The Effect of Modeling Based Science Education on Critical Thinking[1]

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Abstract
In this study to what degree the modeling based science education can influence the development of the critical thinking skills of the students was investigated. The research was based on pre-test – pst-test quasi-experimental design with control group. The Modeling Based Science Education Program which was prepared with the purpose of exploring the influence of the modeling based science education on the critical thinking skills of the students was designed in the way to include the objectives and the modeling process steps of the units of Physical Phenomena Learning Field, Electricity in Our Lives of Science and Technology Teaching Program of the 7th grade level which was enacted by the Ministry of National Education (MEB) in 2005. The study was conducted with four groups from different secondary schools; two were experiment groups and the other two were control groups of which were availability samplings. In the study the participants were 56 girls, 58 boys and in total 114 students. At the end of the research, it was found that there existed a significant difference ($p<0,05$) between the pre-test and post-test average scores of the control group. However, it was ascertained that there was not a statistically significant difference ($F1,111 = 3,332$, $p = ,071$, $\pi2 = 0,029$) between the post-test average scores which were refined according to the experimental and control groups' critical thinking pre-tests.

***Keywords*:** Science education, modeling, critical thinking

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[1] This study is based on Kaan Batı's doctorate dissertation titled *The Effectiveness of the Modelling Based Science Education; The Impact of This Education on Students' Views on the Nature of Science and Critical Thinking Skills*.

Introduction

Although history of science education at elementary and secondary schools levels dates back to the beginning of last century, a great deal of change and improvement took place particularly in last 30 years. New paradigms in philosophy of science and the arising needs of the time were among various factors leading to this change. The second half of the 20th century witnessed enormous changes in technology and industry which brought about a change in policies of science education since this era necessitated new generations of people capable of understanding and internalization science and accessing to information. In other words, contemporary approach in education is based on a strong conviction in the scientific knowledge and methodology and emphasizes competencies enabling individuals' access, understand, produce and critically evaluate scientific information (AAAS, 1995; Harlen, 2006; Hodson, 1992, 1998). As such this new approach has a strong reliance on students' critical thinking skills.

Critical Thinking

Critical thinking has long been one of the essential cognitive skills that science education aims at developing in students. In order to actualize this goal, educators must first decide on what kind of features critical thinking entails which will in turn shed light on the planning of educational methods and techniques that can foster development of these skills in students. Various researchers (Ennis, 1996; Facione, 1990) offer the term "*critical thinking dispositions*." The word "*disposition"* refers to one's tendencies, constitution and abilities[2]. On the other hand, viewing critical thinking from a dispositional standpoint poses challenges for educations since changing or improving individuals' inborn characteristics is not an easy task. Therefore, other researchers such as Perkins, Jay and Tishman recommend three essential components of critical thinking instead of using the term *disposition*: *inclination*, *sensitivity* and *ability* (Cited by Ennis, 1996). This conceptualization of critical thinking views it as a set of learned (acquired) skills. Lai (2011) views critical thinking as consisted of two dimensions, namely, *cognitive ability* and *disposition*. However, she does not see disposition as an inborn quality but rather as an *attitude*.

Considering different views on critical thinking, one can conclude that it consists of inborn (dispositional) as well as acquired traits. Lai (2011) views disposition as "attitudes or habits of mind, include open- and fair-mindedness, inquisitiveness, flexibility, a propensity to seek reason, a desire to be well-informed, and a respect for and willingness to entertain diverse viewpoints" (p.2). The ability dimension of critical thinking refers to "*cognitive skills of analysis, interpretation, inference, explanation, evaluation, and of monitoring and correcting one's own reasoning*" (Facione, 2000. p. 2). Although researchers conceptualize critical thinking as consisting of dispositional (inborn) and acquired tendencies and qualities, no empirical study examining critical thinking from a dispositional standpoint was found in the literature. Only Gega (Cited by Yıldırım, 2009) noted that a well-designed science education program can foster and improve such dispositions. Lai (2011) proposed that individuals acquire critical skills competencies in young ages and continue improving them through their life spans. Although a great number of adult people lack in critical thinking skills, theoretically individuals can acquire these skills at any stage of adulthood.

