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Abstract

Modeling activities enriched with 3D printers are effective in providing teachers with the skills they should have and in using the technology in mathematics education. In this regard, in the present study, ten-week modeling activities were carried out with 3D printers that are widely used in different fields along with educational environments and the engineering and modeling skills used by pre-service teachers were revealed. In the study, eight teacher candidates studying in the 2nd grade of the Department of Elementary Mathematics Education in the Yozgat Bozok University Education Faculty took part. The study was designed as a case study defined as the study of specific situations in a certain context. Individual interviews, video recordings of the application and produced models were used as data collection tools to determine emerging engineering and modeling skills of teachers during Model-Eliciting Activities (MEAs). At the end of the study, it was revealed that pre-service teachers used engineering skills in designing, modeling and model producing. When the participants' views on the use of technology before and after the MEAs conducted with 3D printers were examined, it was observed that MEAs had a positive effect on the pre-service teachers' interest and motivation related to technology.

Introduction

Lesh and Doerr (2003) describe modeling as a process of creating a physical, symbolic and abstract model of a situation. Mathematical modeling, which is one of the sub-concepts of modeling, is the explanation and expression of real life problems with mathematical models (graphs, tables, equations, geometric shapes, etc.; Blum & Niss, 1989). The modeling process in mathematical modeling starts with real life problems. At this stage, the problem and information about the problem are put forward. Then the real life problem situation is interpreted and modeled mathematically. After this model, the model is used to find mathematical results related to real life problem. By evaluating the suitability of the model, the loop is repeated by making improvements if need be (Stillman, Galbraith, Brown, & Edwards, 2007).

By modeling and making use of real life problems in mathematics education, a connection and communication between real life and mathematics are provided (Freudenthal, 1968; Pollak, 1968). Thanks to modeling activities, real life situations are modeled mathematically (Yoon, Dreyfus, & Thomas, 2010). Modeling activities involving real life problems regarding other disciplines related to engineering, science and mathematics are defined as Model-Eliciting Activities (MEAs; Lesh, Hoover, Hole, Kelly, & Post, 2000). MEAs involve the development of effective solutions to problems in real life through practices in line with students' conceptual understanding (Lesh & Doerr, 2003). Thanks to MEAs, students are provided with the opportunity to do interdisciplinary studies; to understand, to express, and to solve the problems of open-ended real life mathematically; to develop metacognitive skills; and to create mathematical models (Tekin Dede & Bukova Güzel, 2014).

Mathematical modeling appears as theoretical modeling and real life modeling in education (Bukova Güzel, 2016). Different perspectives appear in the light of the philosophical and theoretical foundations of mathematical modeling (Kaiser, & Sriraman, 2006). Realistic/applied modeling includes the ability to develop creative and realistic solutions for open-ended real-life situations, and to model real-life situations (Pollak, 1969). In this respect, it is important to develop modeling skills in the training of the individuals who can solve the real life problem effectively.

Epistemological/theoretical modeling aims to contribute to the development of theory and mathematical concept (Freudenthal, 1973). In epistemological/theoretical modeling, models have the aim of providing a mathematical theory based on a situation (Revuz, 1971). Educational modeling is an approach that integrates teaching practices and modeling. This modeling is discussed under two headings as instructional and conceptual modeling. In this modeling process, there are pedagogical objectives and objectives related to the subject matter. In this modeling, the objectives related to the subject matter are effective while teaching mathematics.

In socio-critical modeling studies, there is a critical approach to the questioning of real life situations and their reasons (D'Ambrosio, 1999). With the reflection of this inquiry process, it is provided to produce solutions through mathematical models.Cognitive modeling aims to analyze the cognitive processes in the modeling process (Skemp, 1987). By analyzing the modeling process, it is possible to determine and develop the individual's mathematical thinking and learning processes throughout the process.

Contextual modeling involves the process of understanding real life problem solutions and introducing model products (Lesh & Doerr, 2003). The aim of contextual modeling is to provide conceptual learning by associating mathematical concepts with real life. In contextual modeling, individuals create models in the process of modeling that they actualize when encountered problems of real life (Lesh & Zawojevski, 2007). The activities in contextual modeling appear as Model-Eliciting Activities (MEAs).

Modeling-Eliciting Activities (MEAs)

Modeling-Eliciting Activities (MEAs) allow students to do demonstrations in various ways by using their knowledge (Lesh & Caylor, 2007). MEAs processes generally involve switching between representations and models (Lesh, 2010). In this process, "the model defines the process designed to create a different system for a specific purpose" (Lesh, 2010, p.18). In MEAs, students develop, construct and explain conceptual systems (Moore et al., 2013).

MEAs consist of realistic and non-routine, interdisciplinary and collaborative problems (Chamberlin & Moon, 2005). It also enables students to develop conceptual models in the cycle of expression, testing and review (Moore et al., 2013). MEAs are powerful teaching tools that allow students to think mathematically and be productive (Lesh & Doerr, 2003). MEAs integrate engineering education in mathematics education (e.g., Diefes-Dux, Zawojewski, & Hjalmarson, 2010; Moore, 2008; Moore & Hjalmarson, 2010; Yildirim, Shuman, & Besterfield-Sacre, 2010; Zawojewski, Diefes-Dux, & Bowman, 2008). Because MEAs are teaching practices that provide an effective learning experience by doing cognitive, metacognitive, and affective activities within the framework of a specific problem (Litzinger, Lattuca, Hadgraft, & Newstetter, 2011).

Engineering is among the professions based on modeling. For this reason, MEAs focuses on the development of mathematical ideas, thinking and skills that are necessary after school and out of school (Lesh, Hamilton, & Kaput, 2007). At the same time, because we are in a technology-based information age, it provides an understanding of technology and engineering areas (Moore et al., 2013). For these reasons, MEAs have been recently introduced in engineering education (Bursic, Shuman, & Besterfield-Sacre, 2011; Hamilton, Besterfield-Sacre, Olds, & Siewiorek, 2010; Verleger & Diefes-Dux, 2008; Zawojewski, Diefes -Dux, & Bowman, 2008). MEAs enable students to think about real life situations and develop solutions through modeling. MEAs lead students to work in teams and collaborations, while providing opportunities for testing and developing the product. In addition to developing a solution to the problem, MEAs provide the usage of the created model for effective solutions in various contexts (Doerr, Ärlebäck, & Costello Staniec, 2014).

Lesh (2010) refers to MEAs as "solution-oriented activities that enable arrangements for objectives and their possible solutions" (p. 25). In this way, students are given the opportunity to put forward their thoughts about the problem solving process, test theses thoughts and improve them (Diefes-Dux, Moore, Zawojewski, Imbrie, & Follman, 2004; Lesh & Doerr, 2003; Zawojewski et al., 2008). According to the researches, it was stated that MEAs encouraged students for high participation by developing positive attitudes (Csikszentmihalyi, 1991) and encouraged them to be more successful and participate for a long time (Hamilton et al., 2008; Lesh, Carmona, & Moore, 2009). In this context, the content of this study was planned and applied according to MEAs used in engineering education.

