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# Use of 3D Printers for Teacher Training and Sample Activities*

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## Abstract

The aim of this study was to determine the effects of 3D (3-dimensional) printing activities on pre-service teachers' self-efficacy in technological pedagogical content knowledge (TPCK) and their views of 3D printing activities. The study sample consisted of 39 students of science education, classroom teaching and preschool teaching departments of the faculty of education. An exploratory sequential mixed method design was used. In the quantitative part, a one group pre-test post-test design was used, and data were analysed using statistical methods. In the qualitative part, phenomenology was used, and data were analysed using content analysis. Results showed that 3D printing activities improved participants' self-efficacy in TPCK. Participants stated that 3D printers helped them develop skills in many areas and that 3D printer teaching materials contributed to both learning and teaching. The majority of participants had positive views on the effect of 3D objects on learning. They stated that 3D objects turned abstract concepts into concrete visual representations, facilitated learning, made lessons enjoyable, provided learning retention, encouraged them to learn more about their fields, increased their interest, and helped them develop creative thinking and design skills, and thus, create different content-specific educational materials.

**Keywords:** 3D Printers, Technological Pedagogical Content Knowledge, Teacher Training, Mixed Research Design

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# INTRODUCTION

Today, technology is widely used in learning environments. It has, therefore, been an important topic of discussion to develop technology-based processes in teaching design and to help students develop technology skills (Yanpar-Yelken, Sancar-Tokmak, Özgelen & İncikabı, 2013) because technology-based learning environments actively engage students in the learning process and provide them with the opportunity to develop thinking, interpretation, and self-expression skills (Baki, 2002; Ersoy, 2003). Software provide permanent and efficient learning by helping students turn abstract concepts into concrete visual representations and imagining them in their minds (Eryigit, 2010). It is, therefore, of paramount significance to provide teachers with the opportunity to learn how to combine technology and pedagogical content knowledge and put it into practice and use tools and materials to solve problems pertaining to the use of technology in learning environments. Graduate pre-service teachers should therefore not only have content knowledge or know how to teach but also integrate content knowledge with technology. Teachers should be able to use technology to teach and evaluate a topic of their own areas of interest. In other words, they should have adequate technological pedagogical content knowledge. Therefore, universities should provide students with such training that makes sure that they can develop appropriate teaching skills and acquire TPCK to be able to design technology-integrated classroom activities.

Technology is in every aspect of our life and also widely used in learning environments. The concept of TPCK has emerged with the premise that pedagogy and field components should also involve technology (Doğru & Aydın, 2017). TPCK, which is an expanded version of pedagogical content knowledge, is defined as teachers' ability to integrate technology into pedagogical strategies and their awareness of the effects of technological materials and presentations on students' comprehension of content (Graham, Burgoyne, Cantrell, Smith, St. Clair & Harris, 2009). In other words, TPCK refers to teachers' or pre-service teachers' ability to integrate technology with pedagogical content knowledge and put it into practice in their teaching. Teachers with TPCK can integrate appropriate educational technologies into their pedagogy knowledge to provide effective learning environments (Doğru & Aydın, 2017). Research generally focuses on teachers' TPCK levels and self-efficacy (Archambault & Crippen, 2009; Bilici & Güler, 2016; Jang & Tsai, 2013; Jordan, 2011; Karadeniz & Vatanartıran, 2015; Karataş, 2014; Lee & Tsai, 2010; Özbek, 2014; Şad, Açıkgül & Delican, 2015; Timur & İmer-Çetin, 2014) and pre-service teachers' self-confidence in TPCK (Sancar-Tokmak, Yavuz-Konokman & Yanpar-Yelken, 2013; Sarıkaya, Kaya, Akdağ, Ay & Doğan, 2012; Savaş, Öztürk & Tüzün, 2010) and development of TPCK levels (Akkaya, 2009; Canbazoğlu-Bilici, 2012; Niess, 2005; Timur, 2011). Most of these studies investigate whether teachers' and pre-service teachers' self-efficacy and self-confidence in TPCK differ by major, branch, age, experience, gender etc. Most studies on 3D printers are conducted in the fields of engineering (Golub, Guo, Jung & Zhang, 2016), robotics (Hamidi, Young, Sideris, Ardeshiri, Leung, Rezai & Whitmer, 2017), special education (Buehler, Kane & Hurst, 2014), anatomy education (Vaccarezza & Papa, 2015), earth science (Horowitz & Schultz, 2014), design (Greenhalgh & Greenhalgh, 2016), science education (Byun, Jo & Cho, 2015), STEM education (Taylor, 2016; Nichols, Schuster & Ball, 2016), mathematics and geometry education (Huleihil, 2017). Since 3D printers are new to the field of education, there is only a small number of studies on this topic. The vast majority of those studies focus on higher education while only a handful of them are concerned with primary and secondary education (Karaduman, 2018).