[2] Disposition: A person's inherent qualities of mind and character (Oxford Dictionary)

Viewing critical thinking from an educational point of view, Kayabaşı (1995) refers to critical thinking skills as problem solving strategies a person uses, and a disciplined focus on phenomena as well as the perfect thinking ability. On the other hand, Crawer's definition of critical thinking focuses more on one's judgments of viewpoints and as his or her construction of relationships between concepts (Cited by Akar, 2007). Norris (1985) sees critical thinking as "…rationally deciding what to do or believe" (p. 40). This definition also includes one's critique and evaluation of thoughts and viewpoints. However, this definition lacks some essential components since individuals with critical thinking skills should also offer reasonable hypotheses, firm observations and accurate inferences. In short, the person should have creative thinking, reasoning and additional dispositions. Facione (1990) proposes that an ideal critical thinker is;

> habitually inquisitive, well-informed, trustful of reason, open-minded, flexible, fair-minded in evaluation, honest in facing personal biases, prudent in making judgments, willing to reconsider, clear about issues, orderly in complex matters, diligent in seeking relevant information, reasonable in the selection of criteria, focused in inquiry, and persistent in seeking results which are as precise as the subject and the circumstances of inquiry permit. (p. 9)

Likewise, Marzano and colleagues (1988) noted that people with critical thinking skills and competencies have the following characteristic;

- Seek a clear statement of the thesis or question
- Seek reasons
- Try to be well informed
- Use credible sources and mention them
- Take into account the total situation
- Try to remain relevant to the main point
- Keep in mind the original or basic concern
- Seek alternatives
- Be open-minded
- Take a position (and change a position) when the evidence and reasons are adequate to do so
- Look for as much precision as the subject permits
- Deal in a systematic manner with the parts of a complex whole
- Be sensitive to the feelings, levels of knowledge, and degree of sophistication of other people
- Use one's critical thinking ability (Marzano et al., 1988, p 32)

Although there is not a consensus on the definition of the term "critical thinking" (Obay, 2009), there is reasonable consensus that the objective of teaching critical thinking should be enabling people to think, be fair, open-minded and decisive (Marzano, Brandt, Hughes, Jones, Presseisen, Rankin & Suhor, 1988). In emphasizing the need for inclusion of critical thinking skills and disposition in teaching programs, Yıldırım (2009) claimed that individuals with critical thinking skills and dispositions will inevitably use them in their personal conducts. Vieira, Tenreiro-Vieira and Martins (2011) suggest that efforts toward development of critical thinking skills as a part of science education should involve the following features: obtaining reliable information by using reliable resources; forming valid arguments and counter-arguments based on sound evidence; analyzing these arguments and counter-arguments; and posing questions and answers in order to arrive at further clarification and challenges. Hence, this study uses this conceptualization by Vieira et al (2011) and envisioned that critical thinking taught in educational environments will be generalized to other settings in which their daily lives take place.

Literature on critical thinking has not arrived at an agreed upon definition of the term yet (Obay, 2009). On the other hand, some studies report that a problem-based learning approach enhances students' critical thinking skills (Eren, 2011; Obay, 2009; Yıldırım, Yalçın, 2008). There have been studies reporting no significant impact of a problem solving approach on individuals' critical thinking skills (Özcan, 2007). However, there have also been research findings reporting that scientific process skills approach (İleri, 2012), inquiry based 7E model (Macit, 2006) and the argumentation approach (Gültepe, 2011) might have significant contribution to individuals' critical thinking skills. These studies found a medium-linear relationship between students' scientific process skills and their critical thinking skills. On the other hand, in process of the problem solving and the scientific process skills application students tend to be overly dependent on the operational process as they proceed to further stages of the process thus they experience an anxiety over the ending of the operation (İleri, 2012). As a result, students tend to not sufficiently think on alternatives. One of the striking findings regarding work targeting development of critical thinking skills has proven to be work involving book and newspaper reading habits. Findings of two studies with different samples showed that book and newspaper reading and reviewing news on the papers significantly increased students' critical thinking skills (Kaloç, 2005; Kırıkkaya & Bozkurt, 2011).

In addition, a study examining a science and technology instructional program's effect on 4^{th} and 5^{th} grade students' critical thinking skills found significant improvement (İleri, 2008). On the other hand, in a study with a large sample Akar (2007) found that students' critical thinking skills were significantly lower than the norms of the measurement instrument. The discrepancies between findings by İleri (2012) and those of Akar (2007) could in part be attributed to the years of the studies and the program in use in 2007 was newly enacted. Furthermore, Akar (2007) found that variables such as new-old programs, age and gender did not significantly contribute to the variance in critical thinking skills. Notwithstanding, academic achievement and socio-economic status were variables with greatest contribution to the variance in students' critical thinking skills.

