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EFFECT OF TEACHING VIA MODELING ON ACHIEVEMENT AND CONCEPTUAL UNDERSTANDING CONCERNING ELECTRICITY

Abstract. *In this study, it is aimed to determine the effects of teaching via modeling on academic achievement and conceptual understanding concerning some selected undergraduate electricity topics. Dependent variables of the research are academic achievement and conceptual understanding. Academic success was measured by using Electricity Success Test and Electricity Classical Exam and conceptual understanding on the other hand was measured by using an Electricity Concept Test. A total number of 41 students attended the research, 21 of the students were in the modeling group and 20 of the students were in the control group. The study was carried out experimentally by means of pre test-post test research design. In conclusion it is found that teaching via modeling method meaningfully enhances the academic achievement and conceptual understanding.*
Key words: *achievement, conceptual understanding, electricity, modeling instruction, physics education.*

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Introduction

In Physics Education Research (PER), it is continuously and globally investigated optimum teaching conditions, techniques and methods to get closer and closer to the desired perfect outcomes. Therefore, some realistic amount of effort has recently been spent to assessing students' academic achievement (Campbell & Campbell, 1999; Hazari, Tai & Sadler, 2007; Hoffmann, 2002; Okpala & Onocha, 1988; Sadler & Tai, 2001), conceptual understanding (Andre & Ding, 1991; Bilal & Erol, 2009; Dupin & Johsua, 1987; Furio & Guisasola, 1998; Maloney, O'Kuma, Hieggelke & Van Heuvelen, 2001; Periago & Bohigas, 2005; Planinic, 2006), attitudes and expectations (Gardner, 1975; Johnstone, Watt & Zaman, 1998; Nilsson & van Driel, 2010; Osborne, Simon & Collins, 2003; Reid & Skryabina, 2002; Redish, Saul & Steinberg, 1998) that all play an important role in PER.

PER, in general, forwards two important results. The first one is the belief that "Physics is a very difficult subject" (Angell, Guttersrud, Henriksen & Isnes, 2004; Carlone 2003; Osborne & Collins 2001). The second one is the reality that "Physics students have a lot of misconceptions in different areas of physics." It is found that most students gain preconceptions before attending schools and those preconceptions have very deep roots (Tytler, 1998) and also mostly are in opposition to the scientific reality and this situation influences the education to a large amount (Hestenes, 1996; Vosniadou, Ioannides, Dimitrakopoulou & Papademetriou, 2001). The other very interesting point is that similar misconceptions have been detected through the same age group students living in different countries, even some teachers demonstrate some similar misconceptions to the ones detected through the students (Pardhan & Bano, 2001).

A brief scrutiny of the PER demonstrates that the most intensively studied topic of physics is mechanics which then followed by the electricity (Rebello & Zollman, 2005). Nevertheless, misconceptions on mechanics and electricity originate from naturally different sources. The students have a vast amount of experience relating the sub topics of mechanics out of their daily life. Electricity, one of the most fundamental sub topics of physics, nevertheless investigates the natural phenomena originating from the small charged particles of the materials such as electrons, protons or neutrons. Those concepts are considered to be abstract because of not being directly detected by the human sensory system. Therefore the majority of the students have some distinctive difficulties on internalizing the concepts relating electricity in general. Even the most principle concepts such as electric field (Furio & Guisasola, 1998; Planinic, 2006; Pocovi, 2007; Pocovi & Finley, 2002), electrical current (Brna, 1988; Küçüközer & Kocakülah, 2007; Lee & Law, 2001; Kibble, 1999), electrical potential and resistivity are all considered to be abstract and have certain misconceptions.

It is almost that conventional teaching methods and techniques are not sufficient to acquire desired achievement levels (Hestenes, 1996). Conventional instruction, a deductive approach, offers the teacher right at the centre of the instruction process and only activates the teachers; nevertheless the students are in a role of just passive followers. During the conventional teaching, the topic is generally explained initially and then some quantitative problems are solved by the instructor/teacher and in some cases additional problems are given students to be solved as homework. The course of action supported by some close ended experimental activities. The conventional instructing does generally not take into account any misconceptions and considers that the students learn easily by means of problem solving, however many researchers have shown that the reality is quite different (Lattery, 2007).