Design-oriented engineering practices are effective in order to improve students' technology literacy and to understand its importance in society (Lin et al., 2018). With the rapid development of technology and its widespread use in education, technology and engineering applications in K-12 education have been started to be used effectively (Lin et al., 2018). The main purpose in engineering education is to reveal the place and importance of engineering in society (Douglas, Iversen, & Kalyandurg, 2004). Brophy et al. (2008) proposes design-oriented engineering practices based on the development of engineering skills in education. Design-oriented engineering practices enable students to develop conceptual understanding as well as skill development (Kimmel et al., 2006; Sadler, Barab, & Scott, 2007). Similarly, many researchers (e.g., Brotman & Moore, 2008; Clewell & Braddock, 2000; Lai, 2018; Reid & Skryabina, 2003) suggest that engineering practices in education will be effective to direct students toward STEM areas that include science and mathematics disciplines.

Atman et al. (2007) defines three stages in design-oriented engineering practices: (1) identifying the problem; (2) producing ideas for solution to the problem and developing, designing, and modeling these ideas; (3) implementing, testing and redesigning (Atman et al., 2007). In engineering applications, design and modeling are effective in students' identifying the complex problems as well as creating their products (Lin et al., 2018). Developing modeling skills and using and creating representations in the modeling process are important elements in engineering education (Lin et al., 2018). Felder and Silverman (1988) point out the importance of visualization, drawing and mathematical modeling of what students learn visually or auditory, logical or intuitional. In the modeling process, students have to express their ideas, test them, correct them and use different representations for communication. For this reason, the ability to switch between different forms of representations and use them is important. In this respect, it is also useful to develop a high level understanding of modeling concepts in engineering education (Lesh, Yoon & Zawojewski, 2007; Moore et al., 2013; Moss, Kotovsky, & Çağan, 2006; Streveler et al., 2008).

Model development has an important place in engineering activities (Zawojewski et al., 2008). In developing students' modeling skills, MEAs that include solutions to open-ended problems are used (Diefes-Dux, Hjalmarson, Zawojewski, & Bowman, 2006). These types of learning activities enable students to develop their own ideas for solving problems and to explain their realistic life situations. Modeling activities make students effective in problem solving process and help them create their designs, make products, test these products and improve them (Doerr, Ärlebäck, & Costello Staniec, 2014; Lesh & Doerr, 2003). MEAs helps students develop in-depth understanding of complex concepts and high-level skills through technical and team work (Bursic, Shuman, & Besterfield-Sacre, 2011; Kean et al., 2008; Ridgely & Self, 2011; Self & Widmann, 2010).

In MEAs, the technological equipment students use in the process of forming and modeling the models has a significant effect. A single modeling task that students do has a limited effect on modeling skills development (Doerr, Ärlebäck, & Costello Staniec, 2014). For this reason, there should be an enriched modeling process in MEAs. That is why modeling and design-oriented practices with digital and technological tools have become effective today (Blikstein et al., 2017). These tools include 3D printers. Researchers stated that engineering practices including 3D printers improve students' skills to use computers and information and communication technologies (Brown & Burge, 2014), provide the use of concrete materials in education (Horowitz & Schuitz, 2014), provide meaningful understanding regarding characteristics of related model in the process of creating concrete materials (Scalfani & Vaid, 2014), and provide the opportunity to develop understanding and communication about visually impaired individuals. At the same time, 3D printer technology enables students to use 3D modeling programs. According to Blikstein et al. (2017), 3D printer technology enables students to obtain procedural knowledge in problem solving processes through modeling. In this study, it is aimed that undergraduate students use 3D printer technology effectively and demonstrate their engineering skills in problem solving processes through modeling in MEAs.

Studies on the use of technology in mathematical modeling activities have run (Abramovich, 2007; Barbosa, 2008; Ang, 2006, 2010; Galbraith et al., 2007; Hıdıroğlu, 2012; Hıdıroğlu & Bukova Güzel, 2013, 2014; Lalinská & Majherová, 2010; Lingefjärd, 2000, 2002, 2012; Mousoulides et al., 2006; Siller & Greefrath, 2010). In addition, it is seen that MEAs studies involving 3D printer technology are limited. Therefore, this study will contribute to the international literature from this aspect.

The effects of a single model development process are presented in studies on modeling activities (e.g., Bursic, Shuman, & Besterfield-Sacre, 2011; Diefes-Dux et al., 2006; Kean et al., 2008; Ridgely & Self, 2011; Self & Widmann, 2010). However, the use of a single model for the model to be used in different contexts is not enough (Doerr & English, 2003; Lesh et al., 2003; Lesh, Doerr, Carmona, & Hjalmarson, 2003). In order to achieve this goal, students should be encouraged to participate in a number of activities (model development-testing-re-structuring) that they can perform a series of actions (Hjalmarson et al., 2006; Hjalmarson, Diefes-Dux, & Moore, 2008). In this study, it is aimed to determine the effectiveness of the model building processes in different contexts by providing teacher candidates with different problem situations in MEAs and model development. In this study, answers to the following questions were sought in the MEAs performed with 3D printers.

1. What are the emerging engineering skills of pre-service teachers in modeling activities with 3D printers?
2. What are the pre-service teachers' views on the use of technology in mathematics education?
3. What are the pre-service teachers' views on modeling activities with 3D printers?

Method

In this study, the case study model of qualitative research methods was used. Case studies include the examination of the special circumstances in a context (Creswell, 2009). Yin (2003) classified the case studies as a holistic single-case design, a nested single-case design, a holistic multiple-case design, and a nested multiple-case design. In this study, holistic single-case design is used from case study models. The holistic single case is the studies on a single case (an individual, a program, etc.). The aim of this study was to determine the engineering skills of pre-service teachers in the 3D modeling process in MEAs. For this purpose, each MEAs is treated as a case.

Participants

Participants in the study were chosen by criterion sampling method among the second grade students studying at Yozgat Bozok University Faculty of Education. Participants were identified from 58 individuals in terms of their positive and negative views about technology. In order to determine the attitudes of the participants in the use of technology and technological equipment, semi-structured individual interviews were conducted with 10 questions.

Information on the content of the application for the participation of pre-service teachers was given. Eight students who were willing to participate in the study were identified and included in the study. The demographic characteristics of the participants are presented below.

Table 1. Demographic characteristics of participants

Participant	**Gender**	**Views on Technology Use**
Mustafa	Male	Negative
Medine	Female	Positive
Kübra	Female	Negative
Ayşe	Female	Negative
Duygu	Female	Negative
Perihan	Female	Positive
Sema	Female	Positive
Aynur	Female	Negative

It is seen that the participants in the study differ in their views about the use of technology.

