depends on the size of the material of which it is made'.

Correct conceptual understanding which is attempted to be measured through the concept of internal energy, is 'internal energy depends on the size of an object', but potential misconception answer which students may provide is 'internal energy is the amount of heat which an object possesses'.

Cronbach Alpha reliability coefficient calculated for the correct responses given to the three-tier questions in the original HTIET was given as .75 (Gurcay & Gulbas, 2015). It was calculated as .71 in this research.

3. Results

Descriptive statistics were conducted to investigate students' levels regarding HTIE conceptual understanding, their meaningful learning orientation and rote learning orientation levels and their levels of logical thinking abilities. Results of descriptive statistics belonging to these variables are given in Table 1.

Table 1. Descriptive statistics for the scores of HTIE Understanding, Meaningful Learning, Rote Learning, Logical Thinking Ability

	HTIE Understanding	Meaningful Learning	Rote Learning	Logical Thinking Ability
Mean	4.42	31.03	27.18	6.32
Std. Dev.	2.35	7.32	5.22	2.45
Skewness	-0.14	-.559	-0.7	-7.34
Kurtosis	-.40	.71	.83	-.01
N	120	120	120	120

According to the results of the descriptive statistics in Table 1, it was found that students' HTIE conceptual understanding levels were low and that their levels of meaningful learning orientation were almost high, However, their orientations towards of rote learning and their logical thinking abilities were at a medium level.

Multiple regression analysis was conducted to determine to what extent students' logical thinking abilities, and orientations towards meaningful learning and rote learning predicted their levels of understanding of HTIE concepts. Before conducting the multiple regression analysis, whether or not the assumptions were met was investigated. To this end, first whether sample size was adequate was examined. Since there are three independent variables in this study (logical thinking ability, meaningful learning-and rote learning orientation), sample size ($N \geq 50+8m$; m=number of independent variables) must be 74 at least (Tabachnick & Fidell, 2007). When the proportion of the dependent variable to the predictive (predictor) variables (40 to 1) was also taken into consideration, it was seen that the sample of this study (N=120) met the sample size for conducting stepwise multiple regression analysis. Moreover, preliminary analyses were performed to ensure no violation of the normality, linearity and homoscedasticity assumptions.

The relationships among students' conceptual understanding levels of HTIE, meaningful learning orientation, rote learning orientation and logical thinking abilities were calculated using Pearson Product Moment Correlation Coefficient and the results are given in Table 2. According to Table 2, there are medium level, positive but statistically significant correlations between scores of HTIE understanding, logical thinking ability and meaningful learning orientation. Moreover, there is a low level, negative but statistically significant correlation between scores of HTIE understanding and rote learning orientation. No statistically correlations could be found between scores of rote learning orientation, meaningful learning orientation and TOLT. Multicollinearity assumption was checked by examining Pearson Correlations between the independent variables. Moreover, there were no VIF values above 10 (Table 3). Since all the correlations were lower than .6, and all VIF values were lower than 10, there was no violation of the multicollinearity assumption.

Table 2. Pearson correlations between scores of HTIE understanding, meaningful learning, rote learning, logical thinking ability

	HTIE Understanding	Logical Thinking Ability	Meaningful Learning
Logical Thinking Ability	.577**		
Meaningful Learning	.526**	.584**	
Rote Learning	-.222*	-.132	-.021

Stepwise multiple regression analysis was performed to examine to what extend students' logical thinking abilities, meaningful learning orientation and rote learning orientation scores predict their understanding scores on the HTIE concepts on three-tier test. According to the results of this analysis, the main predictor variable that explains students' understandings on those concepts is their logical thinking abilities. As a predictor, students' logical thinking ability scores explained 33% of the variance related to the students' understanding scores of HTIE (R^2= .33; F (1,118) = 58.81, p<.005). When the students' meaningful learning orientation scores are added to the model, both predictor variables explain 39% of the variance related to the students' understanding scores of HTIE (R^2= .39; F (2,117) = 36.91, p<.005).

When the students' rote learning orientation scores is entered into the model, it explains 41% of the variance related to the students' understanding scores of HTIE (R^2= .41; F (3,116) = 27.27, p<.005). As it is given in Table 3 in the final model, all three predictor variables, logical thinking ability, meaningful learning orientation and rote learning orientation were statistically significant. In addition, direction of the relations between students' understanding scores on HTIE and the students' logical thinking ability scores and meaningful learning orientation scores were positive. On the contrary, direction of the relation between students' understanding scores and students' rote learning orientation scores was negative.

Table 3. Stepwise multiple regression results

Model	Beta	t	p	Collinearity Statistics VIF
1				
Reasoning Ability	.577	7.669	.000	1.000
2				
Reasoning Ability	.409	4.584	.000	1.519
Meaningful Learning Orientation	.287	3.217	.002	15.19
3				
Reasoning Ability	.379	4.276	.000	1.553
Meaningful Learning Orientation	.301	3.429	.001	1.526
Rote Learning Orientation	-.165	-2.300	.023	1.023

4. Conclusion, Discussion and Implications

Results of the study indicated that the most important variable that affected students' understandings of concepts of HTIE was their formal reasoning abilities. Moreover, it was also found that students who adopted a meaningful learning orientation understood the concepts of HTIE at a better level. On the other hand, students with rote learning orientation had a lower level of understanding with regard to the concepts of HTIE. Therefore, it could be concluded that as the students' reasoning ability and the meaningful learning orientation scores increased, students' understandings on the HTIE concepts increased. However, as students' rote learning orientation scores increased, their conceptual understanding scores decreased.

