Effects of Model-Based Teaching Approach on 7th Grade Students' Conceptual Development of "Electrical Circuits"

Semra DEMİRÇALI

Merkezefendi Bilim ve Sanat Merkezi, Denizli, Turkey

sdemircali@gmail.com

ORCID: 0000-0002-0321-4333

Mahmut SELVI
Gazi Üniversity

mselvi@gazi.edu.tr

ORCID: 0000-0002-9704-1591

Abstract

The primary objective of this research was to investigate the effects of model-based science instruction on the conceptual development of 7th grade students in the topic of electricity. This qualitative research was conducted during the 2022-2023 academic year, using purposive sampling method. The study comprised 33 7th grade students (18 boys and 15 girls) from a secondary school located in the city center of the Aegean Region.

Students' conceptions were introduced as a conceptual framework representing individuals' mental models. In the study, a conceptual understanding test consisting of five open-ended questions was developed as a data collection tool within the framework of the related literature and science curriculum. In order to evaluate the effects of the designed learning environment, this achievement test was administered to students before and after the instruction. Rubric was used in the analysis of the obtained data. Analyzes were carried out by one researcher and their accuracy was checked by another researcher. The effectiveness of the learning environment is based on the comparison of the pre- and post-test findings. The implementation process lasted 12 lesson hours. The data were analyzed descriptively and classified according to their conceptual knowledge levels. Conclusively, the study demonstrated that the implementation of model-based lessons within the 'Electric Circuits' unit had positive impact on the conceptual development of 7th grade students. In addition, model-based learning sequence reduced misconceptions of students about the topic of electric. Based on these results, model-based teaching was recommended to teachers in the instruction processes and researchers were recommended to investigate features of models and the nature of modeling, the relation between students' knowledge about modeling and the quality of the models they create.

[This paper was published in: "EJER Congress 2023 International Eurasian Educational Research Congress Conference Proceedings," Ani Publishing, 2023, pp. 520-537]

Keywords: *Scientific modelling; Conceptual development; Mental model, The concept of electricity*

Introduction

Students' misconceptions known as significant obstacles for comprehension and acquisition of scientific concepts. In many studies on learning the concept of electricity (Bilal & Erol, 2012; Harman & Çökelez, 2016), it is seen that students at almost all levels have incomplete information and misconceptions. In the literature, there are studies on the use of different methods and techniques related to the effective teaching of this concept. For example, in a study conducted by Bilal and Erol (2012), it was seen that model-based physics instruction effected students' conceptual understanding of electrical subjects positively.

Schwarz and White (2000) propose model-based instruction as an educational setting in which students actively participate in the process of constructing and utilizing models. Model-based teaching is a pedagogical approach that employs explicit models and a variety of educational experiences to foster model-based learning, which encompasses a range of instructional strategies. Model-based learning involves the iterative process of constructing mental models through their formation, utilization, revision, and elaboration.

Models are external representations of mental concepts and include diagrams, three-dimensional physical structures, mathematical formulations, analogies and computer simulations. Greca and Moreira (2000) categorized models into mental models and expressed models. Mental models encompass an individual's internal conceptualizations of the explanatory mechanisms, predictive patterns, and fundamental laws that govern natural phenomena. Expressed models are external representations of the target phenomenon, originating from an individual's mental models. They can take various forms, including verbal expressions, drawings, written descriptions, and computer simulations. Expressed models play a crucial role in facilitating communication, experimentation, and develop one's internal mental models.

In model-based science lessons, students develop their own models, form scientifically acceptable subject-related models and they become able to understand more complex models (Demirçalı & Selvi, 2022). Studies have shown that model-based teaching increase academic achievement (Sarıkaya et al., 2004). It has been revealed that the implementation of model-based pedagogical approaches wherein students actively engage in the construction of scientifically acceptable models about the subject, they can understand more complex models, and model-based teaching affects conceptual learning positively (Bilal & Erol, 2012; Ogan-Bekiroğlu, 2007). It has also been found that it helps to develop mental models, conceptual development, social structuring, understanding and evaluation of the nature of science with these mental models (Baek et al., 2011).