There are very few studies investigating the effects of 3D printers on pre-service teachers' TPCK. The aim of this study was, therefore, to determine the effects of 3D printing activities on pre-service teachers' self-efficacy in TPCK and their views of 3D printing activities. We believe that this study will contribute to the literature and pave the way for further research.

## METHOD

This study employed an explanatory sequential mixed methods design and involved two stages; (1) quantitative data collection and analysis, and (2) qualitative data collection and analysis. “Qualitative data are collected to better understand, investigate, and enrich the quantitative data” (Creswell & Plano Clark, 2015, p. 79). In the quantitative part, a one group pretest-posttest design was used. In the qualitative part, phenomenology was used.

## PROCEDURE

1. Opening an elective course “3D design and modeling” in the departments of science, classroom education and preschool education and organizing a 3D printer workshop in the faculty of education.

2. Training the “3D design and modeling” course instructors on 3D printers and then performing activities with participants (students who took the course)

3. Training participants on Microsoft 3D builder for 3D object design and introduction to 3D printers

4. Training participants on 3D design and modeling during the first five weeks of the 14-week curriculum to ensure that they are equipped with the skills to perform 3D activities. The training involved converting 2D designs to 3D models, software programs and interfaces for 3D object design, the 3D printing process, and use of 3D printer apparatus and printing methods.

5. Figure 1 presents the 5-week training process in detail.

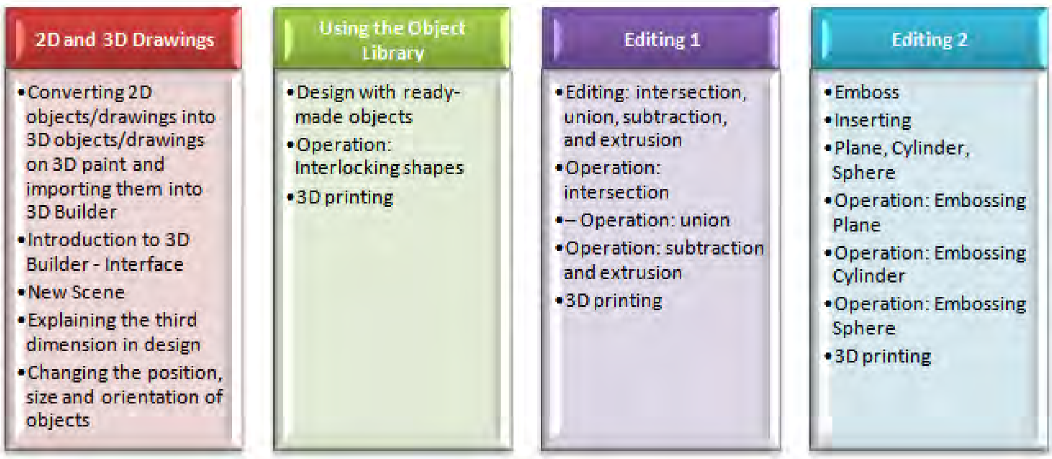


**Figure 1. Training topics**

6. Allowing participants for the remaining eight weeks to develop content-specific or unique materials that they believe might promote their students' learning. Figure 2 shows some of the learning objects (materials) designed by participants on 3D Builder.


**Figure 2. Learning object designs**

7. Allowing participants to present their 3D learning objects as a group or individually every week.

**Participants**

The study sample consisted of 39 third-year students (11 men and 28 women) of the primary school, preschool, and science teaching departments of the faculty of education.

**Data Collection Tools**

*TECHNOLOGICAL PEDAGOGICAL CONTENT KNOWLEDGE SELF-EFFICACY SCALE*

The technological pedagogical content knowledge self-efficacy scale (TPACK-SeS) was used as pretest-posttest to determine participants' self-efficacy in TPCK. TPACK-SeS was developed by Graham et al. (2009) and adapted to Turkish language by Timur and Taşar (2011). It consists of four subscales: technological pedagogical content knowledge (TPCK), technological pedagogical knowledge (TPK), technological content knowledge (TCK), and technological knowledge (TK) (Timur & Taşar, 2011). TPCK (Cronbach's alpha $\alpha = .89$) consists of eight items on internet and digital technology usage in science classes to detect misconceptions, to collect data, and to conduct research. TPK ($\alpha = .87$) consists of seven items on self-efficacy in classroom management and effective communication during digital technology-based teaching. TCK ($\alpha = .89$) consists of five items on self-efficacy in using digital technology in the field. TK ($\alpha = .86$) consists of 11 items on self-efficacy in using digital technology. TPACK-SeS has a Cronbach's alpha of .92.