According to the results of the descriptive statistics, it was seen that conceptual understanding levels of high school students concerning the concepts of HTIE were low. This indicates that students have various misconceptions about the concepts of HTIE and that they mistake these concepts for one another. When we look at the studies in the relevant literature regarding students' understanding levels of concepts of HTIE at elementary education (Baser, 2006; Baser & Geban, 2007), secondary education (Gurcay & Gulbas, 2015) and higher education (Warren, 1972; Kaptan & Korkmaz, 2001, Gurcay & Gulbas, 2016), we observe that students' levels of understanding of these concepts are below average. Given that misconceptions are independent of gender (Wessel, 1999), it transpires that concepts of HTIE should be taught correctly at an early age. Since concepts of 'heat and temperature' and concepts of 'heat and internal energy' are concepts that are often mistaken for one another by students (Warren, 1972; Harrison et al., 1999), above all, these concepts need to be taught correctly. Students may develop misconceptions about concepts that are not taught correctly and this situation may also prevent accurate learning of other concepts of thermodynamics which are related to HTIE.

When the mean scores of students' logical thinking abilities were examined, it was seen that their scores were at medium level. This indicates that students' abstract thinking and hypothetico-deductively reasoning abilities are at a medium level. However, since formal reasoning abilities are at the same time skills that are related to scientific literacy, formal reasoning abilities need to be developed because abstract thinking and hypothetico-deductively reasoning abilities are factors that are effective in students' understandings of HTIE concepts. It was found that meaningful learning orientation mean scores of the students were high. This indicates that students prefer to understand a subject rather than memorize it, which is to say that they learn new subjects by linking them with their previous learning. On the other hand, rote learning orientation mean scores of the students were also found to be medium level. This indicates that while learning a subject, students have an additional inclination to adopt the rote learning orientation without linking it to previously learned subjects.

Results of stepwise multiple regression analysis showed that variables that were significantly correlated with Anatolian High School students' conceptual understandings regarding HTIE were students' formal reasoning abilities, meaningful learning orientation and rote learning orientation. The whole model explained 41% of the variance with regard to students' conceptual understanding scores from three-tier HTIET in a statistically significant. However, while logical thinking ability and meaningful learning orientation predicted students' understanding levels of HTIE in a positive direction, it was found that rote learning orientation predicted them in a negative direction. In addition, it was found that the variable that best predicts students' understanding of concepts of HTIE was their formal reasoning abilities.

Students' formal reasoning ability scores explained 33% of the variance belonging to the scores they received from three-tier HTIET in a statistically significant way. This indicates that as the students' formal reasoning scores increased, they better understood the concepts of heat, temperature and internal energy. Likewise, Baser and Geban (2007) found a statistically significant and positive correlation between elementary school students' understanding levels of concepts of HTIE and their formal reasoning abilities. It is seen that since the concepts of HTIE are abstract, students need to have good formal reasoning abilities to be able to grasp those concepts. In a similar way, Lawson and Thompson (1988) stated that the variable that best predicted misconceptions about genetics was logical thinking ability.

When students' formal reasoning ability scores and meaningful learning orientation scores were added to the model together, both variables explained 39% of the variance related to the three-tier HTIET scores. In other words, students' meaningful learning orientation explained 6% of the variance regarding students' understandings of HTIE concepts. This indicates that as students' meaningful learning orientation scores increased, they better understood the concepts of HTIE. Although there are no studies investigating the relationship between the learning orientations students have adopted and their levels of understanding of HTIE concepts, in studies investigating secondary education students' understanding levels of biology (Cavallo, 1992) and chemistry (BouJaoude, 1990; BouJaoude, Salloum, & Abd-El-Khalick, 2004) concepts, a statistically positive correlation was found between meaningful learning orientation and their levels of understanding science. When rote learning orientation scores were added to the model, it was found that rote learning orientation scores explained 2% of the variance with regard to the scores for understanding concepts of HTIE. However, the direction of the relationship between rote learning orientation and understanding the concepts of HTIE was negative. This means that as students' rote learning orientation scores increased, their learning levels decreased and possessed more misconceptions. Likewise, Kılıç and Sağlam (2014) investigated the effects of logical thinking ability, and meaningful and rote learning orientation on 11^{th} grade students' understanding levels of concepts of genetics, and concluded that logical thinking ability and meaningful learning orientation had a statistically significant and effect in a positive direction whereas rote learning orientation had a significant effect in negative direction.

In short, students' logical thinking abilities were a significant factor on their understandings of concepts related to HTIE. This indicates that students who are better at thinking processes such as controlling variables, proportional thinking, probabilistic thinking, relational thinking and combinational thinking may learn these concepts better. Therefore, physics teachers need to create opportunities for students to develop their thinking abilities while designing learning environments. In addition, it was also determined within the scope of this study that learning orientation which students adopted affected their understanding levels of concepts of HTIE. However, it was found that students who adopted meaningful learning orientation were better at understanding subjects compared with individuals who adopted rote learning orientation. Taking into consideration the fact that individuals who understand the subject less will have some conceptual misconceptions, it is better understood that meaningful learning and teaching based on meaningful learning is extremely important in secondary education. Therefore, it is important that physics teachers, taking this into account, prepare learning environments where students can find an opportunity for meaningful learning.

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