The learning environment designed according to the 'Model-Based Learning' approach, has a significant effect on students' misconceptions about energy (Kurnaz & Saglam-Arslan, 2011). In their study, Birinci and Apaydın (2016) concluded that the sound subject, which is conducted according to the modeling cycle, affects the conceptual development of primary school 4th grade students positively and reduces the misconceptions about sound. In another study, it was seen that the activities designed within the scope of Model-Based Teaching and Learning enabled primary school fourth grade students to reach the scientific model in terms of their understanding levels and mental models about microscopic creatures, but some students continued to have incomplete and alternative concepts for different dimensions of microscopic creatures (Bozdemir-Yüzbaşıoğlu and Sarıkaya). 2019). In the study in which the effect of writing and model-based learning activities for learning in the "Simple Electrical Circuits" unit of the fourth-grade science lesson was investigated, a significant difference was found in favor of the experimental group students (İspir &Yıldız 2022).

In the study conducted by Ogan-Bekiroglu in 2007, the focus was on assessing the knowledge and comprehension levels of Turkish pre-service physics teachers regarding various aspects related to the Moon. In addition, the study's primary objective was to investigate the impact of model-based teaching on the pre-service physics teachers' pre-existing conceptual understandings. During the initial stages of the instructional phase, it became evident that physics teachers possessed a range of flawed, disconnected, and incomplete mental models concerning the Moon and lunar phenomena. However, the implementation of model-based teaching strategies effectively guided these pre-service teachers in discarding their misconceptions and acquiring a more scientifically accurate understanding. Model-based teaching enabled pre-service teachers to gain scientific knowledge.

Encouraging students to actively engage in modeling tasks, is very important for enhancing science education. The creation and utilization of models are intrinsic components of both human cognitive processes and the scientific inquiry method. Consequently, it is advisable to involve students in a comprehensive process that entails the creation, testing, revision, and application of externalized scientific models, which can effectively represent their underlying internalized mental models (Schwarz & White, 2000).

It holds principal significance for students to actively engage in the construction of models aimed at explaining natural phenomena, demonstrating the alignment of their models with available evidence, and acknowledging the inherent limitations within these models. In a study conducted by Baek and colleagues in 2011, four fundamental elements of modeling practice were identified, which serve as central and accessible aspects for learners:

• *Model construction*: Students are tasked with the construction of models that adhere to prior evidence and established scientific theories.

• *Model use*: Students employ these models as tools to effectively illustrate, clarify, and make predictions about various natural phenomena.

• *Model evaluation*: Students are encouraged to use the criteria such as explanatory and consistency with empirical evidence and engage in the critical comparison and evaluation of different models.

• *Model revision*: An integral part of the modeling process, students adjust their models to enhance their explanatory and predictive capabilities and incorporate additional evidence or explanatory elements as necessary.

Furthermore, as students engage in these practices, they are likely to develop more sophisticated understanding of how scientific knowledge is generated and evolves. At the same time, it is important for learners to realize the nature and principle of models and modeling with the aim of constructively participate in modeling. In these learning cycles, learners are enabled to acquire expertise about modeling practice that constitutes the practice meaningful.

Literature Review about Conceptions of Electric Circuits

Students' common misconceptions about simple electric circuits, according to the studies in the literature, are summarized by Borges and Gilbert (1999), Sencar et al. (2001) and Yıldırım et al., (2008):

1. Sink Model: Students perceive that a single wire connection enables electricity to sink from the power source to the device, powering it.

2. Clashing Current Model: Students believe that positive electricity moves from the positive terminal and negative electricity moves from the negative terminal, meeting and clashing at a device.

3. Weakening Current Model: Students assume that current flows in one direction and gradually weakens because each device consumes some of the current.

4. Shared Current Model: Students think that devices share current equally, resulting in less current returning to the power supply.

5. Local Reasoning: Students tend to focus on the point where a change occurs in a circuit, often failing to recognize that changes at one point may affect other parts of the circuit.

