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Effects of Model-Based Science Education on Students' Academic Achievement and Scientific Process Skills

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ABSTRACT
This research aims to determine the effects of model-based science teaching on students' academic achievements and science process skills for a science and technology course. A quasi-experimental research method was used for this study. Study participants were 48 7th grade students. The application was carried out over a period of 4 weeks. During this research, the study's experimental group received the model-based science teaching, while the study's control group received regular science teaching in accordance with their usual coursebook. The assessment tools "the Achievement Test" and "the Science Process Skills Scale" were administrated as pretest and posttest. The SPSS 11.5 software package program was utilized to analyze the study data. It was found that the experimental group achieved higher scores in the achievement test and higher scale scores regarding science-process skills compared with those of the control group. It was concluded that the model-based science teaching made a positive contribution to the development of the students' academic achievement and scientific process skills that might henceforth be successfully applied in science and technology courses.

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Introduction

Science lessons are a means of exploring and thinking according to experimental criteria, logical thinking, and inquiry, while modeling is the essence of thinking and working scientifically. Models are essential to science learning, much like they are essential to learning in any field (Gilbert, 2011). The National Science Education Standards (NSES) emphasize the use of models in science instruction by making modeling one of the five unifying concepts of science that apply to all grade levels. Unifying concepts and processes include a) Systems, order, and organization, b) Evidence, models, and explanation, c) Change, constancy, and measurement, d) Evolution and equilibrium, and e) Form and function. This standard describes some of the integrative schemes that can bring together students' many and varied experiences in science education across grades K–12. The unifying concepts and processes standard can be the focus of instruction at any grade level, but it should always be closely linked to those outcomes that are aligned with other content standards (NRC, 1996). The NSES recommend that models be a focus of instruction; they help students understand the use of evidence in science, as well as help them to make and test predictions, use logic, and assemble their own understanding of how things work (Gilbert & Ireton, 2003).

Models and modeling play a central role regarding the nature of science, its conduct, and the accreditation and dissemination of its outcomes, while also forming a bridge between science and technology (Franco & Colinvaux, 2000). Models are used to teach science concepts to students as well as teach them something about the process of learning and about the nature of knowledge itself. A *model* is a system of objects or symbols that represents a specific aspect of another system, called its target. We use models every day in conversation, to learn, to experiment, and to make predictions. Indeed, model building can be said to be at the heart of learning (Gilbert, 2011). A scientific model is a representation of a system that includes important parts of that system (along with rules and relationships of those parts) to help us think about and test ideas of the phenomena. Modeling is the experience of constructing, using, evaluating and revising scientific models and knowing what guides and motivates their use (Kenyon et al., 2008).

Model-based thinking is a sophisticated process that should comprise an explicit part of learning in science (Harrison & Treagust, 2000). Gilbert (2011) classifies models into two kinds: *personal models*, which underlie science and learning across various fields (mental models); and *expressed models*, which are important in science and science teaching (physical models, analog models, plans, mathematical models, computer simulations). Mental models are personal cognitive representations, which educators sometimes refer to as models once these cognitive representations have been expressed in the public domain (Greca & Moreira, 2000). Modeling involves the building, critiquing, modifying, and expressing these mental models.

Modeling is the essence of thinking and working scientifically (Harrison & Treagust, 2000) while also being an important process in the production, evaluation, and dissemination of scientific knowledge (Gilbert et al., 2000). Passmore et al. (2010) emphasize that; scientists engage in inquiry other than controlled experiments, use existing models in their inquiries, engage in inquiry that leads to revised models, use models to construct explanations, use models to unify their understanding, and engage in argumentation.