Modeling is considered to be a student centered instruction and students are normally supposed to construct their own models and to discover certain concepts via self activity and effort (Brewe, 2008; Halloun, 2004; Hestenes, 1992). The key factor on developing a specific model and its application is the convenience of the model to the actual physical environment (Brewe, Sawtelle & Pamela, 2007). Hence, it is very important to firstly let students to collect their own data by means of observations and experimentations and then let them to evaluate and to reach a conclusion. Effective and successful student learning is only possible if the students experience the case and laboratories are not the places of verification but rather the places to apply and evaluate models and specific aims are to be reached at the end of the overall process (Lattery, 2007).

Physicists generally provide work for modeling and modeling based reasoning to objectify specific subjective thoughts to clarify some very complex events to estimate trends to explain mechanisms and sequences (Bryan & Fennell, 2009; Hestenes, 1996; Sperandeo-Mineo, 2002). Modeling process can be viewed as the sequence in order to reach any specific scientific law or principle. Modeling and models have been attracting ever increasing interest as a part of modern science instruction because they reflect the nature of physics and also seem to be very beneficial tools to learn some critical physical concepts (Angell, Guttersrud, Henriksen & Isnes, 2004). It is also expressed that understanding scientists depends very much upon the understanding the models scientists use (Harrison & Treagust, 2000). In fact, Gilbert (1991) proposed that science can be defined as 'a process of constructing predictive conceptual models'.

Gilbert and Boulter (2000) classify the existing models as follows: Physical (concrete; 3D objects), gestural (kinesthetic; body movements), verbal (spoken/written text; analogy; metaphor), pictorial (visual diagrams; animations), numerical (data table; lists), graphical (ordered pairs presented on a grid), mathematical (formulae; equations). Such models serve as multiple representations of the physical phenomena and are powerful tools in science teaching (Bryan & Fennel, 2009). Physics education, along with many other objections, also aims to raise scientific curiosity and capacity of students preparing them as both future potential scientists and scientifically capable citizens. Modeling seems to be one of the most convenient methods to especially reach those aims but specifically to ignite self curiosity. Therefore it is very important to employ modeling at all levels of education.

There are quite a number of papers focusing on the modeling but following items are especially taken into account for the specific scope of the present paper. Vesenka, Beach, Munoz, Judd and Key (2002), in their work, deal with the instruction by means of modeling on the mechanics. The overall

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conclusion of the research can be expressed that modeling group students are much more successful comparing the conventional group students. In addition, lab instructors reported that a great deal of improvement is detected on the modeling instruction. Similar results were reported by a number of different groups and studies (Brewe, 2008; Halloun, 1996;; Hestenes, 1996, 2006; Niedderer, Schecker & Bethge, 2008).

Brewe, Karamer and O'Brien (2009) investigated the effect of modeling instruction on university students' attitudes about science. In their study modeling instruction is designed to engage students in scientific practices that include model building, validation, and revision. Attitudes towards science were measured by using the Colorado Learning Attitudes about Science Survey (CLASS). It was found that there were positive shifts from the CLASS in the modeling-based introductory physics sequence, for both mechanics and electricity and magnetism.

Brewe, Sawtelle, Kramer, O'Brien, Rodriguez and Pamela (2010) had recently shown that teaching via modeling increased the student attendance independently from their ethnicity. Araujo, Veit and Moreira (2008) searched the effects of Modellus Complementary Software, developed by means of Halloun's (1996) modeling approach and Ausubel's instruction theory, which specifically employ some modeling activities, on the student academic achievement. The investigation was carried out on the evaluation of kinematics graphs. The overall results had shown that there is a statistically meaningful difference between the modeling and conventional group students in favor of the modeling group. Woolridge (2000) employed the modeling method through mechanics at the undergraduate level. The research was on the comparison of the results of Force Concept Test of the modeling and conventional group students. At the end of the research, the students thought via conventional methods have shown a rise of %13 reaching to the level of %39. However the modeling group students have shown an increase of %27, reaching to the level of % 49. The difference between the two groups was, in fact, statistically meaningful in favor of the modeling group students.