Data Collection Process

A pre-application was done to evaluate the MEAs based on 3D modeling and to eliminate the deficiencies in the data collection tools. By doing pre-application of the activities, the functioning of the activities, the applicability of the activities, and the adequacy of the data collection tools were evaluated. After the pre-application, activities were revised and finalized.

The main application of the study was conducted in the spring term of 2017-2018 academic year. The main application was carried out with eight pre-service teachers who were studying in the 2nd year of Elementary Mathematics Education program. The participants were briefed about the content of the application. Subsequently, individual interviews were conducted on the use of technological equipment with the volunteered teacher candidates. As a result of these interviews, eight participants were identified.

Within the scope of the study, MEAs were carried out for three months. In the implementation of the study, the researcher participated as the participant observer and carried out the application herself. After the MEAs, group interviews and individual interviews were conducted to determine pre-service teachers' views on the MEAs and the use of technology.

MEAs Content

In this study, which focuses on engineering and modeling skills resulting from teacher candidates' activities, 10-week MEAs were conducted. The study included 10 mathematics teacher candidates.

Table 2. 3D models in MEAs

Activities	Model Created in the Activity	Working Type on the Activity
Activity 1	Key Chain and Logo Design	Individual
Activity 2	Geometric Objects	Group
Activity 3	Geometric Equipment	Group
Activity 4	Fractal	Individual
Activity 5	Number Line	Individual
Activity 6	Counting Chips and Number Blocks	Group
Activity 7	Abacus	Group
Activity 8	Tangram and Katamino	Group
Activity 9	Geometry Watch	Group
Activity 10	Geometry Board	Group

MEAs were carried out individually and the environment was provided for the participants to interact and communicate with each other and the researcher. For this purpose, some activities were planned to work as a team. MEAs were carried out according to the problem situations defined by the participants within the framework of a certain problem situation. The application of MEAs is depicted in the following scheme;

- Problem
- Discussion- Brain blooming
- Designing
- Modelling
- Testing (or redesign)
- Problem solving

MEAs, which constitute the content of the study, have been developed by the researchers as a result of examining the activities in the related literature. MEAs consist of introduction step that include identification of the problem and discussion; application step that include design and modeling; evaluation step that include testing the model, evaluating the solution for the problem, and redesigning if necessary. MEAs' problem situation is composed of content that can be used for modeling by taking advantage of the mathematics and geometry knowledge of the participants.

The aim of this study is to create and use materials that can be used in mathematics education. Tinkercad 3D modeling program was used to enable students perform mathematical modeling. In order to gain experience and knowledge about using computer and modeling program, information was presented in the first activity. In this presentation, the usage areas of 3D printers and their importance in education are mentioned.

At the same time, the researcher explained how to use Tincerkad program with a demonstration in order to enable the effective use of the program. For the students to gain experience in 3D modeling, free activities were carried out at the first activity and the participants were asked to design a keychain and logo model. In the later activities, it is aimed that the participants make 3D modeling and create their models through the necessary mathematical representations. In this way, the materials that can be used in mathematics education have been produced.

Data Collection Tools

In this study, data were obtained from many sources in order to examine the case in detail (Creswell, Hanson, Clark, & Morales, 2007). For this purpose, semi-structured interviews and MEAs application videos and the models created by teacher candidates were used as data collection tools.

Individual Interviews

Individual interviews were conducted to determine the views of the participants about technology and MEAs before and after the MEAs. Through these interviews, it was aimed to determine the views of the participants about the use of technology and the MAEs applied. Individual interviews were carried out in the researcher's office, where the researcher and the participant were one-to-one, the participants could feel comfortable and confident, and a quiet environment was provided. Individual interviews lasted for 15-20 minutes. Prior to the interview, each participant was informed that the contents and the name of the interviewee would be kept confidential and that there would be no information sharing with the third parties. A voice recorder has been used in order to record interviews, prevent loss of data, and help in transcribing the interviews. Permission was requested from each participant to record the interview. The participants were informed about the purpose of the interviews by the researcher.

Individual Interview Form: The individual interview form was created by the researchers as a result of the literature review in order to reveal the views of the participants on the use of technology and the applied MEAs. In order to determine whether the draft form that included 15 questions was understandable and appropriate for the intended purpose, it was presented to the opinion of two researchers who are experts in mathematics education. After receiving the feedback from the experts, the individual interview form with 10 questions was finalized.

MEAs Application Videos: The data regarding the teacher candidates’ design and modeling in MEAs process were obtained by recording the application process in a video tape.

Model/Product: Modeling products and 3D models created by teacher candidates are concrete items used in the study.

Data Analyses

In order to determine the emerging engineering skills of the pre-service teachers, the data obtained from the data collection tools were recorded separately under each MEA. The emerging engineering skills of the pre-service teachers during the MEAs were examined in line with the studies and the sub-skills were listed and themes were determined. Encodings related to these sub-skills were determined under the themes of defining the problem, designing, modeling, problem solving, testing, evaluation, and improvement. Such analysis made by predetermined codes and categories is defined as descriptive analysis (Yıldırım & Şimşek, 2013). At the same time, direct visual quotations about the modeling of the pre-service teachers are given.

Individual interviews were conducted before and after the MEAs in order to determine the views of the participants about technology and MAEs. The data obtained from these interviews were analyzed by content analysis. Data on student views were obtained through codes and categories and presented with direct excerpts.

Findings and Comments

Findings Regarding Engineering Skills

When the engineering skills of pre-service teachers were examined in MEAs, the sub-skills of defining the problem, solving the problem, designing, modeling and evaluating were reached. According to the findings in the table 3, it is seen that engineering skills of pre-service teachers have emerged in MEAs process. Below are examples of case studies regarding each engineering sub-skills.

Table 3. Pre-service teachers' engineering skills

Activities	Engineering Skills					
	Defining the Problem	Solving the Problem	Designing	Explaining Designing Process	Modeling	Evaluating
Keychain and Logo Design	√	√	√	√	√	√
Geometric Objects	√	√	√	√	√	√
Ruler, Miter and Protractor	√	√	√	√	√	√
Fractal	√	√	√	√	√	√
Number Line	√	√	√	√	√	√
Counting Chips and Number Blocks	√	√	√	√	√	√
Abacus	√	√	√	√	√	√
Tangram and Katamino	√	√	√	√	√	√
Geometry Watch	√	√	√	√	√	√
Geometry Board	√	√	√	√	√	√

Identifying and Solving the Problem

It was observed that participants defined the problem in all MEAs during the study. The sample problem definitions that occurred within the scope of the activities are presented below. During the Keychain and Logo Design activity, students were asked to create a realistic 3D model that they could use in real life. The problem definitions of Sema, Duygu and Perihan are given below.

