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**Fatma Karaismailoglu & Mehtap Yildirim**

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# The effect of 3D modeling performed using Tinkercad or concrete materials in the context of the flipped classroom on pre-service teachers' spatial abilities

Fatma Karaismailoglu [a,b] and Mehtap Yildirim [b]

[a]Department of Science Education, Mersin University Ciftlikkoy, Mersin, Turkey; [b]Department of Science Education, Marmara University Goztepe, Istanbul, Turkey

## ABSTRACT

**Background:** Spatial ability has an important place in science education, which is effective in raising future scientists. Although not in large numbers, studies show that teachers' spatial abilities somehow affect their teaching practices in the classroom and thus the spatial abilities of their students.
**Purpose:** This study aimed to investigate the effect of 3D modeling activities performed by preservice science teachers in the Biology course using Tinkercad or concrete materials in the context of the Flipped Classroom (FC) model on their spatial ability.
**Sample:** The participants of the study were fifty-seven preservice science teachers studying at a state university in Istanbul, Turkey.
**Design and methods:** The study was designed according to the explanatory sequential design. The Purdue Spatial Visualization Test was utilized to investigate the effect of the implementation on the participants' spatial abilities. In addition, semi-structured interviews were conducted with twenty-four participants to examine their experiences regarding the implementation.
**Conclusions:** The results of the study show that 3D modeling performed in the context of the FC model, regardless of Tinkercad or concrete materials are used, improves the spatial abilities of preservice teachers, as well as 3D modeling with Tinkercad, is a more effective implementation to develop spatial ability. While the participants' statements supported the quantitative results, they were toward that the classroom atmosphere they missed during the pandemic process was created by the FC model's in-class process and there was a significant improvement in their communication skills.

**KEYWORDS**
3D modeling; flipped classroom; pre-service teachers; science education; spatial ability

## Introduction

Due to the impact of the COVID–19 pandemic, face-to-face education was suspended around the World, online education was started accordingly the use of technology was emphasized. Although there are studies on distance education in the literature, the small number of them has led to the lack of sufficient knowledge and experience in this regard, and thus the disruptions in education. In this case, studies in which new learning models

**CONTACT** Fatma Karaismailoglu fkaraismailoglu@mersin.edu.tr Department of Science Education Faculty of Education, Mersin University Ciftlikkoy, Mersin 33343, Turkey

are tried and which one is good in what way are researched respect have gained importance.

One of the important learning models that have emerged recently and can be applied in this process is the Flipped Classroom (FC) model, in which technology is integrated into the learning process. FC is a learning model in which the content of a certain subject is shared by the teacher with the students through an electronic platform, during the outside of school hours and at a place the out-of-school, where the students learn the subject at a basic level, and then active learning activities on the same subject are carried out in the class with the presence of the teacher (Staker and Horn 2012). As can be understood from this definition, the FC model consists of two learning processes that follow each other: out-of-class process and in-class process.

In the FC out-of-class process, the student learns the subject at a basic level through the content shared on the online platform and makes preliminary preparations for the activities to be carried out in the classroom (McLaughlin et al. 2016). Thus, it is ensured that the student reaches the sub-cognitive levels of Bloom's taxonomy with web-assisted and individual learning in the out-of-class process (Arshad and Imran 2013). Furthermore, the transfer of students' subject learning outside the classroom increases the time allocated to active learning activities in the classroom (Bergmann and Sams 2012). In the FC model's in-class process, in parallel with the content shared in the out-of-class process, activities in which the students will actively participate are carried out under the teacher's guidance, enabling students to reach metacognitive levels (Arshad and Imran 2013). One of the methods that can be applied as an active learning activity in this process is modeling.

Modeling is an active learning activity that provides effective and permanent learning in terms of appealing to more than one sense of the learner, concretizing abstract facts, simplifying complex events, and giving the person first-hand experience (Harrison 2001; Haury 1989). Models not only allow students to visualize and test their thoughts, but also contribute to the development of their spatial abilities (Baki, Kosa, and Guven 2011).