This research therefore focuses on the effects of teaching via modeling on electricity sub topics. Specifically, in this research, it is aimed to compare the academic achievement and conceptual understanding of the students thought via modeling and conventional teaching method.

Methodology of Research

Research Design

In this research, pretests and posttest were employed in order to resolve the effectiveness of modeling method. In order to measure the effectiveness of the modeling compared to the traditional, modeling was employed in the experimental group and traditional/conventional method was employed in the control group. The data collection tools of the research are Electricity Success Test (EST), Electricity Classical Exam (ECE) and Electricity Concept Test (ECT), all of the data collection tools then were administered to both groups as pre-measurement tools and following the application period the same tools were employed as a post measurement tools.

Participants

The students, all attending to General Physics II Course, were from Elementary Mathematics Education Department at a State University. The students attending the same General Physics II Course divided into two groups, namely experimental and control, in accordance with their pre test results such that the groups have approximately same mean values. A total number of 41 students voluntarily participated in the research, 21 of the students were in the experimental group and 20 of the students were in the control group. The number of students in the sampling is not as much as desired due firstly to the specific legal restriction in the institution and secondly to the voluntarily selected students whose motivation observed being to be high.

Data Collection Tools

Three separate data collection tools were used in order to collect the data in this research. Academic achievement of the students is measured by means of Electricity Success Test (EST) and Electricity Classical Exam (ECE), conceptual understanding is measured by using Electricity Concept Test (ECT) that they were performed before and after the instruction. Tests having only multiple choice questions are not sufficient for a deeper success evaluation so in this research it is used a second data collection tool namely ECE, in order to determine the academic success. Detailed explanation of the measurement tools is given below.

1. Electricity Success Test (EST)

EST is designed to measure students' success by the researcher. 50 multiple-choice questions covering relating topics were previously prepared, then four experts were asked to review the content validity and in accordance with their suggestions two questions were removed from the test. The test was applied to 218 students who finished the General Physics Course for reliability analysis. After the item analysis 16 questions having item discrimination index less than 0.20 were eliminated from the test. Distribution of the EST question numbers according to the topic can be seen in table 1.

Table 1. Distribution of the EST questions with respect to the topics.

Topics	Question number
Electric Field	1, 2, 3, 4, 5
Gauss Law	6, 7, 8, 9
Electrical Potential	10, 11, 12, 13, 14
Capacitors	15, 16, 17, 18, 19, 20
Current and Resistance	21, 22, 23, 24, 25
DC Circuit	26, 27, 28, 29, 30, 31, 32

In the final version of the EST, it has 32 questions having item discrimination index between 0.20-0.52 and item difficulty index between 0.12-0.86. The Kuder-Richardson 20 reliability coefficient was calculated as 0.76. Minimum and maximum possible scores of the EST are 0 and 32, respectively.

2. Electricity Classical Exam (ECE)

ECE is designed in order to find out a deeper look for students' electricity success. ECE consists of six problems each having several sub problems and student's success is calculated by taking into consideration of their problem solving performance. The evaluation has three steps namely understanding the problem, processing the solution and result.

ECE was administered 36 students who previously learned the relating topics and evaluated twice by the same researcher within three weeks. Correlation coefficient between the two evaluations was found as 0.90. Distribution of the question numbers to the topic can be seen in the table 2.

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Table 2. Distribution of the ECE questions with respect to the topics.

Topics	Question number
Electric Field	1a, 1b, 1c, 1d, 1e
Gauss Law	2a, 2b, 2c, 2d, 2e
Electrical Potential	3a, 3b, 3c, 3d
Capacitors	4a, 4b, 4c, 4d
Current and Resistance	5a, 5b, 5c
DC Circuit	6a, 6b

A rubric is developed by the researchers in order to evaluate students' performances. Students are given 3 points in the case of correct answer and full explanation, given 2 points for partly correct answer and explanation, given 1 point for mostly incorrect answer and explanation and finally given 0 point for no answer and no explanation. Minimum and maximum possible scores of ECE are 0 and 207, respectively.