*INTERVIEW FORM*

The researchers developed an interview form to determine participants' views of 3D printing activities. The form consisted of seven open-ended questions designed to probe participants' views of the contribution of 3D printing activities to skill development and contribution of 3D materials to teaching and learning. Three academics were consulted for content and face validity. The questions were revised, and the form was finalized based on their feedback. The form questions are as follows:

1. What skills do you think 3D printer design and modeling activities helped you develop?

2. In what way do you think 3D printer design and modeling activities helped you acquire TPCK?

3. What kind of problems (challenges) did you have to deal with when using 3D printers?

4. In what way do you think 3D learning objects (course materials) contributed to your learning?

5. What kind of problems (challenges) did you have to deal with when building 3D learning objects (course materials)?

6. In what way do you think using 3D printers in learning environments can contribute to learning?

7. For what purpose would you consider using 3D printers in your professional life?

### Data Analysis

Within the scope of the research, interviews were conducted with 27 volunteer preservice teachers.

Quantitative data was tested for normality using the Shapiro-Wilks test and then analysed using either parametric or nonparametric tests, depending on whether they were normally distributed. Qualitative data were analysed using content analysis. Interview data were transcribed and prepared for analysis. The researchers assessed the interview data independently and coded as short, simple, and clear symbols. After coding, they identified common points and then developed themes. They identified the parts on which they agreed and disagreed during coding and discussed and revised the codes on which they disagreed in order to reach a consensus. Participants were assigned pseudonyms (Yeliz, Kader, Mehmet etc.) in order to assure anonymity. An expert was consulted to determine whether the themes were representative of the codes for reliability. The expert matched the codes with the themes. The researchers compared the expert matching with theirs and discussed the themes on which they disagreed in order to reach a consensus. Direct quotations were used to ensure internal validity. The entire research process (from the development of the data collection tool to implementation and analysis) was elaborated, and all results were presented and compared to those of previous studies in order to ensure external validity. It was made sure that the research questions were open-ended and consistent with the research stages in order to ensure internal reliability. The research steps were described in detail to increase external reliability.

## RESULTS

### TPACK-SeS RESULTS

Descriptive statistics were used for quantitative data analysis. Quantitative data was tested for normality and then analysed using either parametric or nonparametric tests, depending on whether they were normally distributed. Table 1 shows the analysis results.

**Table 1: Normality testing of TPACK-SeS pre test-post test scores**

| Groups | N | Shapiro- Wilks | $\overline{X}$ | Df | Sd | Coefficient of Skewness | Coefficient of Kurtosis |
|---|---|---|---|---|---|---|---|
| TPACK-SeS | 39 | .099 | .29 | 38 | .10 | -.758 | .232 |
| TPCK | 39 | .930 | .31 | 38 | .11 | -.164 | -.107 |
| TCK | 39 | .279 | .37 | 38 | .14 | -.509 | -.006 |
| TPK | 39 | .724 | .47 | 38 | .19 | .256 | .017 |
| TK | 39 | .014 | .16 | 38 | .14 | -.098 | 1.433 |

Participants' TPCK, TCK and TPK pretest-posttest scores were normally distributed, and therefore, analysed using dependent groups t-test, which is a parametric test. Their TK pretest-posttest scores were non-normally distributed, and therefore, analyzed using the Wilcoxon signed ranks test, which is a nonparametric test (S-W= .099 df=38 p >0.05).

The main research question was "Do 3D printer design and modeling activities have an effect on pre-service teachers' self-efficacy in TPCK?" Dependent groups t-test was used to analyse participants' TPACK-SeS pretest-posttest scores. Table 2 shows the results.

**Table 2: T-test results for participants' TPACK-SeS pretest-posttest scores**

| Measure(TPACK-SeS) | N | x | S | df | t | p |
|---|---|---|---|---|---|---|
| Pretest | 39 | 3.31 | .52 | 38 | -2.852 | .007 |
| Posttest | 39 | 3.61 | .62 | | | |

Table 3 shows the standard deviations, means and dependent groups t-test results of the participants' TPCK, TCK, and TPK pretest-posttest subscale scores.