Modeling Based Science Education

In announcing "*A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas"* (NRC, 2012) The National Research Council of the United States stated the priority of the new approach to science education as elimination of the mundane aspects of scientific methods. Indeed, in addition to the experimental processes, the scientific process involves modeling, a critical stance and communication. The more applications of scientific methodology moves away from scientific content, the more difficult it becomes to understand, of scientific concepts, principle and generalization. Therefore, instead of using a single scientific method scientists use a diversity of methods. Thus the produced information has strengths and weaknesses depending upon the techniques used and the culture in which the production of information takes place. Not merely relying on a simple-linear ordering of methods will help students evaluate as to how/why some theories have stronger properties than the others (NRC, 2012). The transformation of scientific method to a model based approach has given rise to the need for science educators to widen their views points so as to include; improvements in scientific information; social processes by which it is evaluated and communicated; contexts; redefinition of the epistemological values and the role of modeling (Develaki, 2007). Model based approach or model-based inquiry are essentially processes by which scientists produce new information (Develaki, 2007).

To put it more concretely, the modeling process involves steps such as: Encountering a question or problem; forming temporary models or hypotheses regarding the causal or holistic relations of phenomena, conducting systematic observations in order to test accuracy of these hypotheses; forming models based on these observations; evaluating the models in terms of their usefulness, predictive value or their capacity in explaining and revising the model and applying it to new circumstances (Windschitl, Thompson & Braaten 2007). Indeed the modeling process refers to a process similar to that frequently used by scientists. Model based science education has to do with teaching strategies that bring about constructing cognitive models, critiquing and changing processes (Khan, 2007). Model based science education involves the following steps: suggesting sub-models; expressing/sharing these models with peers; planning and applying data collection in order to evaluate one's own suggestions; critiquing one's own and peers' models and changing models based on emerging evidence. (Cardoso Mendonça, Justi, 2013).

In defining modeling process, Gilbert (2005) used the following categories and conceptualizes their interrelations as shown in Figure 1: mental models, expressed models, consensus models, scientific models and teaching models.

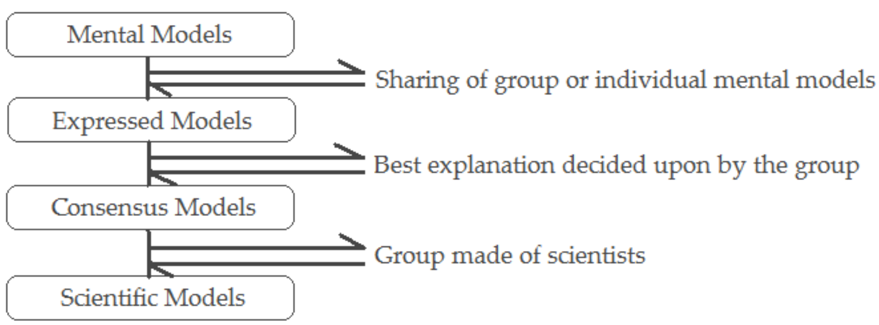

Figure 1: Interrelations of Different Models (Gilbert, 2005)

Gilbert (2005) proposes that all models used in science education should be viewed as teaching models. Since the next stage (step) requires participants to be scientists, in class modeling process for this study was designed up to the consensus stage.

This study examined the degree to which a model based science education program improved primary school students' critical thinking skills. More specifically, does the model based science education program have significant impact on primary school students' critical thinking skills? The following two research questions were addressed in seeking answers to this main research question;

1. Is there a significant difference between experimental groups' critical thinking skills pre-test and post-test scores while using a modeling based science education program with primary school students?

2. Is there a significant difference between experimental and control groups' post-test critical thinking skills scores while using a modeling based science education program with primary school students?

Method

In the study**,** the pre-test – post-test quasi-experimental design with control group was used. This design can be given as in the following:

Experimental Group	*M*	CCT-X	MDFEP	CCT-X
Control Group	*M*	CCT-X	Routine Practices	CCT-X

The Modeling Based Science Education Program (MBSEP) which was prepared with the purpose of exploring the influence of the modeling based science education on the critical thinking skills of the students was designed in the way to include the objectives and the modeling process steps of the units of Physical Phenomena Learning Field, Electricity in Our Lives of Science and Technology Teaching Program of the 7th grade level which was enacted by the Ministry of National Education (MEB) in 2005. The 7th grade Electricity in Our Lives unit which was chosen within the scope of the research composed of 32 objectives and covers 16 class hours. The reasons why these units were chosen are generally they include abstract concepts like "electrification" and "electrical current," these concepts are often used in daily lives and they are observable phenomena and the experiments can be carried out easily and with attainable materials. In the program sticking to the anticipated duration, daily plans and activities covering 16 hours were prepared. For each activity special forms for teacher and the students were prepared, activity flyers of the students were collected during the study which made it possible to use them as a qualitative data source in investigating the views of the students in regard to their critical thinking skills (Table 1).