> Researcher: We will create with a 3D printer and what should you pay attention to in making a keychain, logo or ornament that you can use in your daily life?
> Sema: Their size must be suitable for use.
> Researcher: What size for example?
> Sema: For example, the width of the ring on the keychain that we will pass the key or the keychain itself.
> Medine: I'm going to do some embossing on the keychain, if I don't make the letters right here in Tinkercad, it can fall into pieces.
> Researcher: What else can happen?
> Perihan: If we want to make an item to use at the table, then it should be bigger.
> Medine: But if it is too big, it may not be printed.
> Duygu: If we want them in different colors, we have to model those parts separately in the program.

When considered the expressions of pre-service teachers, it is seen that they defined the model size as the problem, which they should take into consideration in the use of the 3D modeling program. At the same time, it is seen that the points that needed to be taken into consideration in modeling in order to ensure that the model size and parts can be formed correctly due to the feature of the 3D printer were defined as the problem by the students.

In the Counting Chips and Number Blocks activity, it is seen that the pre-service teachers also defined the problem based on the Tinkercad usage and the feature of the 3D printer.

> Ayşe: In the number blocks, we have to measure the diameter of the rods so that the bars are placed right on the floor.
> Researcher: How are you trying to adjust it?
> Kübra: For the diameters, we made a 1 cm excess in the gaps in the floor, so it would be easier to install the rods.

Similarly, it is seen that the correct measurement of the objects in 3D modeling was important in Tangram and Katamino activity while pre-service teachers were identifying the problem. The following are exemplary cases.

> Researcher: If you want to do Tangram and Katamino to your students as a mind game, what do you think you should pay attention to?

Kübra: Actually it's not hard, but we have to pay attention to the dimensions. For example, I'm going to do Tangram; the edge lengths of the parts in Tangram must overlap each other.
Researcher: Let's say you couldn't do the measurements correctly or you had a problem in your model, what happens?
Kübra: So we wouldn't be able to do Tangram or Katamino in fact. We can't use it.

Considering the sample problem definition presented from different activities, the pre-service teachers stated that they were paying attention to the size of the printer and the usage and measurements of the objects during the 3D modeling process. In MEAs, it is considered that it is important for pre-service teachers to identify the problem situation in creating effective, useful and realistic products and effective problem solutions. Pre-service teachers had the opportunity to compare and evaluate the models they had created by defining the problem situation. It is thought that "how and why" questions posed by teacher candidates were effective in defining and presenting problem situation.

Designing

In MEAs, it is seen that pre-service teacher made designs about their models and made explanations about the design process. In MEAs, pre-service teachers modeled different products in various contexts and created their products. Prior to product modeling, pre-service teachers designed how they would do their products and explained the design process to answer the researcher's questions. Exemplary cases of this are presented below. In the construction of Geometric Objects, Medine decided to make a truncated cone and made a design and explanation for it.

Researcher: Medine, which object are you planning to do?
Medine: I thought about making a truncated cone, but I was thinking about how to cut the top.
Researcher: How do you think you can do it?
Medine: Now, there is already a cone shape in Tinkercad. In order to cut the top, I will take a plane shape and place on top of it. When I merge these two shapes, there's a cut. The problem is that I am having hard time to adjust the angle. Can't cut from the top of the cone.

When the teacher candidate's explanation is examined, it is seen that she is designing the geometric object she will model. In this process, it is seen that the teacher candidate tries to make a decision about the model through trial and error.

In the activity of fractal making, pre-service teachers were asked first to make measurements and clarify the length of their models.

Researcher: Mustafa, what did you decide to do as fractal model?
Mustafa: I just saw golden ration spiral. I think I'll do it if I can adjust the length of the spiral.
Researcher: How, for example?
Mustafa: Now, this spiral will be three-dimensional. I should adjust both the length of the edges and the height. So there will be pyramids. The first one will begin from the inside through the big pyramid. The first triangle is 1,1 with the hypotenuse length of $\sqrt{2}$, followed by the second triangle with the edge length of $\sqrt{2}$, 1 hypotenuse $\sqrt{3}$… so I will continue to the point where it can go.

When the teacher candidate's explanations are examined, it is seen that he used to design primarily mathematical representations for his model. In the following process, he made 3D modeling of his design. Likewise, the sample activities related to the teacher candidates' designs using mathematical representations in "Katamino and Tangram", "Geometry Watch" and "Geometry Board" activities are presented below.

Researcher: What did you do for Katamino?
Sema: We measured the length of the floor of the Katamino to find out that if we can not get out of the printer and we divided it in half, we thought we can merge them when they are printed. The length of the floor is 10×10. For the shapes that will be in Katamino, we are planning to use unit cubes. Because cubes should be able to made out of these.
Perihan: I am doing Tangram with similar logic. For example, I have written the shapes of Tangram and now I am writing the dimensions, so that it will be Tangram logic. If the lengths are not equal to each other, we cannot have the desired shapes.
Researcher: Kübra, what did you calculate before moving to watch making?

Kübra: Now, we need to locate hours and minutes on the watch. To do this, because the watch is 360°, we divided the watch into 12 slices (360/12 = 30). So each slice will be 30°. Then we divide it into 5 to set the minutes. So they're going to be 6°. Of course, we can do that in the program.
Medine: I'm planning to make a circle and a rectangular geometry board. The floor is already 10 × 10, so there is no problem with the rectangular. The diameter of the circle will be 10. The radius will be 5 cm, I will make 5 bars and then it will go like 4, 3, 2, 1 till to the middle point. So each bar is going to be 1 cm.

Looking at the explanations of teacher candidates about their designs related to different models in MEAs, it is seen that they used mathematical representations to perform the measurement process and give detailed explanations about it. It is thought that pre-service teachers' design make models to solve problems effective. In this way, it can be said that it is easier to identify and correct the deficiencies in their models and their solutions will be effective.

Modeling

Pre-service teachers solved the problems by creating a model for the problem presented during the activities. Since MEAs were based on 3D modeling and printing the model out of 3D printer, all of the teacher candidates modeled through the 3D program. In addition to this, it is seen that mathematical 3D modeling is applied in order to these models be effective and accurate. In this process, they have also modeled with mathematical representations at the same time by using 3D programs.

In the first activity "Keychain and Logo Design", pre-service teachers were provided with the experience of using 3D modeling and Tinkercad program. "Geometric Objects" and "Geometry Set" (Ruler, Miter and Protractor) activities were given to the pre-service teachers after gaining experience related to the program. Below are examples of ruler, miter, and protractor that are being modeled by pre-service teachers.