6. Short circuit preconception: Students believe that in a circuit, wire connections without attached devices can be disregarded.

7. Empirical Rule: Students incorrectly suppose that the further a bulb is from the battery, the dimmer it becomes.8. Constant current source: Students perceive a battery as a constant current source rather than a constant voltage source.9. Resistance and equivalent resistance: Students mistakenly believe that if the number of resistors increases in a circuit, the equivalent resistance also increases, regardless of their connection type.

10. Potential and potential difference: Students betray to realize that the brightness of identical bulbs depends on how they are connected in the circuit, rather than where they are connected.

11. Sequential reasoning: When a circuit element changes, students tend to analyze the circuit in terms of the current passing through that location before and after the change occurs.

Purposes of the Study

The purposes of this study were to investigate students' nonscientific conceptions and to investigate effectiveness of model-based science lessons on students' conceptual development. Researchers (Bilal & Erol, 2012; Campbell & Neilson, 2012) recommend model-based teaching to promote conceptual change in learners' electric concepts. Under the purposes of this research, the following questions were addressed:

- What are seventh grade students' existing knowledge of Electric Circuits?

- What is the effect of model-based teaching on seventh grade students' conceptual development in the subject of "Electric Circuits" ?

Method

Research Design and Participants

In this study, Qualitative research method was used so it provides the researcher with a valuable framework for gaining deeper insights into the process of constructive meaning and for describing the specific nature of these constructed meanings (Creswell, 2013). Throughout the course of the study, a questionnaire, included five different open-ended questions, were employed to assess students' knowledge and comprehension levels, as well as to systematically investigate any changes in their conceptions following the implementation of model-based teaching. This approach allowed for a comprehensive and thorough examination of the shifts in students' understanding.

The study group consists of 33 7^{th} grade students (18 boys, 15 girls) studying in a secondary school. This school is in a city center in the Aegean Region. The study group selected according to the purposive sampling method.

Data Collection Tools and Analysis

In this study, open-ended questions were used as a data collection tool to reveal the conceptual understanding of the participants about the concept of Electricity. The reason why open-ended questions are preferred over multiple-choice tests is that they provide students with the chance to give explanatory or diagnostic answers with different methods, while providing researchers with the opportunity to obtain in-depth data (Chiou & Anderson, 2010; Kurnaz, 2011,). It is seen that open-ended questions are used in many studies carried out to reveal students' mental models about various concepts (eg. Kurnaz, 2011, Bilal & Erol, 2012; Campbell & Neilson, 2012). For this purpose, in this study, "Electrical Unit Conceptual Test" (ECT), a 5-question test consisting of open-ended questions was developed to reveal the mental models of the students about the subject. The achievements in the curriculum, the studies related with alternative conceptions in the literature were examined and questions were prepared considering how the students perceived the events. Students were asked to support their explanations by drawing.

Expert opinion was sought for the validity study of the "Electrical Unit Conceptual Test" (ECT) questions. The content validity of the questions was assessed through a collaborative evaluation involving two science teachers. having phd degree in science education, working in different schools. The scale was finalized by applying ECT to five 8th grade students apart from the sample. In the pilot application, it was observed that the students perceived some parts of the first and second questions the same, and the statements were corrected and rewritten in a more understandable way. Thus, face validity was tried to be ensured.

In the data analysis process, students' perceptions of describing and visualizing target concepts were determined on the basis of questions. In this sense, students' answers were evaluated as 'with scientific content' and 'with non-scientific content'. Based on the comparison of the findings, mental models were determined. In table 1, *"Mental model classification* proposed by Chi & Roscoe (2002)*"* were used in the process of determining mental models.