Spatial ability is the ability of an individual to visualize objects in his mind to make arrangements on objects and create new visuals (Lohman 1996). It also enables individuals to organize and visualize information about the problems they face, to understand and interpret the relationship between them (Turgut and Yilmaz 2012).

It is known that many distinguished scientists showed schizothymic features such as dyslexia (Smith 1964). One of them, Einstein, who revolutionized physics, reached the results of his first scientific paper as a result of his famous thought experiment, imaging what he could observe while he running after a light beam in space at the same speed. He developed the theory of special relativity with the information he obtained from this thought experiment (Mehra 2001). This indicates that Einstein processed information in terms of images in his mind instead of words or numbers and that his success's reason is his high spatial ability (Smith 1964). At the same time, this situation shows that spatial ability has great significance in the process of doing science.

Spatial ability, which is an important part of the process of doing science, has an important place in being successful in different professions and courses and in high-level thinking (West 1991). For example, geologists reasons about the physical processes that lead to the formation of the structures that make up the Earth, such as continental drift, chemists study models of the structure of molecules, and doctors detect diseases using imaging devices such as MRIs. All this requires the use of the spatial ability. A study supporting this idea was performed by Wai, Lubinski, and Benbow (2009). Wai, Lubinski, and Benbow (2009), in their 11-year longitudinal study with high school students, showed that spatial ability has critical importance in terms of education and profession and showed that success in STEM fields increases depending on the development in spatial ability. Another study showed that STEM fields, except biology, have higher spatial ability scores than other fields (Hegarty et al. 2010). Looking at the biology's content, it is seen that the development of spatial ability has great importance to be successful in this discipline as well. For example, Watson (1993), in his book describing the discovery process of the structure of DNA, stated that according to the information he obtained, he constantly imagined the 3D model of DNA, such as how the DNA is folded, the sugar-phosphate skeleton, and base positions. This process, in which Watson and Crick make sense of the 2D picture, and discover the orientations of the bases in the structure of DNA, involves the use of the spatial ability to a large extent. Therefore, It can be concluded that their spatial abilities were also effective in the emergence of models they created.

Based on the previous explaining, it is understood that spatial ability has an important place in science education, which is effective in raising future scientists. Moreover, studies show that there is a positive relationship between science achievement and spatial ability (Bodner and McMillan 1986). Furthermore, Black (2005) stated that although studies were conducted to identify students with weak verbal or mathematical skills and to develop these skills, such an implementation was not carried out for spatial ability. She argues that this may cause students with weak spatial abilities to have difficulties in the subjects they learn at the middle and high school levels, and as a result, they may give up the idea of working in science-related disciplines. Lubinski (2010) called the spatial ability 'sleeping giant' and stated that although it is a very important skill, it is neglected in the education process. In addition, students with the potential to be very successful in the future, such as Einstein, may be eliminated by the system because the spatial ability is not taken into account, although they create an important talent pool. Upon this, Wai, Lubinski, and Benbow (2009) stated that educational opportunities should be structured accordingly.

When the studies on the development of spatial ability examined, it is seen that the activities that require hand and eye coordination such as modeling with concrete materials and modeling with computer software are effective in the development of these skills (Baki, Kosa, and Guven 2011). Generation Z constitutes today's learning individuals. Generation Z has been living within technology from the moment they were born. It is inevitable for these people to be technology savvy. Small and Vorgan (2008), as a result of their study, support the claims that people with high exposure to digital technology think and learn differently from other generations. Based on John Dewey (1944)'s words 'If we teach today as we taught yesterday we rob our children of tomorrow', it can be said that the developments in technology in today's society create a propulsive force in the world of education. In addition, the COVID–19 outbreak has led to accelerated the integration of technology into the learning process.

Although not in large numbers, studies show that teachers' spatial abilities somehow affect their teaching practices in the classroom and thus the spatial abilities of their students (Atit and Rocha 2021). Teachers' spatial abilities have been the focus of the research, as science teachers play a leading role in the development of students' spatial abilities as well as constructing their students' knowledge. In addition, the study aimed to examine the development of spatial ability, which is thought to have an important place in the understanding of molecular genetics (Richardson and Richardson 2002).