3. Electricity Concept Test (ECT)

ECT is designed to find out students' conceptual understanding about topics by the researcher. ECT includes a problem case and relating questions for every sub-topic. There were 24 two-tier questions and explanation part in the test. Table 3 shows the test items diversity to the topic.

Table 3. Distribution of the ECT questions with respect to the topic.

Topic	Question number
Electric Field	1,2,3,4,5,6,7,8,9,10,11
Gauss Law	12
Electrical Potential	13,14,15
Capacitors	16,17,18
Current and Resistance	19,20,21
DC Circuit	22,23,24

To develop the ECT, 28 two tier questions were previously prepared and ECT was performed to 178 students who finished General Physics II Course successfully. After the reliability analysis, four questions having item discrimination index less than 0.20 were removed from the test. KR-20 reliability coefficient of the ECT is determined as 0.73. Item discrimination index ranges from 0.24 to 0.59 and item difficulty index ranges from 0.12 to 0.92. In the first, tier there are four choices for every question. Only one of the choices is correct and the rest are selected from the related literature about students' misconceptions as distracters. In the second tier, the students wrote their reasons for their choices. The participants were asked to write their explanations as fully as possible.

ECT score of a student is calculated by using the following procedure. In the first part of the questions there are one correct and three incorrect choices. Students are given 1 point for a correct choice and 0 point for an incorrect choice. In the second part, students are given 2 points for a completely correct explanation and 1 point for a partly correct explanation and 0 point for an incorrect or no explanation. Then the points of the first and the second part of the question are added and the final score is reached. The possible minimum and maximum scores of the ECT are 0 and 72, respectively.

Modelling Process

The modeling process of the study is designed by the consideration of the teaching cycle of modeling. The cycle consists of three steps, namely constructing the model, use of the model and presentation.

Constructing the model step

Problem case (investigation): At this stage, a problem case relating pre determined physical law is given to the students. The students are asked to make some estimation that explains the problem case. The students, at this stage, are free to express their individual thoughts. The students are, for example, asked to tell their own views about what happens when two electrically charged objects are suspended closely. Following this stage, the actual experiment is performed in front of all students and let them to scrutinize what actually happens. The students are then supposed to estimate the actual parameters that the electrical force can be depended on.

Group discussion: The students, at this stage, are asked to briefly write their group views on the whiteboard. The instructor, at this stage, tries to motivate every student to become a part of the discussion and to encourage them to express their individual thoughts. The instructor should also pay attention on keeping the students right on the track. The interacting ability of the students is expected to improve during this special activity (Lattery, 2007; Schmitt & Lattery, 2004).

Classroom discussion: At this stage, selected a student representing the group is asked to share their group views with the classroom. The students are supposed to determine the specific views that can actually be realized through an experiment. Dependent and independent variables of the experiment are, at this stage, to be determined by the classroom.

Group modeling (experiment): The students are asked to perform their own experiment and collect the actual data. Then the data are evaluated via tables, graphs or other techniques to search any realistic link between the variables in order to reach a mathematical and a mental model. The students are trying to understand and model the current variation by using a graph obtained experimentally.

Classroom modeling (generalization): The groups are asked to share their findings with the classroom by selecting a student as a spokesman. The group students discuss their strong and weak points of their model and specifically contradicted findings of the groups are discussed and reached to a genuine conclusion. The instructor, at this phase, moderates the discussion by asking some key questions. Those questions are especially focuses on the well known misconceptions and learning difficulties. Through discussions the mathematical model is checked in terms of various aspects and improved to the scientific reality.

Representation: The instructor, at this phase, presents the problem case as it is carried out in the control group and explains all the concepts and scientific relations. The instructor uses all the possible technological apparatuses such as power point, projector, data show to save the time. Presentation is performed before and after the experimentation to check the details of the well thought-out model and opinions before and after the modeling sequence.