The main philosophy on which the activities are based can be called the process of constituting scientific model. This process was developed by the researcher with the data gathered from the literature (Gilbert, 2005). This process is shown in Figure 2. As it is seen in Figure 2, the modeling process starts with a phenomenon or a problem situation. These problem situations were obtained from the subject titles in the science and technology teaching program. Within the scope of this research, two phenomena which were *"electrification"* and *"electrical current"* were elaborated on. In Table 1 which goals and objectives the activities aimed at were given.

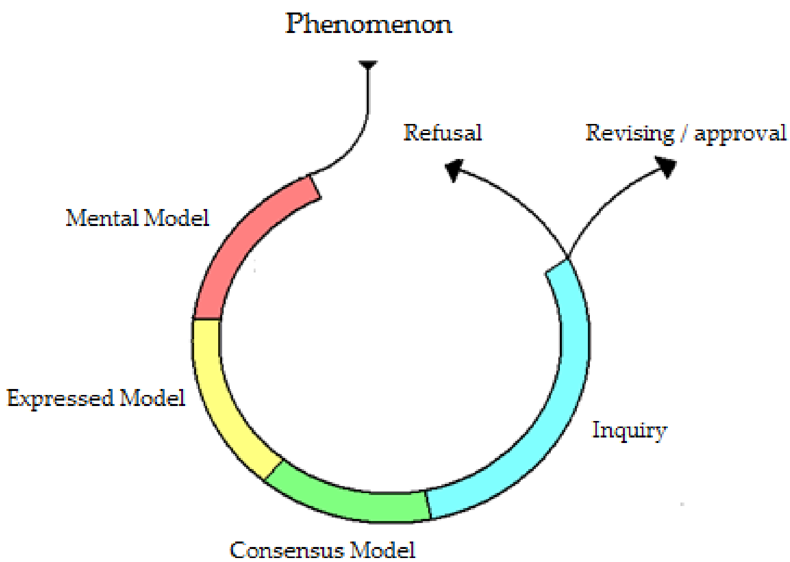

Figure 2: Modeling Process

The first part of the process consists of forming mental models, sharing the mental models (expressed models) and through discussing in the classroom, choosing the model which will make the best statements about the phenomena (consensus model). These processes can be specified as the parts of mental processes in which critical thinking skills of the modeling process are intensely used. At the end of the consensus model, the students were asked to assess the model in terms of individual usefulness, predictive power, coherence and testability. After answering these questions, the consensus model, which was the second part of the process, was proceeded. This part is the one which is, in Figure 2, called inquiry and in which the skills of research-inquiry are used. In this part students were asked to experimentally test the model they had created. Under the light of the data gathered from the experimental processes, there emerged two options as reject and accept about the model developed. The rejection of the model was a result of that it did not overlap with the experimental results. In this case, the revision of the previous models or a reinvention of a new model was expected. In the case of the emergence of any coherence between the experimental results and the model, it was accepted by the students; while in the case of the emergence of any incoherence between the processes and the model at some points, the model was revised. In the control group there was no interference with the time. The teachers were asked to maintain with their routine practices.

Table 1: Activities Based on Modeling: Goals and Objectives

Name of the Activity	Goal of the Activity	Target Objectives (Science and Technology Teaching Program)	Target Attainments:
Faraday and Electromagnetism	Recognition of the Modeling Process	Independent Objective	Openness to new ideas. Considering the evidence supporting the ideas and their reasons Thinking independent from the prejudices or any kind of authorities Create a cause-and-effect relation depending on the evidence and supporting ideas
Modeling Activity	Recognition of the Modeling Process	Independent Objective	Openness to new ideas Considering the evidence supporting the ideas and their reasons Thinking independent from the prejudices or any kind of authorities Create a cause-and-effect relation depending on the evidence and supporting ideas
The Nature of Electrification	Designing Models with Regard to What Electrification is	1.1. Realizes that some articles or objects can be electrified if they are contacted to each other.	Openness to new ideas Considering the evidence supporting the ideas and their reasons Thinking independent from the prejudices or any kind of authorities Create a cause-and-effect relation depending on the evidence and supporting ideas
How Does Electrification Occur?	Testing the Model Created by Electrification	1.2. Discovers through trials that two same articles after being electrified in the same way push each other without contacting while two different articles pull each other without contacting (BSB-8, 9, 30, 31). 1.3. Depending on the experimental results, infers that there are two types of electrical charges (BSB-31).	Create a cause-and-effect relationship Organizing the evidence, main and supporting ideas Considering the evidence supporting the ideas and the reasons