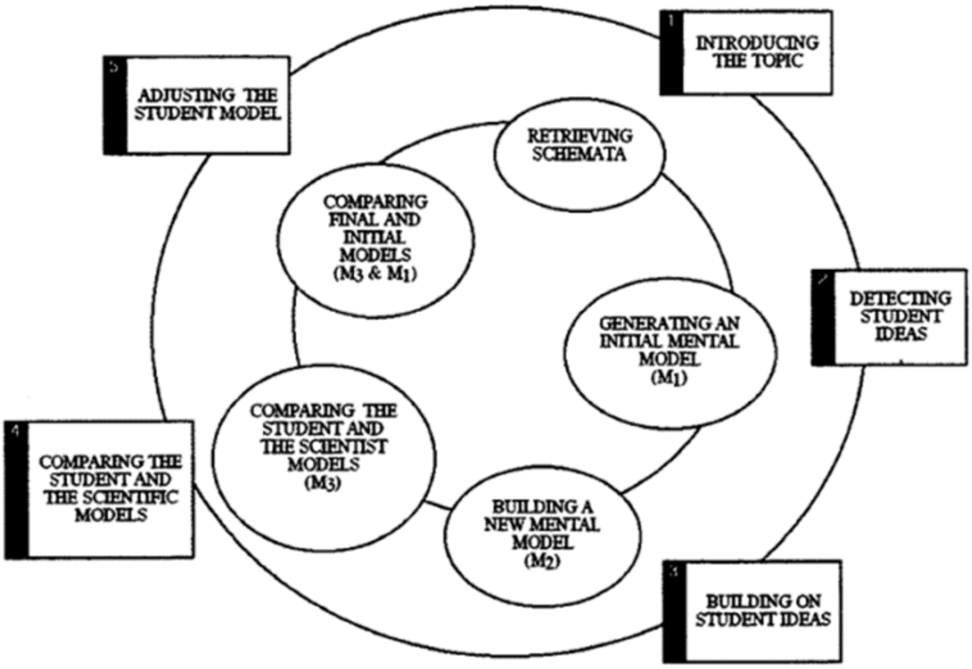
Model-based teaching improves scientific process skills (Baek et al., 2007; Keys, 1997; Kenyon et al., 2008; Ogan-Bekiroglu & Arslan, 2014; Schwarz & Gwekwerere, 2007). Students' scientific process skills develop gradually and experientially through the development of conceptual understandings. Science instruction focused around scientific inquiry and modeling can help learners develop a deep understanding of subject matter, powerful scientific skills, and a strong understanding of the nature of science (Schwarz & White, 2003). Scientific process skills include observing, inferring, measuring, communicating, classifying, predicting, controlling variables, defining operationally, formulating hypotheses, interpreting data, formulating models, experimenting, and organizing and drawing conclusions from data. Scientific processes are used in science education as a tool for scientific learning. Science educators emphasize model-based teaching because students' understanding of scientific process skills is very important in science lessons, and because modeling is a basic characteristic of science (Harrison & Treagust, 2000; Schwarz & Gwekwerere, 2007; Taylor et al., 2000). Model-based teaching (MBT) is a theoretical approach to teaching that supports students' mental-model construction. MBT presupposes that people learn by building, critiquing, and enriching the existing mental models they have of the way a system works (Khan, 2007).

MBT promotes three fundamental cognitive processes—sometimes referred to as ''GEM'' in the literature—among students: **(a)** student generation of mental models (G), **(b)** student evaluation of their mental models (E), and **(c)** student modification of their mental models (M) (Khan, 2007; Rea-Ramirez et al., 2008). Researchers explain the modeling process as involving several cycles. Student-centered approaches to modeling share common phases that mediate student learning by certain successive cycles, including exploration, expression, construction, application, and revision of models. Nunez-Oviedo (2004) examined teachers' and students' responsibilities in detail and constructed a constructivist pedagogic approach.

Nunez-Oviedo (2004) emphasizes that the teacher plays a key role during mental model construction and states that both the teachers and the students contribute ideas to build and evaluate a model. The teacher is the individual who co-constructs knowledge with the student. Accordingly, teachers should be aware of students' mental models so that they can better support the student's criticism and revision cycles. Learning processes needed by students for model construction occur in three essential cycles: *Macro cycle, Micro cycle, and Learning Pathways*.

Figure 1

Circular Diagram of the Macro Cycle



Note. (Adapted from Nunez-Oviedo, 2004)

Throughout the phases of the Macro Cycle (shown in figure 1), the teacher introduces the subject of the unit of instruction and detects students' initial ideas. Different kinds of teaching tactics can be used to foster dissatisfaction and modification until the students' ideas become more compatible with the target. The teacher then shows the students an animation that contained the target model and asks them to compare their final understanding with their initial ideas. Accordingly, the teacher then adopts different modes for each unit of instruction.