Model usage step

The groups are supposed to solve the specific problems structured to relieve the better learning and understanding. Then the group presenter is asked to solve every problem on the classroom board. All the problems are very closely related to the concepts and sub topics of the scientific law. The instructor at this stage tries to lead the students to especially use their models and to force them to internalize the conceptual learning in addition to the empiric calculations. All instructing activities are performed by the same researcher with the help of the second instructor.

Traditional Teaching Process

The activities in the control group are also performed by the researcher and mainly lecturing, discussion and question-answer techniques are employed in the course of the sequence. Weekly 4 hours are used for a specific unit and the last two hours are employed to perform the problem solving activities. The problems matching with the problems solved in the modeling group are solved by the instructor/researcher.

Results of Research

Effects of Modeling Method on Students' Success

Application of descriptive statistics give the success percentages of each measurement for the two measurement tools, EST and ECE. As a result of the analysis, it is shown that students in modeling group have similar scores in EST and ECE comparison with lecturing group at the beginning of the study. However post test results indicate a difference for both EST and ECE in favor of modeling group. Additionally, students' gains for each group seems to have a large difference. The pre-test, post-test means of EST and ECE and success gain for modeling and lecturing groups are given in Figure 1.

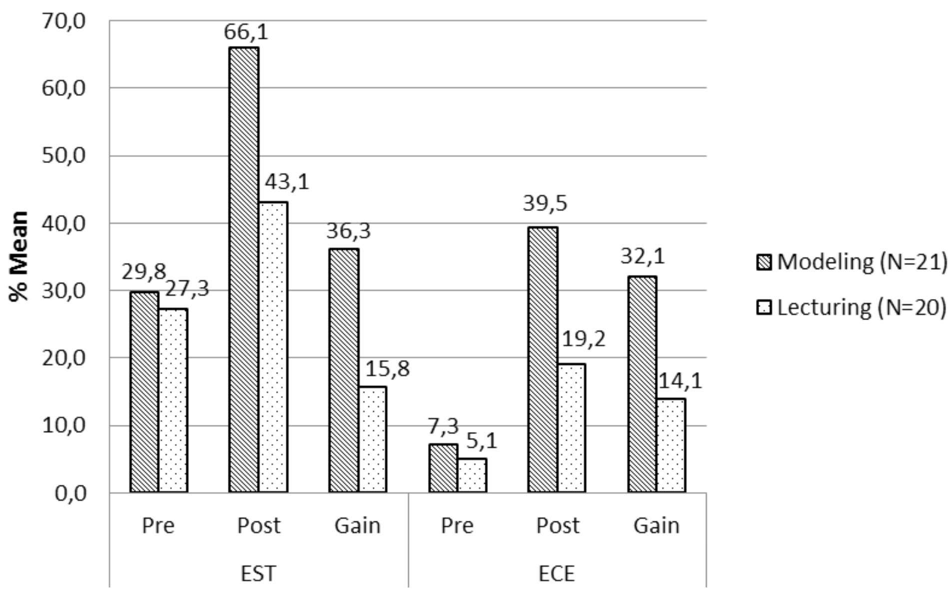

Figure 1: Matched EST and ECE scores for modeling and lecturing classes.

In order to test the mean percentages of success in terms of statistically significance, Mann Whitney U Test is engaged. According to the Mann Whitney U test, there are no significant differences between modeling and lecturing method on the pre measures of EST and ECE but there are significant differences on post measures of EST and ECE. It is also clearly seen that students' gains for modeling and lecturing groups are significantly different. The relevant data for the Mann Whitney U test can be seen in Table 4.

Table 4. Comparison of students' EST and ECE scores.