I am Making Electroscope	Designing Electroscope and Testing the Model	1.9. Shows the function of the electroscope on a tool s/he has designed (BSB-18, FTTC-5).	Considering the evidence supporting the ideas and the reasons Create a cause-and-effect relation depending on the evidence and the supporting ideas
What is Electrical Current?	Forming Models Related to the Electrical Current	2.1. Realizes that electrical current is a type of energy transfer. 2.2. States that electrical energy sources provides the circuit with electrical current. 2.3. Realizes that a closed circuit is needed for the generation of the current in electrical circuits. 2.4. Explains that the direction of a current in an electrical circuit is from the positive pole of the generator towards the negative pole and shows this on a circuit schema by drawing.	Openness to new ideas Considering the evidence supporting the ideas and their reasons Thinking independent from the prejudices or any kind of authorities Create a cause-and-effect relation depending on the evidence and supporting ideas
Current Voltage Resistance	Investigation of the Interrelations of Electrical Current, Voltage and Resistance	2.10. Through trials discovers the relation between the voltage of an element of a circuit between two poles and the current on it (BSB-8, 9, 30, 31). 2.11. Explains that the ratio of the voltage between the poles of a circuit element to the current on it is called the resistance of the circuit element.	Creating a cause-and-effect relation Organizing the evidence, main and supporting ideas Considering the evidence supporting the ideas and the reasons

Sampling

Application of the Modeling Based Science Education Program was done by science and technology teachers. Three schools with similar socio-economic backgrounds were chosen for the study. A science and technology teacher from each school was selected. Teachers were randomly assigned to experimental and control groups. Then teachers assigned to experimental groups were provided a 4-hour training on scientific models' roles in science education, modeling process and the Modeling Based Science Education Program. Distribution of teachers and the groups are illustrated in Table 2.

Table 2: Distribution of Teachers and Groups

	Teacher 1	Teacher 2	Teacher 3
School 1 (Sincan)	E1 - C1		
School 2 (Keçiören)		E2	
School 3 (Keçiören)			C2

(E: Experimental group, C: Control group)

Demographic information on teachers selected to apply the program is illustrated in Table 3.

Table 3: Demographic Information of Teachers

	Gender	*Work Experience*	*Attained Degree*
Teacher 1	Female	3 years	Undergraduate
Teacher 2	Male	6 years	Master's
Teacher 3	Male	10 years	Master's

Given that teachers in experimental and control groups might interact and thus impact each other's application, such grouping arrangement was done. Although teachers in both groups were informed prior to the applications, such arrangement was still necessary in order to further ensure that groups will not impact one another. In other words, assigning teachers from different schools to experimental and control groups was done in an attempt to ensure the internal validity of the study.

Participant students were selected from the science and technology classes the respective teachers were teaching. Participants were 56 female and 58 male students (a total of 114 students). Students distribution to experimental and control groups and to gender are shown in Table 4.

Table 4: Demographic Information According to School Attended

School	Group	Female	Male	Total
1 (Sincan)	E1 – C1	27	26	53
2 (Keçiören)	E2	16	18	34
3 (Keçiören)	C2	13	14	27
Total		56	58	114

(E: Experimental group, C: Control group)

In order to test if the groups' critical thinking skills differed prior to application of the program, their pre-test scores were examined. Descriptive statistics of groups' scores on CCT-X pre-test are given in Table 5.

Table 5: Descriptive Statistics CCT-X Pre-Test Scores

Group	N	Mean	sd
E1 (Experimental 1)	26	36.6154	6,21660
E2 (Experimental 2)	34	30.9118	6.60288
C1 (Control 1)	27	35.0741	6.18886
C2 (Control 2)	27	34.5185	6.06611
Total	114	34.0526	6.58349

In order to test if experimental and control groups' mean scores on pre-test Critical Thinking Skills Scale differed significantly, ANOVA was used. ANOVA results are illustrated in table 6.

Table 6: Comparisons of CCT-X Pre-Test Means of the Groups

Source	Sum of Squares	df	Mean Square	F	p
Group	540,202	3	180.067	4.546	0.005
Error	4357.482	110	39.613		
Total	137090.000	114			

($p<0.05$)

As shown in Table 6, a significant difference between means of experimental and control groups on pre-test scores of the Critical Thinking Skills Scale was found ($F_{3.110} = 4.546$, $p = 0.005$). In order to find the specific pairs of groups with mean significant mean differences, multiple comparison tests were used. Results of these comparisons are shown in Table 7.