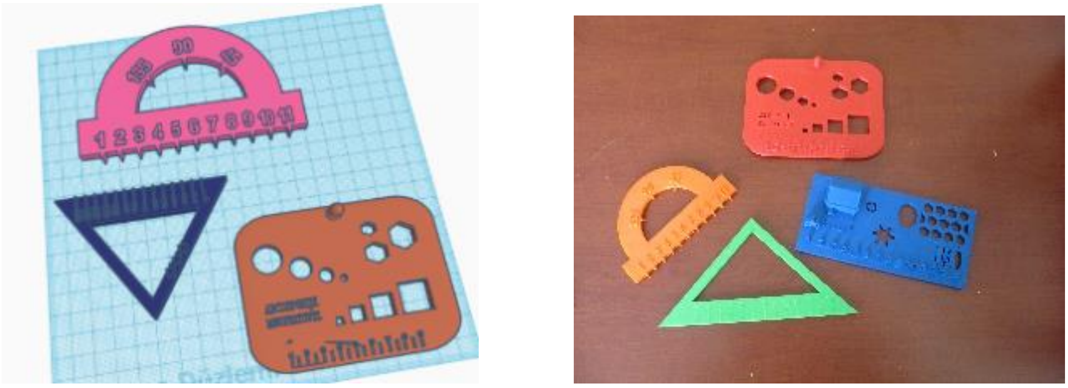

Figure 1. Sample geometry set modeling

The explanations related to modeling by Medine, Ayşe and Duygu are presented below.

Researcher: How did you do the modeling process?
Medine: I first wrote in how many degrees and how many centimeters it will be. Then I decided to do using the program because writing was not useful. So I transferred my thoughts directly into the program.
Researcher: Does it match with what you designed in your mind and what you modeled?
Medine: I thought it would be easier but it was hard to adjust the lengths and measuring. For example, I thought that the angles on the protractor would be 30° but it was not happening, then I decided to go with 45°.
Researcher: How did you set 45° but couldn't set 30°?
Medine: There is an angle adjustment feature in the program, so I could set 45° by using that feature. And because this will be used at the end of the process, I had to use the correct lengths, so I did not randomly draw.
Researcher: Ayşe, how did you do the miter?
Ayşe: I took the ruler in the program and made the ruler part of the miter. And because there was not measure in the other parts of the figure, I ornamented there.
Researcher: Duygu, how did you model yours?

> Duygu: Actually, mine had the same logic, but first it was hard because the edges of the ruler were oval. Other than that, I added circles, squares, pentagons and letters in the ruler to make it useful.

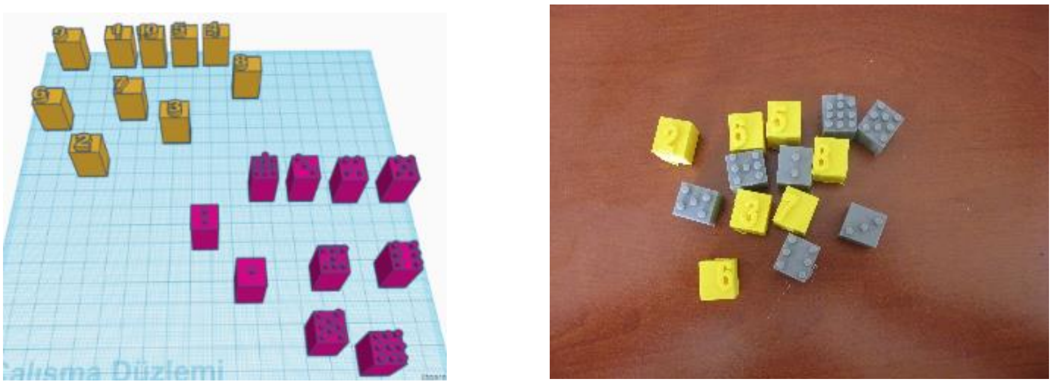

Figure 2. Sample lego set with numbers

In the “Counting Chips and Number Blocks” activity, it is seen that Sema designed “Lego Model with Numbers” by continuing her individual work. Teacher candidate's modeling and explanations for her modeling are presented below.

> Researcher: Sema, can you explain what you did?
> Sema: I wanted it to be a little different. I wanted that students both learn the numbers and think they are playing with the Lego. Thus, they can learn by pairing. I created unit cubes of 2 × 2 × 2. With the numbers above the cubes, I made their height 3 cm to make Lego's studs emboss. Then I noticed it was hard to make studs on a 9-unit. That is why I decided to do the cubes of 3 × 3 × 3 and for the studs I made the height 4 cm.
> Researcher: Why did you use number embossments on the Lego set in your model?
> Sema: In this way, the child both learns to count and match numbers and figures with objects. We have also talked about the use of printers and these can also be used in the teaching of children with visual impairment. They can feel it by touching.
> Kübra: Their system isn’t different, though?
> Sema: Whether or not at least they can count, numbers are also apparent.

When the explanations of Sema’s modeling process are examined, it is seen that she made arrangements to make her model effective as Kübra and Ayşe, who made the number blocks. Based on these findings, it can be said that pre-service teachers’ pay attention to create practical and realistic products in their models. At the same time, it was seen that the teacher candidate made explanations about the usefulness of her model. It is also seen that she reflected the effective use of material in mathematics teaching and the use of visually impaired individuals in the model. In this respect, it can be said that the teacher candidate’s model is useful in real life and in different contexts.

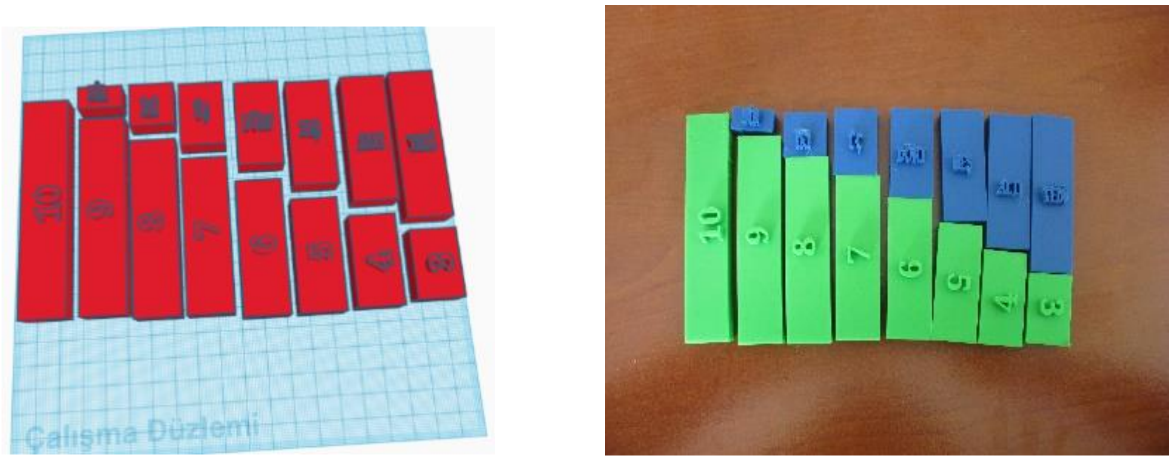

Figure 3. Sample number block modeling

The following is an example of Perihan's 3D model called “Number Blocks that Complete to 10” in the same MEA.