Table 1

The coding scheme developed from the mental model categorization made by Chi and Roscoe (2002)

Mental model	Definition
Correct mental model (CM)	both the response and the reasoning behind it were according to the scientifically accepted perspective
Complete flawed mental model (CFM)	the response was correct at the first sight but the reasoning behind it, was not consistent with the scientifically accepted viewpoint
Incomplete correct mental model (ICM)	the response included some correct scientific terminology, but the explanation was not sufficient
Flawed mental model (FM)	the response was not consistent with the scientifically accepted perspective
Incoherent mental model (IM)	the response, whether it was scientific or not, was given, but the reason for the answer was neither given nor clear
No answer	the respondent stated that she/he did not know the answer or left it blank

The first question used in ECT is given below. Other questions are given in the "Findings" section.

1) Draw a circuit diagram consisting of light bulbs connected in series. Show the direction of the electric current in the circuit and the polarity of the battery. Explain how the bulb gives light.

This question aims to determine students' misconceptions about the current passing through an electrical circuit consisting of series-connected bulbs.

Procedures- Modelling Process

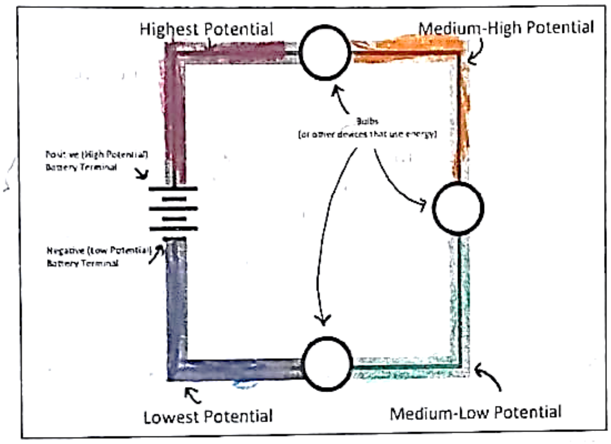
In this research model-based teaching process was structured according to the instructional sequence proposed by Schwarz et al. (2009). Instructional sequence begins with constructing a model to explain a phenomenon in which students express initial models. Then students; test the model to demonstrate, explain, and predict phenomena, compare and evaluate differences, modify models to increase their explanatory and predictive power. Lastly, they present models and experience more challenges. The students were requested to explicit the limitations of their models and the events if their models unsuccessful to represent throughout their presentations.

In the process of model-building students tried to light a battery with two bulbs and wires in as many ways as possible. The students formulated the concept of a complete circuit and realized that all four arrangements can be represented by a single diagram. Then, they tried to light two bulbs in a serial or parallel circuit. Some examples of student activity sheets were given in figure 1 and a picture of a group of students experiencing the brightness of bulbs, in different electric circuits were given in figure 2.

Figure 1

Some examples of student activity sheets

Bir Devredeki Elektriksel Potansiyeli Eşleştirin.

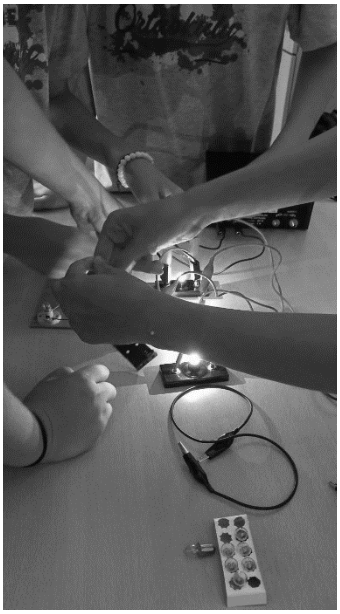


1. "Kablolarınızı Renklendirin"
Bu simülasyonda, bir devredeki potansiyeli eşleştirmek için renkleri kullanacaksınız. En yüksek potansiyel kırmızı, ardından turuncu, sarı, yeşil olacak ve en düşük potansiyel mavi olacaktır. İlk aktivite örneğine bakın, ardından kalan dört aktiviteyi deneyin!