	Pre	Post	Gain
Electricity Success Test (EST)			
Lec. (N=20)	27.34	43.12	15.78
Mod. (N=21)	29.75	66.06	36.31
U, Z, p value	U=187.00, Z=-0.60, p>0.05	U=18.50, Z=-5.01, p<0.05	U=31.50, Z=-4.67, p<0.05
Effect size	0.09	0.78	0.73
Electricity Classical Exam (ECE)			
Lec. (N=20)	5.11	19.20	14.09
Mod. (N=21)	7.32	39.45	32.13
U, z, p value	U=158.50, Z=-1.34, p>0.05	U=18.50, Z=-4.99, p<0.05	U=39,50, Z=-4.44, p<0.05
Effect size	0.21	0.78	0.70

These results suggest that modeling method produces improved electricity success while the groups have similar electricity information at the beginning of the course. To see how powerful the significant differences the effect sizes of measurements are calculated. According to Table 4, effect sizes for the post measurements and gains for the both measurement tools are large. However the effect sizes concerning pre measurements are small.

Effects of Modeling Method on Students' Conceptual Understanding

As a result of the analysis, it is clearly seen that students in modeling group have higher mean scores than students in lecturing group concerning post ECT while they have similar mean scores at the beginning of the study. The pre measurement mean scores, post measurement mean scores and gains for modeling and lecturing group students relating ECT given in Figure 2.

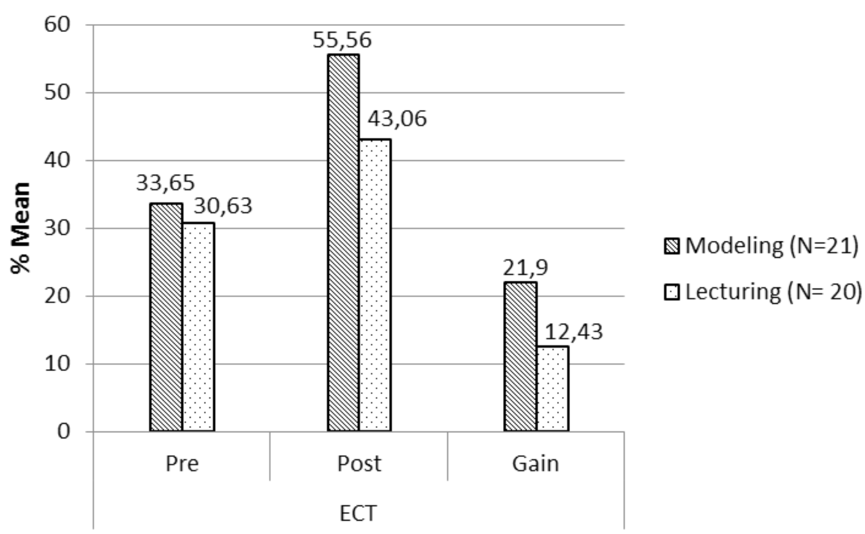

Figure 2: Matched ECT Scores for Modeling and Lecturing Classes.

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According to Mann Whitney U test results as seen in Table 5, there is no significant difference on pre measures of ECT while there is a significant difference between on post measurements of ECT. It is also clearly seen that there is a significant difference of the gains of the modeling and lecturing groups.

Table 5. Comparison of Students in Lecturing Group and Modeling Group on ECT.

	Pre	Post	Gain
Lec. (N=20)	30.62	43.05	12.43
Mod. (N=21)	33.66	55.56	22.10
U, Z, p value	U=194.00, Z=-0.41, p>0.05	U=91.50, Z=-3.09, p<0.05	U=130.50, Z=-2.07, p<0.05
Effect size	0.06	0.48	0.32

These results suggest that modeling method produces improved electricity conceptual understanding, while the groups have similar electricity knowledge at the beginning of the course. The effect sizes indicating that the conceptual understanding differences are small for Pre ECT but medium for post ECT and raw gain.

Discussion

It is very crucial to investigate the optimum conditions and techniques that would enhance learning level and understanding. The results have shown that teaching via modeling method leads to greater improvement on undergraduate students' achievement and conceptual understanding compared to the traditional teaching. The main difference between the two teaching processes is that modeling is student centered method while traditional one is not. During the modeling processes students are active builders of their own learning. Modeling maintains/offers much more effective environment to reach the academic knowledge. Through modeling, the students personally perform experiments, record the data, evaluate the data and try to reach the actual scientific laws and models. The conventional method, on the other hand, makes the students passive and the teachers are responsible to give the scientific concepts and laws via mainly lecturing and some other classical methods. Schwarz and White (2005) stress that modeling helps students to express and externalize their thinking and also students can visualize and test components of their conceptual ideas during the process. Sauer (2000) expressed that the students who gain the scientific concepts and laws by means of modeling are much more self-confident on especially problem solving and using that knowledge in daily life in comparison to the students who gain the law and concepts through classical methods and techniques. This specific work is in a good agreement with our present research.