> Researcher: What did you think of as number blocks?
> Perihan: I've looked at what I can do online and decided to make blocks that complete to 10.
> Researcher: What did you do for this?
> Perihan: The size of all the blocks should be equal, when they come end to end. And the numbers will be 1 to 10, so I decided to make the length of the blocks as 10 cm and width of them as 20 cm. Then the lengths are set up by the number itself 9 cm, 8 cm…1 cm. I did the same in the writing on the blocks. I've just copied it, not just with numbers but also in writing.
> Researcher: How did you use the measurements for the figures and the numbers on the blocks?
> Perihan: The thickness of the rods was 1 cm. I made them 1.5 cm to be seen from the top of the rods.
> Researcher: What are the features of this modeling?
> Perihan: I thought that the students use their fingers when adding, for example. Here it is possible to see the concrete adding directly up to 10, 1 + 9 = 2 + 8 = … = 1 + 9 = 10. For example, we can ask, “what should I add to 4 to get 10?”. So it can be used differently.

It can be seen that “number blocks that complete to 10” modeled by Perihan have explanations for the use of the model for different purposes and contexts. In this respect, it can be said that the teacher candidate has an effective model and the product is useful.

Similarly, in the “Geometry Board” activity, many of the pre-service teachers modeled a rectangular geometry board model, while Medine modeled a double-sided geometry board considering that it could be suitable for use in different situations.

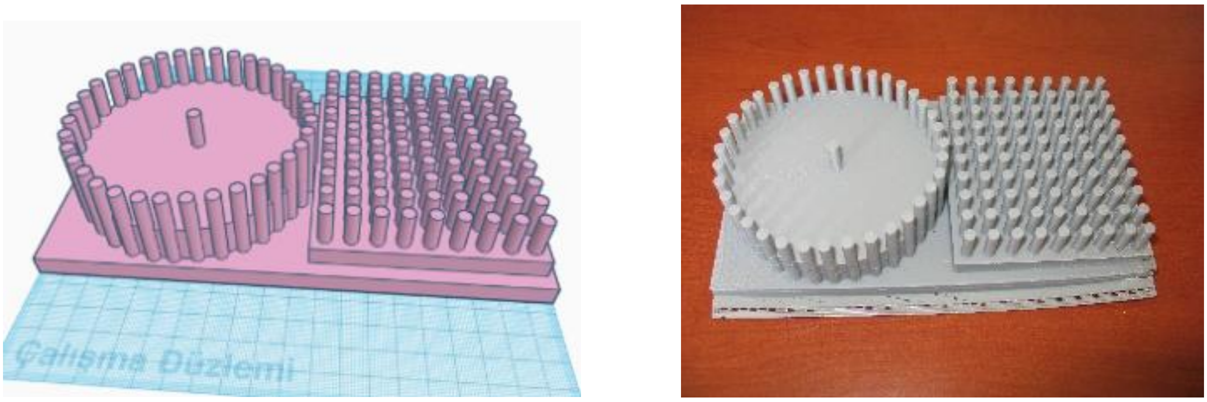

Figure 4. Sample geometry board modeling

> Researcher: Medine, why did you model the geometry board in this way?
> Medine: If I had made it the rectangular way we all know, its use would be limited. Now in this way, there is a rectangular board on one side and a circle board on the other side. So the teachers and the students who use it can show the angles by using the circle side. Arch length, angle etc. or more… So you can use a single product in many ways.
> Sema: I did it in the form of a rectangle, but in the end it can be used for the same purpose. So the circle can be created with this too.
> Medine: But it's easier to show them with this.
> Mustafa: In fact, only the rectangular side can be used to show long objects. So Medine’s model is limited on one hand.
> Medine: So, each model may have advantages and disadvantages.

The pre-service teachers discussed the advantages and disadvantages of the models for the geometry board they modeled. The explanations show that pre-service teachers are modeling by taking into consideration the uses for different purposes. At the same time, it is seen that they were aware of the different uses and purposes of their models. This shows that pre-service teachers have an idea about what develop as their products.

When the MEAs modeling processes with 3D printers were examined, pre-service teachers created their models by using both mathematical representations and 3D visuals to solve the problem situation. Pre-service teachers were able to effectively transfer their designs that they have done mathematically to the 3D modeling program and they could create their products in this way. Participants made arrangements and development in the modeling process by taking into account the fact that their models should be effective in different contexts, usable and realistic. With the development of modeling skills of the pre-service teachers, the products they will produce will be useful and relevant.

Views about Technology

The views of pre-service teachers about technology before and after MEAs conducted with 3D printers and modeling were evaluated. As a result of the evaluation of the views of pre-service teachers, technology and technological equipment categories have been reached.

The views of pre-service teachers about the definition of technology

The views of pre-service teachers about the definition of technology before and after MEAs conducted with 3D printers are presented as sample codes in table 4.

Table 4. The views of pre-service teachers about technology before MEAs

	Category	Participants and Sample Codes
Before MAEs	Electrical and Electronic Tools	Mustafa: For example, this phone is a technology. Like a computer, or calculator. Kübra: When mentioned about technology, things that work with electricity come directly to my mind. Such as this voice recorder or phone. Aynur: Complex tools. Such as the latest model phones, televisions. Ayşe: Tools that are mostly composed of electrical goods… Tools are actually technology. But we also call technological tools… Then technology is something different. Duygu: The first thing that comes to my mind is phone. For example, there are robots currently as advanced technology. These are technology.
	Change	Sema: Technology is a constant change. So let's say you have a model, this model is renewed and changes constantly.
	Development	Perihan: Development comes to my mind. Development of tools according to our needs. Medine: For example, the tools that people use over time have been developed. I am talking about technological development. Over time, the development of tools with different features is technology.

The views of pre-service teachers about technology before MEAs conducted with 3D printers were generally made up of electrical or electronic tools and also the categories of change and development were reached. They indicated that electrical and electronic tools such as mobile phones, computers and calculators were examples of technological tools. The reason for this situation may be the interaction of pre-service teachers with certain technological tools in school life and out-of-school environments. It can be said that teacher candidates' limited experience with technology and technological tools has limited their definitions towards technology. The views of pre-service teachers about the definition of technology after MEAs conducted with 3D printers are presented as sample codes in table 5.

When the views of pre-service teachers about technology after MEAs conducted with 3D printers are examined, it is seen that there are development and change, globalization and engineering dimensions. It is observed that the definitions of pre-service teachers after MEAs have expanded. It is thought that the discussions on the technology, technological tools and developing technology in the process of MEAs had a positive effect in this.