ÖĞRENDİKLERİMİZİ ÖZETLEYELİM:		
	Anahtar Fikir(ler)- Ne öğrendiniz?	**Diğer Modellerle Bağlantılar :**
ETKİNLİK: Potansiyelinizi Bilin	Öğrendiğiniz yeni bilgileri bir kaç ifade ile açıklayınız. Bunlar; tanımlar, ilişkiler vb. olabilir. Ampulün nasıl ve boş yolunu dolu yolunu tercih ettiğini öğrendim	Burada gördüklerinizin diğerleriyle nasıl bir bağlantısı var? ~~diğeri~~ ampulün nasıl yandığını öğrendim. ~~Şimdi~~ ampulün boş yoldan mı (kablo) dolu yoldan mı geçtiğini

Figure 2.

A group of students experiencing the brightness of bulbs, in different electric circuits



Findings

Findings linked to the first sub-problem of "What are 7th grade students' existing knowledge of Electric Circuits?":

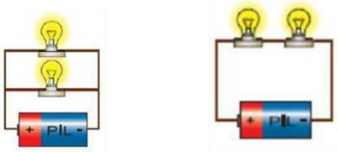
The students' existing knowledge was determined with the pre-application of the ECT. Examples of responses to each question are given below in the following questions.

Question -1: Draw a circuit diagram consisting of light bulbs connected in series. Show polarity of the battery and the direction of the electric current in the circuit. Explain how the bulb gives light.

This question aims to determine students' misconceptions about the current passing through an electrical circuit consisting of series-connected bulbs. Some of the misconceptions are;

- *Current is consumed in the bulb and thus less current returns to the battery.*
- *The power source in the circuit is a current source.*
- *Since current is consumed in the bulb, less current returns to the battery.*

Question -2: The bulbs are identical in the electrical circuit on the side. Is the brightness of the bulbs in the 1st and 2nd circuits the same or different? If different, what could be the reason?



This question aims to determine students' misconceptions about the current passing through serial and parallel connected electrical circuits consisting of identical bulbs.

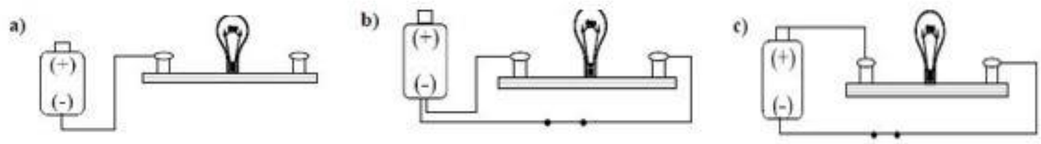
- *bulb brightness indicates the amount of current.*
- *The design of the elements in the circuit doesn't affect bulb brightness.*
- *the electric current in the serial connected electrical circuit is lower, therefore the brightness of the bulbs is less than the bulbs in parallel circuit.*
- *current gradually weakens because each device uses up some of the current.*
- *devices share current equally, less current turns to power supply.*

Question -3: What is electric current? Explain how an electric current occurs in a complete electric circuit.

This question aims to determine students' misconceptions about the phenomenon of a light bulb burning in a complete electrical circuit.

- *In an electrical circuit, the battery transfers energy to the circuit and causes negative charges to vibrate.*
- *The energy transfer caused by the vibration movement of negative charges in a closed electrical circuit is called electric current.*
- *The bulb turns on when the current coming from the (+) end of the battery passes over the bulb and reaches the (−) end of the battery.*

Question- 4: In which of the following electrical circuits does the light bulb turn on? Please explain.



d) None

The aim of this question is to help students realize that in order for current to flow through a simple electrical circuit, it must be a complete circuit, and to determine their misconceptions on this subject.

- *In order for the bulb to light, both of its terminals must be linked to separate terminals of the battery through a continuous path.*

Question -5: Explain, what is the relationship between the voltage magnitude values written on the batteries shown in the figure below and the electric current?

- *Voltage is "strength of a battery"*
- *Voltage is " force of the current".*
- *Bulb brightness increases with battery voltage 'Potential difference'.*

Findings linked to the second sub-problem of "What is the effect of model-based teaching on 7th grade students' conceptual development in the subject of 'Electric Circuits'?"