Kenyon and her colleagues (2008) describe the practice of modeling in 4 steps; 1) Students construct models consistent with prior evidence and theories to illustrate, explain or predict phenomena, 2) Students use models to illustrate, explain, and predict phenomena, 3) Students compare and *evaluate* the ability of different models to accurately represent and account for patterns in phenomena, and to predict new phenomena, 4) Students *revise* models to increase their explanatory and predictive power, taking into account additional evidence or aspects of a phenomenon.

In those science lessons that involve model-based teaching, students create models before using the models they have made. The literature shows that the students formed scientifically acceptable subject-related models as a result of receiving the model-based education in which they had been active; consequently, they were able to understand more complex models due to them having been positively affected by the model-based learning process (Baek et al., 2011; Batı & Kaptan, 2015; Bilal & Erol, 2012; Demirçalı, 2016; Kenyon et al, 2008; Gobert et al., 2011; Ogan-Bekiroglu, 2007; Ogan-Bekiroglu & Arslan, 2014; Sarikaya et al., 2004; Schwarz & Gwekwerere, 2007; Schwarz & White, 2005).

Keys (1997) conducted a study to examine the reasoning discourse of two pairs of ninth-grade students. The purposes of the study were to elucidate specific types of reasoning strategies that students use in ordinary classroom activities and compare the reasoning strategies used in an activity that required little domain-specific knowledge to one that required extensive domain-specific knowledge. Interpretive techniques were used to explore the students' thinking represented in discourse, writing, and interviews. Results indicated that successful model formulation for both activities involved: recognizing the tentative nature of existing models, identifying laboratory observations as evidence and using evidence to modify existing models, and coordinating all mutually consistent knowledge propositions into a coherent new model.

Schwarz and White (2003); created the Model-Enhanced ThinkerTools Curriculum which is an inquiry-oriented physics curriculum for middle school students in which they learn about the nature of scientific models and engage in the process of modeling. Curricular trials with two teachers in six science classes of a middle school indicated that; this approach can facilitate a significant improvement in students' understanding of modeling and learning about the nature of models can play a role in the acquisition of inquiry skills and physics knowledge.

Sarikaya et al. (2004) carried out a study to determine the effect of models on academic success by considering models that had been created by students in relation to mitosis and meiosis. The study was carried out using two groups, an experimental group, and a control group. Students in the experimental group were taught using the traditional teaching method, after which they developed models related to mitosis and meiosis. Comparatively, the control group was taught using the same teaching method, but they did not make any such models. The results of the study show that the final test results of the experimental group were statistically significant than those of the control group.

Ogan-Bekiroglu (2007) examined Turkish pre-service physics teachers' knowledge and understanding of the Moon, Moon phases, and other lunar phenomena, and the effects of model-based teaching on pre-service teachers' conceptions. At the beginning of the instruction, the pre-service physics teachers had various flawed, incoherent, and incomplete mental models concerning the Moon and lunar phenomena. Model-based teaching enabled pre-service teachers to abandon their misconceptions and gain scientific knowledge. The results revealed that periodic observations and sharing information with group peers helped the pre-service physics teachers become more aware of their misconceptions concerning the appropriate categorization of the Moon and lunar phenomena. The construction of concrete models and the use of these models in explanations provided the pre-service teachers with revision of knowledge. Therefore, through the facilitation brought about by model-based teaching, some of the pre-service teachers' mental models shifted from being flawed, incoherent, or incomplete mental models into being correct mental models of the Moon and lunar phenomena.

In their study, Kenyon and her colleagues (2008) found the instructional sequence—constructing a model to explain a phenomenon, testing the model, evaluating the model, testing the model against other ideas, revising the model, and using the model to predict and explain—to be effective in helping students learn key scientific concepts about evaporation and condensation and for developing their understanding about modeling. They found that students enjoyed drawing, writing, and even revising their own science ideas when modeling. Throughout this instructional sequence, students were doing hands-on activities combined with thinking about scientific explanations and incorporating them into their models.

Gobert and her colleagues (2011) conducted a study to explore high school students' understandings of the nature of models, and their interaction with model-based software in biology, physics, and chemistry. Data from 736 high school students' understandings of models were collected using the Students' Understanding of Models in Science (SUMS) survey as part of a large-scale, longitudinal study in the context of technology-based curricular units in each of the three science domains. The results showed that there were differences in students' pre-test understandings of models across the three domains and that higher post-test scores were associated with having engaged in a greater number of curricular activities, but only in the chemistry domain. And also, it was found that relationships between the pre-test understanding of models' subscales scores and post-test content knowledge varied across domains.