Table 7: CCT-X Pre-Test Multiple Comparison Results of the Groups

	(I) group	(J) group	Mean Diff (I-J)	Std. Error	p	95% Confidence Interval Lower Bound	Upper Bound
Tukey HSD	E1	E2	5.7036*	1.63972	.004	1.4260	9.9812
		C1	1.5413	1.72938	.809	-2.9702	6.0528
		C2	2.0969	1.72938	.620	-2.4146	6.6084
	E2	E1	-5.7036*	1.63972	.004	-9.9812	-1.4260
		C1	-4.1623	1.62243	.056	-8.3948	.0702
		C2	-3.6068	1.62243	.123	-7.8392	.6257
	C1	E1	-1.5413	1.72938	.809	-6.0528	2.9702
		E2	4.1623	1.62243	.056	-.0702	8.3948
		C2	.5556	1.71299	.988	-3.9132	5.0243
	C2	E1	-2.0969	1.72938	.620	-6.6084	2.4146
		E2	3.6068	1.62243	.123	-.6257	7.8392
		C1	-.5556	1.71299	.988	-5.0243	3.9132
Scheffe	E1	E2	5.7036*	1.63972	.009	1.0480	10.3592
		C1	1.5413	1.72938	.851	-3.3689	6.4515
		C2	2.0969	1.72938	.690	-2.8133	7.0070
	E2	E1	-5.7036*	1.63972	.009	-10.3592	-1.0480
		C1	-4.1623	1.62243	.093	-8.7688	.4442
		C2	-3.6068	1.62243	.183	-8,2133	.9997
	C1	E1	-1.5413	1.72938	.851	-6.4515	3.3689
		E2	4.1623	1.62243	.093	-.4442	8.7688
		C2	.5556	1.71299	.991	-4.3081	5.4192
	C2	E1	-2.0969	1.72938	.690	-7.0070	2.8133
		E2	3.6068	1.62243	.183	-.9997	8,2133
		C1	-.5556	1.71299	.991	-5.4192	4.3081
Bonferroni	E1	E2	5.7036*	1.63972	.004	1,2980	10.1092
		C1	1.5413	1.72938	1.000	-3.1052	6.1878
		C2	2.0969	1.72938	1.000	-2.5497	6.7434
	E2	E1	-5.7036*	1.63972	.004	-10.1092	-1,2980
		C1	-4.1623	1.62243	.070	-8.5215	.1968

	C2	-3.6068	1.62243	.170	-7.9659	.7524
C1	E1	-1.5413	1.72938	1.000	-6.1878	3.1052
	E2	4.1623	1.62243	.070	-.1968	8.5215
	C2	.5556	1.71299	1.000	-4.0469	5.1580
C2	E1	-2.0969	1.72938	1.000	-6.7434	2.5497
	E2	3.6068	1.62243	.170	-.7524	7.9659
	C1	-.5556	1.71299	1.000	-5.1580	4.0469

Table 7 shows a significant difference between means of Experimental group 1 (E1) and Experimental group 2 (E2) on pre-test CCT-X scores. Therefore, while analyzing post-test results of the students, pre-test scores were used as a covarying variable.

Data Collection

In order to measure students' critical thinking skills Cornell Conditional Reasoning Test X Form was used. The test was originally developed by Ennis and Millman (1985) and is part of Cornell Critical Thinking Test serious. The scale consists of 72 items with 3 choices and is used with people between 4th and 14th grade levels. The purchase and adaptation of the scale was done by Akar (2007). Macit (2006) reports reliability coefficients for the test as ranging between 0.87 and 0.91. The reliability coefficients found in the adaptation study with a Turkish sample was 0.71 (Akar, 2007). In order to further investigate the reliability of the test, a sample of 94 students from schools in Ankara, Turkey were selected. The Cronbach alpha coefficient with this sample was 0.752. The test was used for pre-testing and post-testing of the groups of students participating to the current study. Each administration of the test took approximately 50 minutes. Indeed studies with the same scale indicate a time period of 50-55 minutes for its administration to middle school students (Macit, 2006).

Data Analysis

In order to determine whether there was a significant difference between critical thinking scores of experimental and control groups' t-test, ANOVA and ANCOVA were used. One-Way ANOVA was used to examine whether there was a significant difference between students' pre-test scores in the beginning phase of the study. In order to examine if there was a significant difference between pre-test and post-test scores of students in the experimental group which was the first research question of the study dependent groups t-test was used. To seek answers to the second research question of this study which inquired if there was a significant difference between experimental and control groups' post-test critical thinking skills scores while using a modelling based science education program, ANCOVA was used. While running ANCOVA, students' critical thinking pre-test scores were used as covariates.

Internal and External Validity

In order to improve the generalizability of the findings, 3 schools from two districts of Ankara Metropolitan Area with similar socio-economic backgrounds were selected. Selection of the schools and their assignments to control and experimental groups were articulated in the sampling section. All applications for the study were conducted in regular class meetings. No activity with both experimental groups (whether in class or in laboratories) did not take place outside of school premises. Thus it was assumed that circumstances of both experimental groups were equivalent.