As shown in the table 2; none of the students answered correctly the ECT pre -test questions of 1.,2., 3. and 5. However, in the fourth question, the rate of students who answered correctly, is 6%. The rate of students who answered this question incorrectly is 94%. It can be said that majority of the students have incorrect mental model in the fourth question (73%) and fifth question (30%).

Table 2. Percentage distribution of ECT pre -test answers to questions according to mental model category levels

Questions	NA		IM		FM		ICM		CFM		CM	
	f	%	*f*	%	*f*	%	*f*	%	*f*	%	*f*	%
Question 1	13	39	11	33	6	18	2	6	1	3	0	0
Question 2	2	6	11	33	17	52	2	6	1	3	0	0

Question 3	15	45	10	30	7	21	1	3	0	0	0	0
Question 4	0	0	2	6	5	15	24	73	0	0	2	6
Question 5	9	27	10	30	3	9	10	30	1	3	0	0

It can be said that, in the ECT pre-test students mostly have flawed mental model and incoherent mental model. Only in the 4th question, %6 of the students have correct mental model. *Percentage distribution of* ECT post -test answers classified according to mental model category levels is given in below in table 3 .

Table 3.

Percentage distribution of ECT post -test answers to questions according to mental category levels

Questions	NA		IM		FM		ICM		CFM		CM	
	f	%	*f*	%	*f*	%	*f*	%	*f*	%	*f*	%
Question 1	0	0	3	9	1	3	16	49	11	33	2	6
Question 2	0	0	0	0	12	37	8	24	8	24	5	15
Question 3	0	0	1	3	10	31	8	24	9	27	5	15
Question 4	0	0	0	0	1	3	10	30	1	3	21	64
Question 5	0	0	3	9	3	9	12	36	15	46	0	0

As can be seen in table 3, Students answered all questions in the *ECT post -test*. The rate of students who answered the 1st question correctly is 6%; 2nd and 3rd question is 15%; 4th question is 64%. None of the students answered the 5th question correctly.

Discussion, Conclusion, and Recommendations

Discussion

The purposes of this study were to investigate students' misconceptions and to investigate the effectiveness of model-based science lessons on learners' conceptual development. Conceptions were projected being mental models in this research. According to Ogan-Bekiroğlu (2007), mental models are produced as a response to students' misconceptions through conflicts between their prior and scientific knowledge. Mental model classification proposed by Chi and Roscoe (2002) was used in this study.

Model-Based Teaching process was structured according to the instructional sequence proposed by Schwarz et al. (2009) in this study. The instructional sequence- creating a model, conducting tests on the model, evaluating its effectiveness, comparing it with alternative concepts, making necessary revisions, and using the model for predictive and explanatory purposes- demonstrated its efficacy in facilitating students' acquisition of essential scientific "Electric concepts."

The findings of the current study show that model-based science education enhanced students' conceptual development. This outcome aligns with the conclusions drawn from previous studies in the literature. (Kurnaz & Saglam-Arslan, 2011; Baek et al,, 2011; Bilal & Erol, 2012; Campbell & Neilson, 2012). In these studies, the advantages of modeling on conceptual development are reported. For example, (Bilal & Erol, 2012) found that instructing through modeling methods resulted in significantly greater enhancements on undergraduate students' academic performance and conceptual comprehension in contrast to conventional teaching approaches. Similarly, in another study, the efficacy of the instructional sequence in facilitating students' acquisition of fundamental scientific principles reported (Kenyon et al. 2008). It is imperative to explore the optimal conditions and techniques that can further enhance the level of learning and comprehension (Bilal & Erol, 2012). In their study, Birinci and Apaydın (2016) concluded that the sound subject, which is conducted according to the modeling cycle, affects the conceptual development of primary school 4th grade students positively and reduces the misconceptions about sound. In another study, it was seen that it was seen that 'model-based teaching and learning' enabled 4th grade students to reach the scientific model in terms of their understanding levels and mental models related with microscopic creatures, (Bozdemir-

Yüzbaşıoğlu and Sarıkaya, 2019). İspir and Yıldız (2022) found a significant difference in favor of the experimental group students in terms of conceptual development.