**Table 3: T-test results for participants' TPCK, TCK, and TPK pre test-post test subscale scores**

| Subscales | Measure (TPACK-SeS) | N | x | S | df | t | p |
|---|---|---|---|---|---|---|---|
| TPCK | Pre-test | 39 | 3.29 | .61 | 38 | -2.828 | .007 |
| | Post-test | 39 | 3.61 | .71 | | | |
| TCK | Pre-test | 39 | 3.34 | .77 | 38 | -2.568 | .014 |
| | Post-test | 39 | 3.71 | .79 | | | |
| TPK | Pre-test | 39 | 2.78 | .18 | 38 | -2.411 | .021 |
| | Post-test | 39 | 3.26 | .15 | | | |

Participants had significantly higher mean TPCK, TCK and TPK post-test subscale scores than mean pre-test scores ($X_{TPCKPre}$ = 3.29 and $X_{TPCKPost}$ = 3.61; $X_{TCKPre}$ = 3.34 and $X_{TCKPost}$ =3.71; $X_{TPKPre}$ = 2.78 and $X_{TPKPost}$ = 3.26), indicating that 3D printer design and modeling activities improved participants' self-efficacy in TPCK [$t_{TPCK}(38) = -2.828$, $p_{TPCK} < .05$], TCK [$t_{TCK}(38) = -2.568$, $p_{TCK} < .05$], and TPK [$t_{TPK}(38) = -2.411$, $p_{TPK} < .05$].

The Wilcoxon signed rank test was used to analyze participants' TK subscale pre-test and post-test scores. Table 4 shows the results.

**Table 4: Wilcoxon signed rank test results for Participants' TK subscale pretest-posttest scores**

| Pretest- Posttest | N | Mean Rank | Rank Sum | Z | p |
|---|---|---|---|---|---|
| Negative ranks | 13 | 20.35 | 264.50 | -1.754 | .079 |
| Positive ranks | 26 | 19.83 | 515.50 | | |
| Difference total | 0 | | | | |

There was no statistically significant difference in participants' TK scores between pre-test and post-test, indicating that 3D printer design and modeling activities had no effect on participants' self-efficacy in TK (z=-1.754 and p>.05).

## INTERVIEW RESULTS

### *PARTICIPANTS' VIEWS OF EFFECT OF 3D PRINTER DESIGN AND MODELING ACTIVITIES ON SKILL DEVELOPMENT*

Participants' views of the effect of 3D printer design and modeling activities on skill development were analysed using qualitative methods. Table 5 shows the interviews results.

**Table 5: Participants' views of contribution of 3D printer design and modelling activities to skill development**

| Themes | Codes | Participants |
|---|---|---|
| Skills | Designing | Yeliz, İsmail, Gizem, Derya, Mehmet, Melek, Gökay, Deniz, Erdem, Aylin, Funda, Gökhan, Elif |
| | Using software | Nuray, Özge, Esra, Derya, Gökay, Ezgi, Eda, Şeyma |
| | Developing materials | Özge, İsmail, Eda, Kader, Gamze, Zerrin, Mehmet |
| | Multidimensional thinking | Nuray, Özge, Esra, Erhan, Derya, Melih |
| | Using technology | Yeliz, Mustafa, Fatih, Şeyma, Melih, Hasan |
| | Creative thinking | Gizem, Erhan |

Participants' views of the effects of 3D printer design and modeling activities on skill development were grouped under the theme of "skills" which consisted of the codes of "designing," "using software," "developing materials," "multidimensional thinking," "using technology," and "creative thinking." The following are direct quotations from participants:

> (Ismail): As a pre-service teacher, I think that 3D printers have helped me acquire the knowledge and skills that I need to develop materials and design and produce different kinds of toys.
>
> *Designing, Developing materials*

> (Nuray): First of all, they have expanded our current understanding of things. Even fiddling with a simple cube turned it into objects of different dimensions, which was a nice thing to see. Besides, they've helped us to use the software [3D Builder] better.
>
> *Using software*

> (Gizem): They've made me think more creatively and showed that we can make different things out of simple shapes.This lesson taught us how to make course materials that can help us explain topics during lessons. We designed tangrams to teach topics of our own major and designed materials to teach numbers, which is very good for us.
>
> *Creative thinking*

### *PARTICIPANTS' VIEWS OF CONTRIBUTION OF 3D PRINTER DESIGN AND MODELING ACTIVITIES TO TPCK*

Participants' views of the contribution of 3D printer design and modeling activities to their TPCK were analysed using qualitative methods. Table 6 shows the interviews results.