In their study, Bilal and Erol (2012) explore the effects of model-based electricity instruction on students' academic achievement and conceptual understanding. This research was carried out using two groups comprising second-grade students who took a General Physics II course. Students in the experimental group were subject to model-based electricity instruction, while those in the control group were subject to traditional physics instruction. The findings of the research showed that model-based instruction had positive effects on students' academic achievement and conceptual understanding of electricity subjects.

Ogan-Bekiroglu and Arslan (2014) conducted a study among pre-service physics teachers to empirically identify the effects of the implementation of model-based inquiry on students' scientific process skills and conceptual knowledge. The model-based inquiry was implemented in the experimental group while the control group worked according to an inquiry-based environment. No difference was found between the groups' overall scientific process skills scores and conceptual knowledge following the instruction. However, when the groups' scientific process skills were compared in terms of the five test dimensions it was found that, while those in the control group significantly increased their performances in the identifying variables and stating hypothesis dimensions, the experimental group not only significantly improved their scores in these two dimensions but also in the dimensions of operational definitions, data and graph interpretations.

Batı and Kaptan (2015), conducted a study to test the effect of a model-based science education program on students' views about the nature of science and critical-thinking abilities. It was found that the Model-Based Science Education Program enables meaningful permanent learning and student engagement and enhances students' views of the nature of science. The model-based science education program used in the study (Batı & Kaptan, 2015) was based on skills pertaining to the construction, testing, and revising of mental, expressed, and consensus models in middle-school science education.

Enabling students to engage in modeling has many potential benefits for science education. Model creation and model-based reasoning are core components of both human cognition and scientific inquiry. Students should therefore be involved in a process of creating, testing, revising, and using externalized scientific models that may represent their own internalized mental models (Schwarz & White, 2003).

Astronomy subjects have an interdisciplinary nature and are related to daily life, technological developments, and many academic subjects that are taught from a primary school level to a university level. It is therefore important that students learn about these issues. Students' knowledge level of astronomy subjects—which has an important place in science courses, across all educational levels—has been investigated in the literature, and it has been observed that students do not have sufficient conceptual understanding of them (Cin, 2007; Kurnaz, 2012; Ogan-Bekiroğlu, 2007; Taylor et al., 2003). In the aforementioned studies (Cin, 2007; Kurnaz, 2012; Ogan-Bekiroğlu, 2007; Taylor et al., 2003), it is emphasized that a) students have similar mental models that are not compatible with scientific information, b) students' mental models include similar errors across all grade levels, c) at the base of these problems there is lack of effective learning environments.

The literature contains a limited number of studies about model-based interventions in which students construct models while at the same time discussing the characteristics of scientific models and constructing their own mental models. If today's learners are to start thinking more like astronomers, then their education must become a process in which the learners construct and validate mental models that bind individual knowledge and conceptions into a coherent whole. This is because, within science and astronomy education, mental model construction requires interactive debating, problem-solving, and cooperative learning (Taylor et al., 2003; Tsivitanidou et al., 2018).

Purpose

The purpose of this study was to investigate the effects of a model-based science and technology course on students' academic achievements and science process skills in the seventh-grade unit "Space".

Sub-problems of the Research

1. Is there a statistically significant difference between experimental and control groups' Achievement Test (AT) scores?
2. Is there a statistically significant difference between experimental and control groups' Scientific Process Skills Scale (SPS) scores?

Methods

Research Design and Participants

This study used a pretest-posttest controlled quasi-experimental design with a control group. In these research designs, cases are assigned to an intervention or control group using some method due to the absence of randomization to form the groups. With sufficient controls, a quasi-experimental design can be a powerful tool for testing causal hypotheses (Çepni, 2018; Kline, 2009). In the present study, the control and experimental groups were selected through randomization. An "Achievement Test (AT)" and a "Science Process Skills Scale (SPS)" were applied to both groups before and after the study implementation. In this study, the lessons for the experimental group were taught by model-based science teaching, whereas lessons for the control group were taught only through textbook-oriented teaching. The design of this research study is given as follows:

Table 1

The Experimental Design

	Pretests	Experimental Process	Posttests
Experimental Group	AT	Model-Based Science Education Program	AT
	SPS		SPS
Control Group	AT	Routine Practices	AT
	SPS		SPS

The population of the study comprises 7th-grade students attending a secondary school in the provincial city of Denizli, Turkey, during the 2013–2014 academic school year. The study comprises two randomly selected classes: an Experimental (n=26) class, and a Control (n=22) class, for a total of 48 study participants.