Conclusion

The study yields the following assumptions. Initially, students may possibly join science lessons with different misconceptions. In the starting of the instruction, the students had many flawed, incoherent, and incomplete mental models regarding the electric concepts. The most widespread misconceptions were; 'Weakening Current Model, Shared Current Model, Constant current source, Potential and potential difference'.

Additionally, model-based instruction could affect students leave their misconceptions and acquire scientific knowledge. As emphasized by Ogan-Bekiroglu (2007) the results revealed communicating for information with peers in the group assisted the students becoming aware of both their misconceptions and group work provided students with incorporation of knowledge. Besides, formation of existing models and apply them in their descriptions offered the students to modification of knowledge. Consequently, some of mental models altered from incoherent, flawed, or incomplete mental models to complete flawed mental models. The investigation revealed that some students persisted in harboring incomplete and alternative concepts pertaining to various aspects of microscopic organisms. (Bozdemir-Yüzbaşıoğlu and Sarıkaya). 2019).

Considering this study's findings and conclusions, it is suggested that students' active engagement in scientific modelling- encompassing the construction of models through discussions and the students' construction of their mental models through both intra-group and inter-group discussions, has demonstrably contributed to the enhancement of their conceptual development. Engaging in scientific modeling empowers students to discern patterns, refine their representations, thus yielding practical models for prediction and explanation. Consequently, this active involvement improves their scientific knowledge, fosters critical thinking, and deepens their understanding of the nature of science.

Recommendations

- Model -based teaching method, when applied with teacher support at the 7th grade level, has a positive effect on students' conceptual development and reduces misconceptions. For this reason, modeling-based activities can also be used for concept teaching in classes at different grade levels.
- This research is limited to 3 weeks of application. The research can be repeated by keeping the research period longer.
- Students' opinions on the features of models and the nature of modeling can be investigated. The relationship between students' knowledge about modeling and the quality of the models they create can be investigated.

References

Baek, H., Schwarz, C., Chen, J., Hokayem, H., & Zhan, L. (2011). Engaging elementary students in scientific modeling: The MoDeLS fifth-grade approach and findings. In M.S. Khine, I.M. Saleh (Eds.), *Models and modeling in science education* (pp.195-218). Springer Science+Business Media B.V.

Bilal, E., & Erol, M. (2012). Effect of teaching via modeling on achievement and conceptual understanding concerning electricity. *Journal of Baltic Science Education*, *11*(3), 236-247. DOI: 10.33225/jbse/12.11.236

Birinci, O., & Apaydın, Z. (2016). Modellemeye dayali ögretimin 4.sınıf ögrencilerinin ses konusundaki kavramsal gelisimine etkisi [Effect of modelling learnıng on sound related conceptual development of primary school 4th grade students]. *Uluslararası Türk Eğitim Bilimleri Dergisi, (7*).

Borges, A.T., & Gilbert, J. K. (1999) Mental models of electricity. *International Journal of Science Education, 21,* 1, 95-117, DOI: 10.1080/095006999290859

Bozdemir-Yüzbasioglu, H., & Sarikaya, R. (2019). Mikroskobik canlılar konusunda model tabanli ögrenme yaklaşımının öğrencilerin zihinsel model gelişimine etkisi [The effect of model-based learning approach on students' development of mental model about microorganisms subject]. *Kalem Uluslararası Eğitim ve İnsan Bilimleri Dergisi, 9(17),* 357 - 384. DOI: 10.23863/kalem.2019.131

Campbell, T., & Neilson, D. (2012). Modeling electricity: Model-based inquiry with demonstrations and investigations. *The Physics Teacher 50,* (6): 347–350. https://doi.org/10.1119/1.4745686

Chi, M. T. H., & Roscoe, R. D. (2002). The process and challenges of conceptual change. In M. Limon & L. Mason (Eds.), *Reconsidering conceptual change: Issues in theory and practice* (pp. 3–27). Dordrecht, The Netherlands: Kluwer Academic Publishers.