The study aimed at examining improvements in students' critical thinking skills. No information on students' achievement levels in science and technology classes was obtained nor any information regarding students pre-class work or after class work was included in the study in an effort to ensure internal validity of the study. Planned activities were carried on by the science and technology teachers of each group and the researcher participated only as an observer. No further involvement beyond observing was selected in order to eliminate any bias toward the experimental groups. Observing control groups was also done to ensure unbiased application of teaching processes. Prior to conducting the study, meetings were conducted with each teacher. Their knowledge on the modeling process and whether they have such applications in their teaching activities was inquired. In addition, a class meeting of each teacher was observed. These observations of the groups showed that there were no significant differences between groups prior to the study. Similar observations were made during the study. In order to prevent the control group from being influenced by the program applications done with the experimental groups, the Teacher 3 who was the second control group's teacher was not included in the 4-hour training mentioned above.

Again, prior to conducting the study, the GPower Program was used to determine the power of the study, sample size, error percentage and effect size were estimated. These preliminary calculations revealed an effect size of 0,25 (medium), alpha (α) 0.05, and the power of the study was 0.95. In order to be able to use F tests in the analyses an minimum of 76 people was estimated for the sample size. Thus, a total of 114 students were included in the two experimental and the two control groups of the study. At the end of the study the power of the study was calculated as 0.35[3]. Cohen (1988) stated that power of studies up to 0.10 is considered small up to 0.25 as medium and to 0.40 as large.

Findings

The first research question of this study inquired whether there was a significant difference between experimental group's critical thinking skills pre-test and post-test scores while using a modelling based science education program. Descriptive statistics on pre-test and post-test scores of both experimental and control groups are shown in Table 8 .

[3]

Analysis:	Post hoc: Compute achieved power		
Input:	Effect size f	=	0.25
	α err prob	=	0.05
	Total sample size	=	114
	Number of groups	=	4
	Number of covariates	=	1
Output:	Noncentrality parameter λ	=	7.1250000
	Critical F	=	1.9186393
	Denominator df	=	109
	Power (1-β err prob)	=	0.3547677

Table 8: Experimental Group CCT-X Pre-Test-Post-Test Descriptive Statistics

	N	Min	Max	Mean	sd	Variance	Skewness	Kurtosis
CCT-X Pre	60	14.00	44.00	33.38	6.99	48.88	-0.41	-0.31
CCT-X Post	60	20.00	46.00	35.98	6.17	38.11	-0.56	-0.35

Considering the skewness and kurtosis statistics in Table 8, critical thinking skills pre-test and post-test scores of the experimental group were within the range of normal distribution (+1 , -1). On the other hand, in order to obtain further information on the normality of the data, normality tests and histogram graphs were used. The normality tests results of the experimental group's critical thinking skills pre-test and post-test scores are shown in Table 9.

Table 9: Experimental Group CCT-X Pre-Test-Post Normality Test Results

	Kolmogorov-Smirnov			Shapiro-Wilk		
	Statistics	df	p	Statistics	df	p
CCT-X Pre	.114	60	.050	.963	60	.068
CCT-X Post	.115	60	.045	.956	60	.032

Shapiro-Wilk values in Table 9 shows experimental group's post test scores were not normally distributed. On the other hand, the pre-test scores were normally distributed ($p<0.05$). the histogram graphs of the experimental group's pre-test and post-test critical thinking skills are shown in Table 3.