Data Collection Tools and Analysis

Within the scope of the current study, an "Achievement Test (AT)" and a "Science Process Skills Scale (SPS)" were applied to both groups before and after the study implementation. "Achievement Test (AT)", which was developed by the researcher, consists of 26 items; its reliability coefficient is calculated as 0.781. The "Science Process Skills Scale", developed by Enger and Yager (1998), was adapted to Turkish by Demirçalı (2014). The SPS comprises 26 items and the reliability coefficient is calculated as 0.82.

SPSS 11.5 software package program was utilized to analyze the quantitative data that were obtained from the study. Whether the quantitative data had a normal distribution was assessed by descriptive statistics and the Shapiro–Wilk Test. Descriptive statistics of pretest and posttest scores of both the experimental and control groups are shown in Table 2.

Table 2

Shapiro–Wilk Normality Test Analysis Results

Tool	Test	Group	*N*	Shapiro–Wilk	*p*
AT	Pretest	Experimental Group	26	.950	.236
		Control Group	22	.915	.060
	Posttest	Experimental Group	26	.972	.676
		Control Group	22	.918	.071
SPS	Pretest	Experimental Group	26	.944	.169
		Control Group	22	.925	.098
	Posttest	Experimental Group	26	.888	.068
		Control Group	22	.908	.050

When Table 2 is analyzed according to the analysis results of the measurement tools used, it can be seen that the test scores do not deviate excessively from the normal distribution, and also that the data meet the normality assumption. Based on these results, parametric tests were accordingly used in this research.

When the difference between the pretest and posttest scores is statistically significant, the eta square (η^2) coefficient is used to calculate the effect size. The effect size is calculated to determine the degree of the difference and is frequently preferred to independent groups *t* tests. The eta square (η^2) coefficient, which takes a value of 0–1, shows the variance rate explained by the independent variable over the dependent variable. Up to a value of ".01" shows a small effect size, a value of ".06" a medium effect size, and up to a value of ".14" a large effect size (Büyüköztürk, 2008). In this study, if a statistically significant difference was found between experimental and control groups' posttest scores, the eta square (η^2) coefficient was calculated accordingly.

Modelling Process and Traditional Teaching Process

The modeling process of the study is designed in consideration of the teaching cycle of Nunez-Oviedo (2004). The cycle comprises five steps: Introducing the Topic, Detecting Student Ideas, Building on Student Ideas, Comparing the Student and the Scientific Models, and Adjusting the Student Model.

1) Introducing the Topic: The researcher introduced the topic of a unit of instruction.

2) Detecting Student Ideas: The researcher detected students' initial ideas by posing a question, then asking the students to describe their ideas. Subsequently, a discrepant question or event was used to generate mild or strong dissatisfaction. The teacher then asked students to draw a revised model to foster modification by encouraging them to restructure, tune, or adjust their ideas.

3) Building on Student Ideas: Different kinds of teaching tactics were then used to foster dissatisfaction and modification until the students' ideas became more compatible with the target.

4) Comparing the student's model and the scientific model: The researcher showed the students an animation related to the target model and asked them to compare their final understanding with their initial ideas.

5) Adjusting the Student Model: The researcher gave students a new problem situation that was related to the target model, asked them to solve the problem, then asked them to share their findings with the rest of the class.

Traditional Teaching Process

The activities of the control group were also performed by the researcher with lecturing, discussion, and question-answering techniques mainly being employed during the sequence. Four hours each week were used for this unit.

Findings

Independent samples *t* test was used to determine whether there was a significant difference between pretest and posttest AT and SPS scores of students in the experimental and control groups. Each mean groups' pretest-posttest scores, were then compared with paired sample t-test.

Findings Related to the First Sub-Problem of "Is There a Significant Difference Between Experimental and Control Groups' Achievement Test (AT) Scores?":

The relationship between the experimental and control groups' AT pretest scores before the experimental procedure is shown in Table 3.