To this end, in this study, the effect of the 3D modeling activities performed by pre-service teachers in the biology course using Tinkercad or concrete materials in the context of the FC model on the pre-service teachers' spatial abilities and their views on the process were examined. Furthermore, the FC model's an example in the biology is presented, while it is also shown an example of how spatial ability can be developed in biology subjects with the implementation carried out. Hereunder, this study seeks answers to the following questions:

(1) Does 3D modeling using Tinkercad or concrete materials in the context of the FC model in biology course influence pre-service teachers' spatial abilities?
(2) How did the pre-service teachers evaluate their experiences during the process?

## Methodology

### *Research design*

This study was designed according to a sequential explanatory design (Figure 1). In the study's first stage, pretest-posttest comparison group design was used. In the study, two experimental groups were created to examine the effects of two types of modelings (using Tinkercad or concrete material) on the development of spatial ability. A control

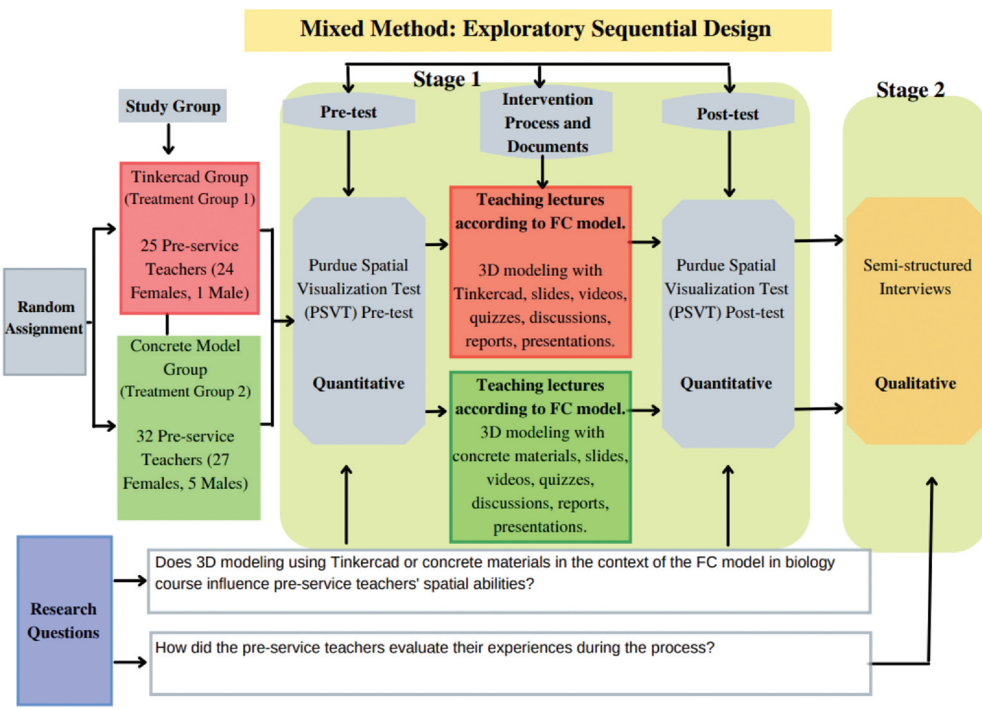


Figure 1. Diagram of the research model.

group was not created since regular classes that use direct instruction can not improve spatial ability (Olkun 2003).

In the second stage, semi-structured interviews were conducted to evaluate the participants' views on the process.

### *Study group*

The research was carried out in the 2020–2021 academic year, in a biology course on molecular genetics. For this reason, the participants of the study's quantitative dimension consists of 57 second-year pre-service science teachers from an education faculty in Istanbul, Turkey. Participants were randomly assigned to groups. Pre-service teachers whose school number's the last digit was odd number were assigned to the Experiment 1 (Tinkercad) group, pre-service teachers whose school number's the last digit was an even number were assigned to the Experiment 2 (Concrete Model) group. 24 females and 1 male in the Tinkercad group, 27 females and 5 males in the Concrete Model group participated in the study.