**Table 6. Participants' views of contribution of 3D printer design and modeling activities to TPCK**

| Themes | Codes | Participants |
|---|---|---|
| Positive | Effective use of technology | Erdem, Yeliz, Nuray, Özge, İsmail, Gizem, Esra, Gamze, Zerrin, Mehmet, Gökay, Ezgi, Elif, Eda, Funda, Deniz, Şeyma |
| | Developing content-specific materials | Yeliz, Gizem, Kader, Gökhan, Fatih |
| | A full grasp of content | Mehmet, Hasan, Gökhan |
| | Attracting students' attention | Melih, Erhan |
| | Turning abstract objects into concrete ones | Yeliz, Gizem |
| | Increasing permanence | Gizem |
| | Making classes productive | Melih |
| | Enjoyable classes | Gizem |
| Negative | No contribution | Melek, Mustafa, Aylin, Derya |

Participants' views of the contribution of 3D printer design and modeling activities to their TPCK were grouped under the themes of "positive" and "negative." The theme of "positive" consisted of the codes of "effective use of technology," "developing content-specific materials," "making classes productive," "attracting students' attention," "turning abstract objects into concrete ones," "a full grasp of content," "enjoyable classes," and "increasing permanence" while the theme of "negative" consisted of the code of "no contribution." The following are direct quotations from participants:

> (Özge): I had no idea about 3D printers before that class. But in that class, I learned what 3D design, and software programs like 3D Builder, and Zaxe were and how to use them. We learned how to 3D print using the software Zaxe during and after the classroom activities.
>
> *Effective use of technology*

> (Gökhan): I learned how to develop content-specific materials and turn abstract objects into concrete ones.
>
> *Developing content-specific materials, Turning abstract objects into concrete ones*

> (Melek): I can't say it did much. I mean, it was only two hours a week and so it was nothing more than rudimentary.
>
> *No contribution*

*PARTICIPANTS' VIEWS OF CHALLENGES OF 3D PRINTERS*

Participants' views of the challenges of 3D printers were analysed using qualitative methods. Table 7 shows the interviews results.

**Table 7: Participants' views of challenges of 3D printers**

| Themes | Codes | Participants |
|---|---|---|
| Challenges | No software know-how | Özge, Gizem, Esra, Kader, Gamze, Gökhan, Mehmet, Gökay, Ezgi, Eda, Funda, Şeyma, |
| | Designing | Yeliz, Özge, Gizem, Esra, Zerrin,Deniz, Erdem, Hasan |
| | Time-consuming | Zerrin, Derya, Elif, Fatih, Funda, Hasan |
| | No 3D printer know-how | İsmail, Gamze, Gökhan, Melih |
| | Inability to think in three dimensions | Nuray, Melek, Mustafa |
| | No challenge | Erhan, Aylin |
| | Inability to supply | Özge |

Participants' views of the challenges of 3D printers were grouped under the theme of "challenges" which consisted of the codes of "time-consuming," "inability to supply," "designing," "no 3D printer know-how," "no software knowledge," "inability to think in three dimensions," and "no challenge." The following are direct quotations from participants:

> (Deniz): The greatest challenge for me is that I can't design. I believe I'll get better as I learn more.
>
> *Designing*

> (Zerrin): It's just that we can't design what we have in mind, and it takes too much time to design things. Besides, the printers take too much time to print.
>
> *Time-consuming*

> (Erhan): There was no challenge whatsoever.
>
> *No challenge*

*PARTICIPANTS' VIEWS OF CONTRIBUTION OF 3D LEARNING OBJECTS TO LEARNING*

Participants' views of the contribution of 3D learning objects to learning were analysed using qualitative methods. Table 8 shows the interviews results.

***Table 8*. Participants' views of contribution of 3D learning objects to learning.**

| Themes | Codes | Participants |
|---|---|---|
| Positive | Developing different materials | Özge, Gamze, Zerrin, Ezgi, Mustafa, Funda, Şeyma, Melih, Aylin |
| | Enhancing creativity | Deniz, Derya, Nuray, Mehmet |
| | Facilitating learning | Aylin, Melek, Gizem |
| | Attracting students' attention to course content | İsmail, Esra, Kader |
| | Engaging students in learning | Yeliz, Kader, Elif |
| | Improving design skills | Nuray, Erhan, Derya |
| | Providing permanence | Fatih, Erdem |
| | Transforming the abstract into concrete | Özge, Yeliz |
| | Making lessons enjoyable | Fatih, Şeyma |
| Negative | No contribution | Gökhan, Gökay, Elif, Hasan |

Participants' views of the contribution of 3D learning objects (course materials) to learning were grouped under the themes of "positive" and "negative." The theme of "positive" consisted of the codes of "transforming the abstract into concrete," "improving design skills," "making lessons enjoyable," "attracting students' attention to course content," "engaging students in learning," "a full grasp of content," "developing different materials," "enhancing creativity," "providing permanence," and "facilitating learning" while the theme of "negative" consisted of the code of "no contribution." The following are direct quotations from participants:

> (Yeliz): 3D printing and turning what I had in mind into something tangible got me more engaged in learning.
>
> *Engaging students in learning, Transforming the abstract into concrete*

> (Erdem): It provided learning retention because it was based on learning by doing.
>
> *Providing permanence*

(Ezgi): I learned about other teaching materials because I did some research on topics and materials.