In this way, it is seen that teacher candidates gained different views and perspectives towards technology. Thanks to the enriched MEAs content including information and communication technologies such as 3D printer, modeling program, and computer, it can be said that the views of pre-service teachers about technology and technological tools have improved.

Table 5. The views of pre-service teachers about technology after MEAs

	Category	Participants and Sample Codes
After MAEs	Improvement	Sema: I think technology has emerged from the need of people to develop. So they have developed many things. Aynur: Tools that people developed based on their needs are technology. Medine: The invention or development of a tool can happen with technology. Either its mechanism is changed and becomes developed, or something brand new that does not exist is created and used. Duygu: Technology is a development in time according to needs. Tools can change in this process, based on our technology perception. For instance, many things that we do not think of as technology at the moment may be technology in the past.
	Change	Ayşe: It is the change and development related to the tools. They don't necessarily have to be concrete. I thought so before. Internet or software, for example. These are technological products.
	Globalization	Perihan: Technology is actually globalization. In other words, it is the development of tools and equipment used in this way all over the world. For example, a technological tool developed in America is being used in many other places as well as in our country. Thus, globalization occurs. Kübra: Our life is actually a technology. Nowadays it is a necessity. So it is developing so fast in the world that it is impossible not to use technology. Moreover, it may be left behind if it was not used or developed. There is such a competition in the world. Whoever has the most advanced technology, that becomes dominant.
	Engineering	Mustafa: Technology consists of tools that can be developed as a result of engineering applications. But these tools are definitely not the ones that electrically operated. That's our perception today. But for people who have lived in the past, a window can also be a technology.

The views of pre-service teachers about the use of technological tools

Teacher candidates were asked questions about using technological tools and feeling themselves sufficient or insufficient. The views of pre-service teachers about the use of technological tools before MEAs conducted with 3D printers are presented as sample codes in table 6.

Table 6. The views of pre-service teachers about the use of technological tools before MEAs

	Category	Participants and Sample Codes
Before MEAs	Positive	Medine: I am curious about technological things; for example, I wonder how things work. I'm not afraid that it would be broken... I would not hesitate to learn anything new about technology. How hard it'll be. Perihan: I like to deal with technological tools, but I didn't have much chance. For example, it is easy to use the computer for me, as well as the programs. Sema: I love it. I like to meddle with things. I was very happy when I got a computer.
	Negative	Mustafa: I don't really understand it; doesn't really attract my attention. We had a computer class, but we didn't do anything. It's hard to use even the Word program. Kübra: I didn't have such a possibility. For example, now most children have a lot of things such as tablets, computers… and frankly I'm afraid because I didn't use it much. Like I can't use or I break it. Ayse: If using technology means using a phone, then yes. But other than that, I didn't use many tools. For example, we took a computer class but I can't use a program properly. That's why I can't do anything. Duygu: I don't think I have much of a skill. For example, I see you are very comfortable using the computer. I don't even know the features properly. I use a phone other than a computer, but it's certain programs. Things like Instagram, Facebook… Aynur: I use the phone as a technological tool like everyone. Such as message or conversation. Apart from that, I do not know much about technological things.

When the views of pre-service teachers about the use of technological equipment before the MEAs conducted with 3D printers are considered, the majority of them had a negative opinion. The reasons for this situation are that they did not have much experience in using technological tools or they had inadequate information about any technological tools. When the views of the pre-service teachers who were positive are considered, it is seen that they were eager to use and learn.

The views of pre-service teachers about the use of technological tools after MEAs conducted with 3D printers are presented as sample codes in table 7. After the MEAs conducted with the 3D printers, it is seen that all of the pre-service teachers indicated a positive view about the use of technological tools. In the explanations of pre-service teachers, it is seen that using technology was finding fun; they improved technology usage skills; they internalized this situation and continued to improve; and their self-confidence increased. As a result of the widespread use of technology in our lives, it is thought that using such technologies in teacher education will be effective in helping pre-service teachers provide teaching content enriched with technology.

Table 7. The views of pre-service teachers about the use of technological tools after MEAs

	Category	Participants and Sample Codes
After MEAs	Positive	Medine: With these activities, I saw that I can even use programs that seem very difficult. For example, I could hesitate to use a modeling program or a 3D printer. But it wasn't too hard. Perihan: Good thing I participated to the activities because I learned to use a lot of things. I would wonder how to use them, but how could I learn the program if it wasn’t for you. In this way, I learned to use a three-dimensional printer. Sema: I'm bragging a lot, for example, for making the keychain by myself. I showed my brother and told him that I printed out myself from the 3D printer. I would like to make my own material for my own students. Mustafa: A friend of mine in engineering was modeling with a different program. I showed him what I did. I did a lot of things when I went home, except what we did here. For example, I made a chess set. We can print this out and use it. I couldn't do anything on the computer before, but I saw that I could do it now. I'm trying to do a lot of things. Kübra: I really liked what we did. We did both mathematics and engineering. We also used technology. I thought I could do a lot of things when I learned to use the program. I can even make designs to give to my friends. Ayse: I had hard time to do the first activities; I got even help from someone because I didn't know how to measure and how to use it. But then I got used to it. We (friends in the study) tried to do a lot of things in the dorms and finally I learned. Duygu: I saw that I could use computers; I could even use the program that I thought was very difficult when I am taught. That's why I can use it now. When I become a teacher, I want my students to use such technological tools. Because nothing was used in the years when we were students, but nowadays they are attracting children's attention. Aynur: I didn't know how to use a computer or a program. I've never even heard of Tinkercad. I can't say I'm using it very well at the moment, but I have improved over time and I believe I can improve more.

Views about MEAs

The interviews were conducted with the aim of determining the views of pre-service teachers about the activities after the MEAs conducted with the 3D printers. By evaluating the pre-service teachers’ views within the scope of the activities, categories of technology in mathematics teaching, engaging activity, developing modeling skills, and providing motivation were reached. The cases are presented as sample codes in table 8.

In line with the opinions of pre-service teachers, it is seen that the MEAs conducted with 3D printers provide a positive view about the use of technology and develops positive ideas about the use of technology in mathematics education. At the same time, such activities had a positive impact on pre-service teachers’ modeling skills, were instructive about the use of the modeling program, and provided development about the usage of the program. It is observed that MEAs had a positive effect on the skills of pre-service teachers and provided motivation for the use of technology. Thanks to the motivation gained by the MEAs, it is thought that the pre-service teachers will contribute positively to self-improvement and benefit from these practices in their profession.