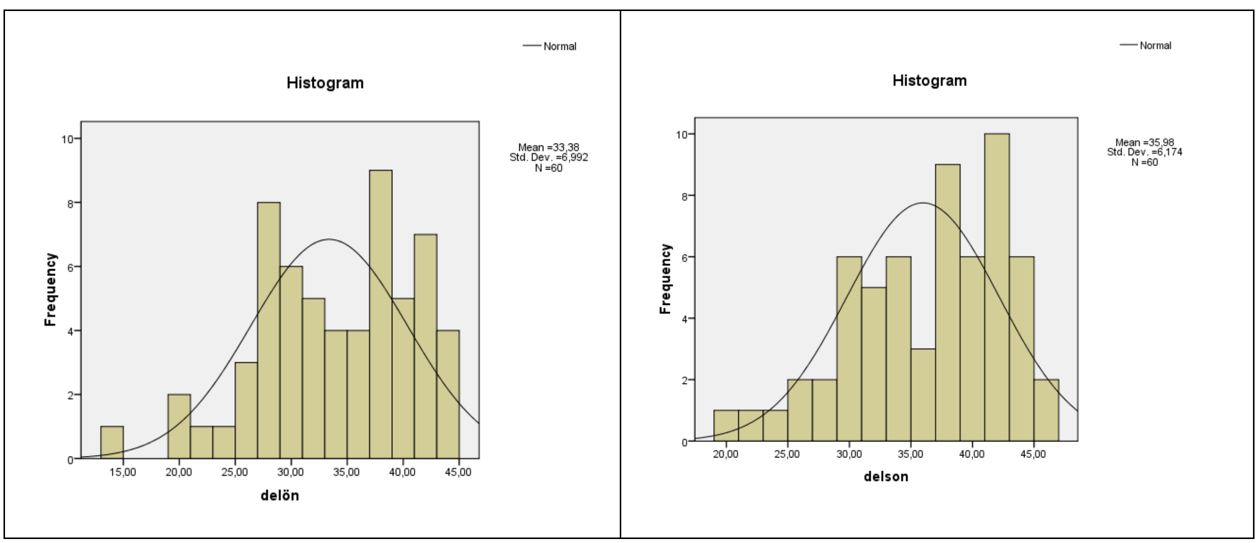

Figure 3: Histogram Graphs of Pre and Post-Test Score of Experimental Group

Group sizes, normality tests, skewness and kurtosis statistics were considered together experimental group's pre-test and post-test scores had satisfactory normal distribution. Thus it was determined that using parametric statistics in examining mean differences between pre-test and post-test scores would be suitable. Hence, t-test was used to determine if there was a significant difference between pre-test and post-test scores of the experimental group. Results of t-test are illustrated in Table 11.

Table 10: Experimental Group CCT-X Pre-Test-Post Test Results

		N	Mean	sd	Df	t	p
CCT-X	Pre test	60	33.38	6.99	59	-3.738	.000
	Post test	60	35.98	6.17			

($p < 0.05$)

Table 10 shows that there was a significant difference between pre and post scores of the experimental group ($p<0.05$). In other words, application of the program led to a significant difference in students' critical thinking scores.

The second research question of this study inquired if there was a significant difference between experimental and control groups' post-test critical thinking skills scores while using a modeling based science education program. Descriptive statistics of experimental and control groups' post-test results are shown in Table 11.

Table 11: CCT-X Descriptive Statistics According to Post-Test Results

Groups	N	Mean	Sd	Corrected Mean
Experimental(Group 1)	60	35.98	6.17	36.48
Control (Group 2)	54	35.53	6.12	35.02

Table 11 illustrates that students' means on corrected post-test scores were quite close to one another. In order to test if there was a significant difference between these means ANCOVA was used. While running ANCOVA, students' critical thinking pre-test scores were used as covariates. ANCOVA results are given in Table 12.

Table 12: ANCOVA Results According to CCT-X Pre-Test Adjusted Test Scores

Sources of Variance	Sum of Squares	df	Mean Square	F	p
Pre Test	2333.900	1	2333.900	135.883	.000
Group	57.235	1	57.235	3.332	.071
Error	1906.509	111	17.176		
Total	150124.00	114			

($p<0.05$)

Table 12 shows that there was not a significant difference between groups' post-test mean scores when they were adjusted for pre-test scores ($F_{1.111}$ = 3.332, p = .071 , π^2 = 0.029). Therefore, it could be concluded that the program did not bring about a significant difference between experimental and control group students' post-test critical thinking scores.

Results and Discussions

In this study the influence of modeling based science education on the development of the students' critical thinking skills was investigated. Modeling Based Science Education Program, which was developed with this aim was applied to the level of lower secondary school 2nd grade (7th grade in primary school) by the course teachers and the critical thinking development of the students was attempted to be detected. The main hypothesis of the study was that the modeling based science education program might contribute to the development of the critical thinking skills of the students. However, although there was a significant difference between the CCT-X pre-test and post-test scores of the experimental group students, there was not any significant difference between the means of the CCT-X post-test application of the experimental and control groups. In this case, the significant difference emerged between the pre-test and post-test scores of the experimental groups should be interpreted cautiously. Though it is stressed that modeling based approach does contribute to the development of the creativity of the students (Arslan, 2013), it is assumed that this development is not reflected on the critical thinking dimension. Another point to be discussed within the theoretical stance of the study was that critical thinking is an inborn quality and can be improved in time. However, in the conducted studies, it is put forward that in our country's educational system students barely find opportunities to develop their critical thinking skills (Akar, 2007). Parallel to this, the teachers who participated in the study agreed that developing critical thinking skills is not an easily attainable skill and students are not sufficiently present at the settings where they can improve their critical thinking skills and thus they do not have experience with such an activity. In addition to these, considering that the program developed for the study was not long enough for the students to enable them to improve their critical thinking skills, it can be understood why this targeted skill was not developed.

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