*Developing different materials*

*PARTICIPANTS' VIEWS OF CHALLENGES OF DEVELOPING 3D LEARNING OBJECTS*

Participants' views of the challenges of developing 3D learning objects (course materials) were analysed using qualitative methods. Table 9 shows the interviews results.

**Table 9: Participants' views of challenges of developing 3D learning objects**

| Themes | Codes | Subcodes | Participants |
| --- | --- | --- | --- |
| Challenges of Developing Objects | Designing objects | | Zerrin, Kader, Mehmet, Mustafa, Erdem, Aylin, Yeliz, Gamze, Melek, Hasan, Nuray, Esra, Ezgi, Fatih, Derya, Gökay, Şeyma |
| | | Dimension-size adjustment | Nuray, Yeliz, Esra, Gamze, Ezgi, Fatih, Erdem |
| | | Union | Kader, Mehmet, Mustafa, Fatih, Aylin |
| | | Extrusion | Yeliz, Melek, Hasan |
| | | Intersection | Yeliz, Şeyma |
| | | Subtraction | Gökay |
| | | Rotation | Zerrin |
| | Using software | | İsmail, Gökhan, Eda, Deniz |
| | Multidimensional thinking | | Nuray, Melih |
| | Creativity | | Gizem, Funda |
| | Power outages | | Özge, İsmail |
| | İnternet connection problems | | Elif |
| | No challenge | | Erhan |
| | Using printer apparatus | | Özge |

Participants' views of the challenges of developing 3D learning objects (course materials) were grouped under the theme of "challenges of developing objects" consisting of the codes of "Internet connection problems," "creativity," "using software," "power outages," "multidimensional thinking," "no challenge," "using printer apparatus," and "designing objects." The code of "designing objects" consisted of the subscodes of "rotation," "union," "subtraction," "intersection," "extrusion," and "dimension-size adjustment." The following are direct quotations from participants:

(Yeliz): First of all, I had a hard time using 3D Builder to design because it was the first time I had ever used it. I had difficulty intersecting and extruding and doing size adjustments, but I got the hang of it.

*Using software, Designing objects, Dimension-size adjustment, Intersection, Extrusion*

(Nuray): As I've said it before, we had a hard time thinking in three dimensions and doing size adjustments on the software.

*Multidimensional thinking, Designing objects, Dimension-size adjustment*

(Elif): It was a bit frustrating that the Internet in the lab kept cutting out.

*Internet connection problems*

*PARTICIPANTS' VIEWS OF CONTRIBUTION OF USING 3D PRINTERS TO LEARNING*

Participants' views of the contribution of using 3D printers in learning environments to learning were analysed using qualitative methods. Table 10 shows the interviews results.

**Table 10: Participants' views of contribution of using 3D printers in learning environments to learning**

| Themes | Codes | Participants |
|---|---|---|
| Positive | Helping to develop different materials | Gizem, Mehmet, Melek, Eda, Deniz, Hasan, İsmail, Esra, Erdem, Melih |
| | Improving design skills | Aylin, Derya, Özge, Yeliz, Gizem |
| | Helping to prepare materials easily | Gizem, Erhan, Gökay, Elif |
| | Improving creativity | Yeliz, Ezgi, Özge, Derya |
| | İncreasing interest | Fatih, Nuray, Gizem, Yeliz |
| | Attracting attention | Nuray, Gizem, Şeyma |
| | Providing learning retention | Nuray, Kader, Hasan |
| | Transforming the abstract into concrete | Yeliz, Hasan, Aylin |
| | Helping to develop educational materials | Fatih, Zerrin |
| | Facilitating learning | Şeyma, Gizem |
| | Promoting participation | Kader |
| | Arousing curiosity | Yeliz |
| Negative | Useless | Mustafa, Funda,Gökhan |
| | Hard to use | Ezgi, Eda, Gamze |

Participants' views of the contribution of using 3D printers in learning environments to learning were grouped under the themes of "positive" and "negative." The theme of "positive" consisted of the codes of "helping to prepare materials easily," "helping to develop educational materials," "helping to develop different materials," "facilitating learning," "improving creativity," "providing learning retention," "improving design skills," "attracting attention," "promoting participation," "increasing interest," "transforming the abstract into concrete" and "arousing curiosity," while the theme of "negative" consisted of the codes of "hard to use" and "useless." The following are direct quotations from participants:

(Erhan): It helps us develop sound materials easily.

*Helping to prepare materials easily*

(Melek): It helps us develop different materials and use them in class.