Table 8. The views of pre-service teachers about MEAs

	Category	Participants and Sample Codes
After MAEs	Technology in Mathematics Teaching	Sema: Thanks to these activities, I have seen how 3D printers can be used in mathematics. We see on television news that prosthesis hand, arm, etc. or in other areas as well. But I've never seen it used in math. Thanks to what I learned here, I know how to use a 3D printer when I become a teacher in my school and how to make my students do models. Mustafa: Let's just say we're working in a school, but we couldn't use if there is such a printer, but we've learned that right now. When we become teachers, we can use it and we can also teach our students what you taught. Or maybe I could buy one for my school, maybe not this much advanced. There are also developers who can do their printers, so we can do too. Aynur: When you asked what could be done with a 3D printer in mathematics at the first week, I could think of nothing. That's because things in math are abstract. After the activities, I have a lot of things on my mind now, many things. Ayşe: Now we have to use this in mathematics lessons because technology is everywhere. But when you ask what could be used, the first thing that comes to our mind is smart board and things like that. 3D printers can be used or modeled for students.
	Engaging Activity	Medine: I was hesitant to attend the first activities because I was also attending to other courses and my schedule was busy. After the first week, I liked it very much and I continued. Perihan: I liked what we did. I wish it would continue.
	Developing Modeling Skills	Sema: I had not heard or used Tinkercad or other modeling programs before. Even when you first said that we would do this work, I never thought we would do it ourselves. I learned to use Tinkercad, I learned to design what I have in my mind. So I had the models I wanted. Perihan: In fact, I learned that different technological tools could be used in mathematics classes. Normally, for example, always students solve written questions and do calculations. Maybe I would think this was not educational at first if you said something was being done using the program. But, for example, we did the measurement while modeling; we examined the properties of something in more detail. We used different types of geometric shapes. We also learned the properties. Medine: …I am happy that I participated because I learned a lot of things. I've never seen a 3D printer, for example, now I've seen it and learned how we can do things we want. You said that Tinkercad is more easy to use to start modeling; perhaps I can improve myself even more. Like other programs used in engineering. Kübra: I never knew how to use this program (Tinkercad); however, I think I improved myself by trying. For example, I know more or less about how I can do what I want in Tinkercad. I learned how it should be to print out of the 3D printer. Duygu: We took modeling as an elective course but we never saw such things to be done. We didn't do this one-to-one. At these activities, I learned to pay attention to how I can make the design in my mind come true, how it can be useful, and for this how its measures and shape should be. For example, modeling in mathematics was still abstract, but here we have concrete materials.
	Providing Motivation	Medine: …I especially like to be able to do something, create something. Aynur: I didn't think I could do anything like that, but I was able to use the computer very well and also Tinkercad. So most of all, it made me see what I could do.

Results and Discussion

In this section, the results obtained based on the findings and comments of the research and the suggestions made in line with these results are included. In this research, pre-service teachers' views about the engineering and modeling skills that emerged in MEAs conducted with 3D printers, technology and MEAs applications were examined.As technology and engineering practices became widespread in teaching and learning, it gained importance that the teachers were equipped in this respect. In this regard, enriched teaching content should be included in the training of pre-service teachers. In this study, thanks to the 3D printer-enriched modeling activities, it was ensured that the pre-service teachers took part in technology and engineering applications.

In the study, pre-service teachers were expected to develop mathematically appropriate, realistic and useful models for use in mathematics education. It was observed that pre-service teachers had problem definition in different contexts and realized problem solving through modeling. Similarly, Brophy et al. (2008) reported that the problem solving skills of the individuals involved in the process of engineering education at the K-12 level were effective. Many researchers (Doerr, Ärlebäck, & Costello Staniec, 2014; Lesh & Doerr, 2003) likewise think that individuals involved in such model-building activities are actively involved in problem-solving and have developed ideas, test these ideas and improve them for realistic problems.

In this study, pre-service teachers created products in 3D modeling process with 3D printers. In this process, it was seen that they created a model for the presented problem after an effective modeling process. It can be said that problem-solving skills of teacher candidates are effective with their products being useful and purposeful. Similarly, it has been reported that 3D printer technology is effective in the studies on the effectiveness of problem-solving skills related to modeling (Atman et al., 2007; Blikstein et al., 2017; Wells et al., 2016).

Doerr, Ärlebäck and Costello Staniec (2014) stated that a single modeling task limits the development of students' modeling skills. For this reason, in this study, pre-service teachers were presented with different application contents and provided with opportunities to create models in different contexts. In this way, it is thought that these activities had a positive effect on the development of modeling skills of pre-service teachers. When the modeling processes of the pre-service teachers are examined, it can be seen that the created models can be used for different purposes. In this context, it can be said that teacher candidates' modeling skills are effective. In similar studies, it is stated that the use of the product produced in different contexts at the end of the modeling process demonstrates the effectiveness of modeling skills (Hjalmarson et al., 2006; Hjalmarson, Diefes-Dux, & Moore, 2008; Sen, Ay & Kiray, 2018).

The pre-service teachers applied the mathematical process followed by 3D modeling to solve the problems in the modeling process. In this respect, they have benefited from different representations. In the modeling process, pre-service teachers benefited from many mathematical knowledge and skills such as measuring, solving equations and using geometric objects. In this way, teacher candidates benefited from the theoretical knowledge they learned during their education and they had the opportunity to use this knowledge through application. This finding is consistent with the statements of teacher candidates in interviews with the pre-service teachers. Therefore, it can be said that activities contributed to the conceptual learning of teacher candidates. Similarly, it is stated that design-oriented engineering applications are effective in developing conceptual understanding of individuals toward concepts and principles (Crismond, 2001; Fleer, 2000; Kimmel et al., 2006; Kolodner et al., 2003; Linn, 2003; Zubrowski, 2002; Sadler, Barab, & Scott, 2007). This result is in line with the conclusion that it is effective in developing high-level understanding in modeling studies with 3D printer technology (Lesh, Yoon, Zawojewski, 2007; Moore et al., 2013; Moss Kotovsky, Cagan, 2006; Streveler et al., 2008).

In the study, interviews were conducted to determine the views of pre-service teachers before and after the MEAs coducted with 3D printers. When the views of the pre-service teachers are examined, it is seen that there is a positive change in the technology definitions and thoughts about the use of technological tools. While it was seen that pre-service teachers had more narrow definitions of technology before MEAs, they had more positive and effective definitions after the practice. The reson for this is the limited technology interaction of pre-service teachers. Similarly, pre-service teachers had negative views about the use of technological tools and materials due to their low experience in using technological tools before MEAs. In the implementation process of the activities, pre-service teachers were provided to use various media and communication technologies by using 3D printer, computers, 3D modeling program (Tinkercad), and Internet. In this way, it is observed that they had a positive view about the use of technological tools after MEAs. It is also observed that pre-service teachers realize the effectiveness and importance of technology in mathematics education. It is observed that the model building activities involving 3D printer usage and modeling provide motivation regarding technology usage and modeling for pre-service teachers. In this way, it is thought that these activities contributed to the pre-service teachers' use of technology in their professional work in the future.

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