Chiou, G.-L., & Anderson, O.R. (2010). A study of undergraduate physics students' understanding of heat conduction based on mental model theory and an ontology–process analysis. *Science. Education, 94,* 825-854. https://doi.org/10.1002/sce.20385

Creswell, J. W. (2013). *Qualitative inquiry & research design: Choosing among five approaches* (3rd ed.). Thousand Oaks, CA: SAGE.

Cepni, S. (2005). *Araştırma ve proje çalışmalarına giriş*. Trabzon: Celepler.

Demircali, S. & Selvi, M. (2022). Effects of model-based science education on students' academic achievement and scientific process skills. *Journal of Turkish Science Education, 19*(2)*, 545-558*. DOI: 10.36681/tused.2022.136

Greca M. I., & Moreira, M. A. (2000). Mental models, conceptual models, and modelling. *International Journal of Science Education, 22* (1), 1- 11.

Harman, G., & Cokelez A (2016). 5. Sınıf ögrencilerinin elektrik devreleri ile ilgili zihinsel modelleri [Mental models of 5th grade students on electrıc cırcuıt]. *Turkish Studies, 11(3),* 1249 - 1272. http://dx.doi.org/10.7827/TurkishStudies.9281

İspir, B,. & Yildiz, A. (2022). The effect of writing for learning and model-based learning activities on success and permanence in the fourth grade simple electrical circuits unit . *Kastamonu Eğitim Dergisi , 30 (4) , 788-804*. DOI: 10.24106/kefdergi.1195568

Kenyon, L., Schwarz, C., & Hug, B. (2008). The benefits of scientific modeling: Constructing, using, evaluating, and revising scientific models helps students advance their scientific ideas, learn to think critically, and understand the nature of science. *Science and Children, 46*(2), 40–44.

Kurnaz, M.A., & Saglam-Arslan, A. (2011). Model tabanlı ögrenme yaklasimini temel alan ögrenme ortaminin ögrencilerin enerji kavramini anlama düzeylerine etkisi [The effects of 'model of model based instruction' teaching model to students' understanding level about energy concept]. *e-international Journal of Educational Research, 2*(2), 1-16.

Ogan-Bekiroglu, F. (2007). Effects of model-based teaching on pre-service physics teachers' conceptions of the moon, moon phases, and other lunar phenomena. *International Journal of Science Education, 29(5),* 555–593. https://doi.org/10.1080/09500690600718104

Sarikaya R., Selvi M., & Dogan-Bora, N. (2004). Mitoz ve mayoz bölünme konularının ögretiminde model kullaniminin önemi [The importance of using models in teaching mitosis and meiosis topics]. *Kastamonu Eğitim Fakültesi Dergisi, 12(1),* 85-88.

Sencar, S., Yilmaz, E.E., & Eryilmaz, A. (2001). High school students' misconceptions about simple electric circuits. *Hacettepe Üniversitesi Eğitim Fakültesi Dergisi. 21*, 113-120.

Schwarz, C.V., & White, B.Y. (2000). Developing a Model-Centered Approach to Science Education. http://schwarz.wiki.educ.msu.edu/file/view/C.+Schwarz+AERA+2002+paper.pdf

Schwarz, C. V., Reiser, B. J., Davis, E. A., Kenyon, L., Ach, A., Fortus, D., et al. (2009). Developing a learning progression for scientific modeling: Making scientific modeling accessible and meaningful for learners. *Journal of Research in Science Teaching, 46*(6), 632–654.

Yildirim, H. İ., Yalçın, N. , Şensoy, Ö., & Akçay, S. (2008). İlköğretim 6., 7. ve 8. sınıf ögrencilerinin Elektrik Akımı konusunda sahip oldukları kavram yanilgilari [A survey study of 6th, 7th and 8th grade students' misconceptions in electric current]. *Kastamonu Eğitim Dergisi, 16(1),* 67-82. Retrieved from https://dergipark.org.tr/tr/pub/kefdergi/issue/49101/626576