Table 3

Independent Samples t-test Analysis Results of AT pretests for the Experimental and Control Groups

Group	*N*	$\overline{X}$	*s*	*SD*	*t*	*p*
Experimental	26	11.04	2.69	46	.493	.625*
Control	22	10.59	3.59			

Note. *$p < .05$

As shown in Table 3, no statistically significant difference was found between the experimental and control group's mean pretest AT scores [$t_{(46)}$ = .493; $p > .05$]. In order to determine whether there was a significant difference between the pretest and posttest AT scores of students in the experimental group, paired samples *t* test was used, the results of which are shown in Table 4.

Table 4

Comparison of AT pretest-posttest Scores of the Experimental Group

Experimental Group	*n*	$\overline{X}$	*s*	*SD*	*t*	*p*
Pretest	26	11.04	2.69	25	-12.45	.00*
Posttest	26	16.65	3.31			

Note. *$p < .05$; $\eta^2 = 0.86$*

The results of the paired samples *t* test revealed that the average pretest score of students in the experimental group was 11.04 and that their average posttest score rose to 16.65. A statistically significant difference was observed between the two results [$t_{(25)}$=12.45, $p<0.05$]. In addition, eta square (η^2) value, which was calculated to determine the effect size, was found to be 0.86. Accordingly, it can be said that 86% of the variance of the academic success scores of the experimental group occurred due to pretest-posttest measurement. The calculated effect size reflects this large effect.

In order to determine whether there was a significant difference between pretest and posttest AT scores of students in the control group, paired samples *t* test was used, the results of which are shown in Table 5.

Table 5

Comparison of AT pretest-posttest Scores of the Control Group

Control Group	*n*	$\overline{X}$	*s*	*SD*	*t*	*p*
Pretest	22	10.59	3.59	21	-3.03	.006*
Posttest	22	13.18	3.59			

Note. *$p < .05$; $\eta^2 = 0.30$

As can be seen in Table 5, the results of the paired samples *t* test revealed that the average pretest score of the control group was 10.59 and that its average posttest score rose to 13.18. A statistically significant difference was observed between two results [$t_{(21)} = 3.03$; $p < .05$]. In addition, the eta square (η^2) value, which was calculated to determine the effect size, was found to be 0.30. Accordingly, it can be said that 30% of the variance of the academic success scores of the control group occurred due to the pretest-posttest measurement. The calculated effect size reflects this large effect.

These findings indicate that both the model-based science education program and traditional teaching approaches are effective for 7th graders in increasing their academic success in the unit of "Space". In order to determine whether there was a significant difference between posttest AT scores of students in the experimental and control group, independent samples *t* test was used.

Table 6

Independent Samples t-test Analysis Results of AT Posttests for Both the Experimental and Control Groups

Group	*n*	$\overline{X}$	*s*	*SD*	*t*	*p*
Experimental	26	16.65	3.31	46	3.48	.00*
Control	22	13.18	3.59			

Note. *$p < .05$; $\eta^2 = 0.21$

According to Table 6, the results of the independent samples *t* test revealed that the average posttest score of the control group was 13.18 and that the average posttest score of the experimental group was 16.65. A statistically significant difference was observed between two results [$t(_{46}) = 3.48$; $p < .05$]. It can be seen that the academic success of students in the experimental group is higher than that of students in the control group. In order to determine the effect size, η^2 (eta square) value was calculated and was shown to be 0.21. Accordingly, it can be said that 21% of the variance of the AT posttest scores occurred due to the group in question, namely the method applied. The calculated effect size value reflects a large effect.

Findings Related to the Second Sub-Problem, "Is There a Significant Difference Between Experimental and Control Groups' Scientific Process Skills Scale (SPS) Scores?"

In order to determine whether there was a significant difference between pretest SPS scores of students in the experimental and control group, independent samples *t* test was used. The results of this test are shown below in Table 7.

Table 7

Independent Samples t-test Analysis Results of SPS pretests for the Experimental and Control Groups

Group	*N*	$\overline{X}$	*s*	*SD*	*t*	*p*
Experimental	26	13.73	3.90	46	146	.151*
Control	22	11.86	4.95			

Note. *$p < .05$

According to Table 7, the results of the independent samples *t* test revealed that the average pretest score of the control group was 11.86 and that the average pretest score of the experimental group was 13.73. A statistically significant difference was not observed between these two results [$t_{(46)} = 1.46$; $p > .05$]. This shows that the students in the experimental and control groups are equivalent in terms of their mean SPS pretest scores.