*Helping to develop different materials*

(Mustafa): A 3D printer is not lot like a factory, and it's costly and time-consuming and so it's useless.

*Useless*

*PARTICIPANTS' VIEWS OF USING 3D PRINTERS IN THEIR PROFESSIONAL LIVES*

Participants' views of using 3D printers in their professional lives were analysed using qualitative methods. Table 11 shows the interviews results.

**Table 11: Participants' views of using 3D printers in their professional lives**

| Themes | Codes | Participants |
|---|---|---|
| Intended Use | I do not think I will ever use them | Gizem, Gökhan, Ezgi, Mustafa, Elif, Eda, Funda |
| | Supplying materials | Fatih, Şeyma, Deniz, Erdem, Hasan, Aylin |
| | Designing and developing materials | İsmail, Kader, Erhan, Gamze, Mehmet |
| | Enriching learning environments | Nuray, Melek, Gökay |
| | Transforming the abstract into concrete | Yeliz, Özge, Melih |
| | Ensuring learning retention | Nuray, Zerrin, Özge |
| | Transforming the abstract into concrete | Yeliz, Özge, Melih |
| | Improving creativity | Yeliz, Esra |
| | Using technology | Esra |
| | Engineering skills | Derya |
| | Providing learning by doing | Özge |
| | Arousing curiosity | Yeliz |
| | Attracting attention | Nuray |
| | Promoting active engagement | Özge |
| | Multidimensional thinkingskills | Derya |
| | Taking learning to the next level | Yeliz |
| | Making classes enjoyable | Zerrin |

Participants' views of using 3D printers in their professional lives were grouped under the theme of "intended use" consisting of the codes of "using technology," "designing and developing materials," "I do not think I will ever use them," "enriching learning environments," "arousing curiosity," "promoting active engagement," "multidimensional thinking skills," and "taking learning to the next level," "supplying materials," "engineering skills," "providing learning by doing," "making classes enjoyable," "improving creativity," "transforming the abstract into concrete" and "ensuring learning retention." The following are direct quotations from participants:

> (Zerrin): I can use these objects to make learning outcomes more efficient and to provide both fun and permanent learning.
>
> *Ensuring learning retention, Making classes enjoyable*

> (Deniz): I can use it when I don't have enough material because I sometimes have a hard time finding stuff online, so, I think the software is useful.
>
> *Supplying materials*

> (Özge): As a pre-service teacher, I think that I will use that software instead of classical methods. Instead of teaching on paper, designing together with students and getting them to turn something abstract into something concrete and getting them to learn by living promote active engagement and ensure learning retention.
>
> *Transforming the abstract into concrete, Promoting active engagement*

## DISCUSSION AND CONCLUSION

Participants' TPACK-SeS pretest-posttest scale and subscale scores show that 3D printing activities improved their self-efficacy in TPCK, TCK, and TPK, but not in TK. This improvement might be because participants learned how to use 3D printing to design 3D content-specific learning objects to use in learning environments. Lower TK scores might be due to lack of experience. These results are also confirmed by the qualitative data. In the interviews, the majority of participants stated that 3D printing activities helped them acquire TPCK. They stated that the activities taught them how to use technology effectively and helped them have a grasp of content and develop content-specific materials which turned abstract objects into concrete ones, attracted students' attention, made the lessons enjoyable and efficient, and promoted learning retention. As for the challenges of 3D printers, participants stated that they had never used such software before and therefore had a hard time getting the hang of the 3D printer and its apparatus at first because they knew nothing about it. Previous studies have reported similar results. Taştı, Avcı Yücel and Yalçınalp (2015) reported that students had positive attitudes towards 3D printing because they believed that it facilitated learning and provided learning retention by turning the abstract into concrete. Jo (2016) reported that 3D printing achieved learning retention by supporting students' learning and teaching activities and boosting their concentration. Cano (2015) argues that 3D printers make schools and classes enjoyable and interesting and trigger students' curiosity, creativity, and passion for learning. Karaduman (2018) found that 3D printers and models helped pre-service teachers to develop technology skills, turn abstract concepts into concrete visual representations, and attract students' attention, and thus, ensure learning retention.

3D printing activities helped participants develop different skills. Most participants stated that the activities improved their creativity and taught them how to use a new software program and design and develop materials and think multi-dimensionally. These results are consistent with the quantitative data. Participants' TPACK-SeS posttest scores showed that 3D printing activities helped them acquire TCK. Previous studies have reported similar results. Chien (2017) argues that 3D printing is an effective technology that can be used to design innovative and versatile materials in learning environments. Güleryüz, Dilber ve Erdoğan (2019) found that 3D printers facilitated learning and improved pre-service teachers' ability to think creatively and in three-dimensions. Computers and new technology provide creative learning environments that improve academic performance (Potter, and Johnston, 2006). According to Karaduman (2018), 3D printing is a revolutionary technology that integrates the third dimension into the learning-teaching process and encourages students to design and develop materials that promote learning and activate the sense of touch, and thus, facilitate learning.