A number of other researches focusing on teaching via modeling mostly carried on certain mechanics sub topics report very similar results underlining the advantage of modeling (Brewe, 2008; Halloun, 1996; Hestenes, 1996, 2006; Niedderer, Schecker & Bethge 2008; Vesenka, Beach, Munoz, Judd & Key, 2002).

Two separate data collection tools were employed in order to determine the students' academic achievement in the present research. These tools are Electricity Success Test (EST) which is a multiple choice test and Electricity Classical Exam (ECE) which is comprised of some classical problems. The pre measurement results are considered to be very low for both tools and both groups (see Figure 1). Nevertheless, both groups have scored higher marks from EST comparing ECE concerning pre measurements. This is likely because of the country's education system. It is very well known that the students greatly improve their multiple choice test abilities due to the student selection system to the higher education. However the students almost never face classical exams through their secondary education therefore they do not have the opportunity to improve.

Conceptual understanding of students becomes more and more important due not only to having higher marks but due also to be faced complicated daily problems. In order to investigate student's deeper understanding Electricity Concept Test (ECT) was employed. The pre measurements have shown no statistically meaningful difference; nevertheless post measurements clearly point to meaningful difference in favor of the modeling group students. The present conclusion is supported by a number of recent studies mostly focused on the mechanics sub topics (Brewe, 2008; Halloun, 1996; Hestenes, 1996, 2006; Niedderer, Schecker & Bethge 2008; Vesenka, Beach, Munoz, Judd & Key, 2002).

There is a strong link between conceptual change and modeling. Modeling is mainly a constructive process. Jonassen, Strobel and Gottdenker (2005) defines the conceptual change as a process of constructing and reorganizing personal conceptual models and model building can be used to represent changes in learners' conceptual frameworks. Hence model building and conceptual understanding are very closely linked together and to grow up side by side (Hestenes, 1996). Model creation and model-based reasoning is fundamental to human cognition and scientific inquiry (Schwarz & White, 2005), in other words, modeling is an important method for engaging conceptual model formation, that is, conceptual change (Nersessian, 1999).

The researchers express that model construction is as important as model usage in order to enhance conceptual understanding (Jonassen, Strobel & Gottdenker, 2005). When students construct models, they own and internalize the actual knowledge. The present research is also important because maintains both specific activities, namely model construction and model use. Representing phenomena in formulas is perhaps the most succinct and exact form of modeling. However, it must be remembered that qualitative models are just as important as quantitative because "qualitative representation is a missing link in novice problem solving" (Chi, Feltovich & Glaser, 1981).

Teaching via modeling has some specific difficulties in addition to many clear advantages. Through modeling, students certainly use and improve their abilities of constructing hypothesis, experimentation, collecting data, recording data, evaluating, discussing, and problem solving, which are not usually employed within any conventional teaching methods. Therefore it is very important to perform some pre-exercises to improve those key abilities in order to prevent possible intervention to the overall results. It is never to be forgettable that improving those abilities is also important for the instructors/teachers.

Conclusions

One of the most important goals of the physics education is to bring into being students who have advanced conceptual understanding. In order to reach this goal, selecting and implementing the correct teaching method is very important. In this research, modeling and traditional methods were compared. The first result of this research indicates that teaching via modeling improves undergraduate academic achievement greatly concerning electricity. The second result is that modeling method produces much more improved electricity conceptual understanding than the traditional teaching methods.

The present research have some limitations that indicate directions for future research. It is carried out with a total number of 41 students, 21 students within the modeling group and 20 students within the control group. These numbers are actually very convenient for the effective modeling instruction however increasing the number of students would certainly enhance the reliability of the overall conclusions.

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