In order to determine whether there was a significant difference between the pretest and posttest SPS scores of students in the experimental group, paired samples *t* test was used, the results of which are shown in Table 8.

Table 8

Comparison of SPS pretest-posttest Scores of the Experimental Group

Experimental Group	*n*	$\bar{X}$	*s*	*SD*	*t*	*p*
Pretest	26	13.73	3.90	25	14.25	.00*
Posttest	26	19.54	4.65			

Note. *p < .05; $\eta^2 = 0.89$

The results of the paired samples *t* test revealed that the average pretest score of the experimental group was 13.73 and that the experimental group's average posttest score rose to 19.54. A statistically significant difference is observed between these two results [$t(25) = 14.25$, $p < .05$]. This situation can be expressed as indicating that model-based teaching has a positive effect on students' mean SPS score; the calculated effect size value is $\eta^2 = 0.89$. Accordingly, it can be said that approximately 89% of the variance observed in SPS pretest scores occurred due to pretest-posttest score disparity.

In order to determine whether there was a significant difference between pretest and posttest SPS scores of students in the control group, paired samples *t* test was used, the results of which are shown in Table 9.

Table 9

Comparison of SPS pretest-posttest Scores of the Control Group

Control Group	*n*	$\bar{X}$	*s*	*SD*	*t*	*p*
Pretest	22	11.86	4.95	21	-6.58	.00*
Posttest	22	14.91	4.80			

Note. *$p < .05$; $\eta^2 = 0.67$

According to Table 9, the results of the paired samples *t* test revealed that the average pretest score of the control group was 11.86 and that the control group's average posttest score rose to 14.91. A statistically significant difference was observed between these two results [$t(21) = 6.58$; $p < .05$]. This situation can be expressed as indicating that current curriculum-based teaching had a positive effect on students' mean scores of SPS. Eta square (η^2) value, which was calculated to determine the effect size, was found to be 0.67. Accordingly, it can be said that 67% of the variance of the control group's SPS scores was due to pretest-posttest score disparity. Here, the calculated effect size reflects this large effect.

In order to determine whether there was a statistically significant difference between posttest SPS scores of students in the experimental and control group, independent samples *t* test was used, the results of which are shown in Table 10 below.

Table 10

Independent Samples t-test Analysis Results of SPS posttests for the Experimental and Control groups

Group	*n*	$\overline{X}$	*s*	*SD*	*t*	*p*
Experimental	26	19.54	4.65	46	3.39	.00*
Control	22	14.91	4.80			

Note. $^*p < .05$; $\eta^2 = 0.20$

When Table 10 is examined, a significant difference can be seen between the experimental and the control group in terms of their mean SPS scores [$t_{(46)} = 3.39$; $p < .05$]. The results of the independent samples *t* test revealed that the average posttest score of the control group was 14.91 and that the average posttest score of the experimental group was 19.54. It is seen that the average posttest SPS scores of students in the experimental group are higher than that of students in the control group. In order to determine the effect size, η^2 (eta square) value was calculated as 0.20. Accordingly, it can be said that 20% of the variance of the SPS posttest scores occurred due to the group in question, namely the method applied to that group. The calculated effect-size value reflects this large effect. It can be said that the development of scientific process skills of students differed according to the teaching method used.

Discussion

The current study revealed that there was no statistically significant difference between the mean AT mean scores of the experimental and control group before the application. This result shows that the average academic achievement of both groups was approximately equal before they were subject to the experimental application.