Participants faced various problems associated with 3D printers. They stated that 3D printing required three-dimensional thinking and took too long and was therefore time-consuming, that 3D printers were too expensive for utilization in a classroom environment, and that they had a hard time designing because they did not know how to use the 3D Builder. However, some participants stated that they had no difficulty using the 3D printers. Previous studies have reported similar results. Although 3D printers offer time and cost advantages, they are still too slow and too expensive to be useful to households (Berman, 2012; Demir Kuzu, Çaka, Tuğtekin, Demir, İslamoğlu & Kuzu, 2016). Jo (2016) argues that not only material development and dissemination, but also design, cost, and production limitations should be taken into account in 3D technology. Gibson, Rosen and Stucker (2010) also maintain that possible changes in the 3D printing process greatly slow down and hinder production.

The majority of participants had positive views on the effect of 3D objects on learning. They stated that 3D objects turned abstract concepts into concrete visual representations, facilitated learning, made lessons enjoyable, provided learning retention, encouraged them to learn more about their fields, increased their interest, and helped them develop creative thinking and design skills, and thus, create different content-specific educational materials. These results are consistent with the quantitative data. Participants' TPACK-SeS posttest scores showed that 3D printing activities improved their self-efficacy in TPK. However, some participants stated that the activities had no effect on their self-efficacy in TPK, which has been reported by some previous studies. Research shows that 3D printers have positive effects on learning. For example, 3D printers can help students enjoy learning, apply what they learn in real-life situations, and develop creative thinking skills (Eisenberg, 2013). Taştı et al. (2015), state that 3D modeling software is effective and easy to use. Participants also stated that 3D learning objects promoted learning by turning abstract concepts into concrete visual representations.

Participants stated that they had a hard time using the software because they lacked multidimensional and creative thinking skills that were necessary to design and create 3D learning objects. They also stated that they were challenged by Internet connection problems and by their own inability to use 3D printer apparatus. Power outages were another challenge because they disrupted the

3D printing process and made participants start it all over again. Research also shows that students and teachers (Maloy, Kommers, Malinowski and LaRoche, 2017) and pre-service teachers (Karaduman, 2018; Taştı et al., 2015) faced challenges in using 3D modeling software such as creating models due to lack of knowledge or finding models online due to limited number.

Participants reported that 3D printers helped them prepare different educational materials easily. They stated that 3D printing can attract students' attention and arouse their curiosity because it allows them to turn abstract concepts into concrete visual representations, promotes learning, provides learning retention, and helps students develop creative thinking and design skills. Some participants, on the other hand, stated that they found 3D printers hard to use and useless. Some studies support our results. Lütolf (2013) argues that cheap 3D printers allow students and teachers to quickly design and produce educational materials, which increases educational opportunities. (Karaduman, 2018) also maintains that 3D printing is an ideal technology to produce materials that are not easily accessible and available.

Participants stated that they would like to use 3D printers in their professional lives to teach their students how to use a new technology, to attract their attention and arouse their curiosity, to help them develop multidimensional and creative thinking and engineering skills, to enrich learning environments, to make classes enjoyable, to promote active engagement, to provide learning by doing and learning retention, to perform high-level learning, and to design and use concrete materials. However, some participants stated that they would not like to use 3D printers in their professional lives, which might be due to the challenges that they faced during the 3D printing process. Previous studies have reported similar results. Schelly, Anzalone, Wijnen, and Pearce (2015) investigated the advantages of the use of open-source technologies in teaching environments. To that end, they provided students with training on how to 3D print by using open-source technologies and found that students immediately put that new knowledge into practice in their own classes. Özsoy and Duman (2017) state that 3D printers help students develop three-dimensional and analytical thinking and design skills.

## RECOMMENDATIONS

The following are recommendations based on the results: Teachers and pre-service teachers should be provided with trainings to raise their awareness of 3D printers and their use in learning environments. Education faculty students should be offered trainings to provide them with the opportunity to develop language proficiency and digital literacy skills necessary to use 3D software. Moreover, future experimental studies should recruit teachers and students at all levels of education in order to investigate the effects of 3D printing technologies on teaching-learning processes. It is recommended that future studies recruit more participants and involve more activities to provide more precise information on the contribution of 3D printing technologies and 3D learning objects to teaching-learning processes.

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