A statistically significant difference was found between the experimental group and the control group in terms of the group's mean AT posttest scores. This result shows that those students in the experimental group experienced greater academic success after the experimental application than the students in the control group. Accordingly, it can be said that the use of model-based teaching in science lessons is more effective in improving students' academic success. This finding of the current study, which indicates that model-based science education makes a positive contribution to students' academic success, concurs with the findings of other studies (Bilal & Erol, 2012; Gobert et al., 2011; Louca & Zacharia, 2015; Nunez-Oviedo, 2004; Ogan-Bekiroglu & Arslan, 2014; Sarikaya et al., 2004; Schwarz & White, 2005; Taylor et al., 2003). Accordingly, it can be said that learners' engagement with modeling processes makes their learning more meaningful. Schwarz and Gwekwerere (2007) argue that the modeling process in modern science involves embodying key aspects of theory and data into a model, evaluating the model using several criteria, and then revising the model to accommodate new theoretical ideas or empirical findings. Based on this notion, Schwarz and Gwekwerere (2007) suggest that model-centered student inquiry should also focus on the creation, testing, and revision of models. Additionally, Khan (2007) showed that undergraduates' sustained involvement in the generation, evaluation, and modification (GEM) of hypotheses resulted in their meaningful engagement with scientific inquiry and the scientific modeling process.

In the current study, it was concluded that there was no significant difference between the two groups in terms of the SPS mean scores that were applied to the experimental and control group students before the application. This result shows that the groups' average science process skills were approximately equal before the experimental application.

A statistically significant difference was also found between the experimental group and the control groups in terms of their mean SPS posttest scores. This result shows that, following the experimental application, the students in the experimental group had higher SPS levels than those in the control group. Accordingly, it can be said that the use of model-based teaching in science lessons is more effective in improving students' science-process skills. This finding of the current study, which shows that model-based science education makes positive contributions to students' science process skills, concurs with the findings of other studies in the literature (Baek et al., 2011; Keys, 1997; Kenyon et al, 2008; Khan, 2007; Ogan-Bekiroglu & Arslan, 2014). Similarly, Ogan-Bekiroglu and Arslan (2014) suggest that opportunities by which students can discuss and change their models also contributed to the learning process in model-based science instruction. Further, Bilal and Erol (2012) showed that even low graders could benefit from model construction activities to understand complex natural phenomena. Finally, the goal of science education should be to teach scientific investigation and inquiry skills; this means providing students with experience in hypothesis formulation and investigation design. The literature also suggests that model criticism and modification processes seem to be promising activities for inquiry (Oguz, 2007).

Considering the findings and the conclusions of the current study, it is believed that students' active participation in model-based science lessons—in which students construct models at the same time by discussing characteristics of scientific models and construct their own mental models, within and between-group discussions, made positive contributions to the development of their academic success and science process skill levels. When students are engaged in scientific modeling, they can notice patterns and develop and revise representations that become useful models to predict and explain, making their own scientific knowledge stronger, helping them think critically, and helping them learn more about the nature of science.

To sum up, student-centered approaches in model-based science education involve phases that mediate student learning in certain successive cycles, including the exploration, expression, construction, application, and revision of models. Researchers especially emphasize that, if students are allowed to build their own mental representations and present them publicly, this can result in an improved understanding of the targeted phenomena and processes (Bilal & Erol, 2012; Nunez-Oviedo, 2004; Ogan-Bekiroglu & Arslan, 2014; Sarikaya et al., 2004; Taylor et al., 2003). This is because when students' mental models are expressed using external representations, they are shared, criticized and improved through interactions with classroom participants. During this mental-model construction process, teachers play a key role (Nunez-Oviedo, 2004) and both teachers and the students contribute ideas for building and evaluating models. Accordingly, teachers should be aware of students' mental models so that they can better support the student's criticism and revision cycles (Oh et al., 2020).

Conclusion and Implications

In this study, it was concluded that model-based education positively contributes to the development of students' academic achievements and scientific process skills. The present research study has some limitations that indicate possible directions for future research. The study was carried out with a total number of 48 students: 26 students in the experimental group and 22 students in the control group. These numbers are highly convenient for the effective model-based instruction carried out as part of this study. However, increasing the number of students in similar research studies in the future would certainly enhance the reliability of the study's overall conclusions.

In order to see the detailed effects of model-based teaching, this research study can be conducted over a longer period. The results from this study suggest that students' learning gains are obtained when the students conduct the tasks assigned to them on their own. During the model-based activities, the students became aware of building models. It can be concluded that model building is a long process and without given specific instruction students may experience difficulties in building models.

The effects on other subjects in science lessons, as a result of using model-based education, can be determined. Model building can also be thought of as a learning cycle, one that feeds students' curiosity and encourages them to learn more. How will the educational experiences of those individuals receiving model-based education be affected by these activities can also be explored.

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