Individuals participating in the qualitative dimension of the study were determined by the maximum variation sampling method. The participants were ranked according to the scores they got from the tests made during the process and 12 participants from each group, four of which were low, four were medium, and four were high, and a total of 24 participants were selected.

### *Intervention process*

Due to COVID−19 pandemic, the implementation's in-class process was carried out synchronized with the video conferencing method. Thus, in-class process' teacher-guided active learning activities were carried out just as planned, and the interaction was ensured between student-student and student-teacher, which is a necessity of this process. Apart from this, every other FC component was implemented as it should be.

In addition to the implementation process consist of two stages, what is done in each stage explained in the following table (Table 1).

'Edmodo' was used as the electronic environment where individual learning would take place outside the classroom. Individual learning was ensured by sharing learning content such as videos and quizzes prepared by the researchers with pre-service teachers through Edmodo and by pre-service teachers completing the shared tasks such as watching videos. For each group, an virtual class was created in Edmodo for the course, and the pre-service teachers registered for that class. Researchers and pre-service teachers shared all kinds of content through the created virtual class. Tinkercad group's participants registered in the class created by the researchers also in Tinkercad and carried out their studies through the created class. Thus, the researchers were able to instantly follow which student made which model and how.

- Stage 1

In the first stage, the researchers gave separate training for both groups. Firstly, the researchers gave theoretical information to the Tinkercad group about how the process

Table 1. The intervention process.

| Stages | Weeks | Groups | Weekly Hours | | Process Applications |
|---|---|---|---|---|---|
| 1.Introduction, 3D modeling training | 1–2. | Tinkercad | 3 | Synchronous | • Meeting with the participants, giving information on the process.<br>• Training 3D modeling with Tinkercad. |
| | 2. | Concrete Model | 3 | Synchronous | • Meeting with the participants, giving information on the process.<br>• Training 3D modeling with concrete model. |
| 2. Teaching lectures according to the FC model | 3–8. | Tinkercad | 4 | Asynchronous/ Out-of-class | • Slides<br>• Videos<br>• Quizzes |
| | | | | Synchronous/ In-class | • Discussions<br>• 3D modelling with Tinkercad<br>• Presentations<br>• Reports |
| | | Concrete Model | 4 | Asynchronous/ Out-of-class | • Slides<br>• Videos<br>• Quizzes |
| | | | | Synchronous/ In-class | • Discussions<br>• 3D modelling with concrete materials<br>• Presentations<br>• Reports |

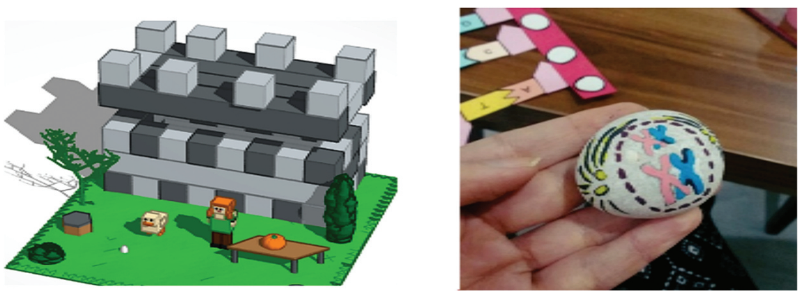

Figure 2. Examples of models created during the trainings.

would work, modeling and the features of the Tinkercad program via Zoom, and showed them how to create 3D models in the Tinkercad program through sample models. Since the training carried out synchronously via Zoom, pre-service teachers created 3D models at the same time with the researchers and had the opportunity to share them with each other. It was learned how to use the Tinkercad program at the end of the first week of the training. In the second week, the skills of pre-service teachers to create complex models in Tinkercad were developed. Similar training was given for the Concrete Model group (Figure 2).

● Stage 2

In the following weeks, the lectures were taught according to the FC model in both groups. In the out-of-class process of FC, the researchers first presented the slides they prepared on the subject to be learned that week on the university's online platform and shared them electronically as a video so that the students could watch them later. Pre-service teachers learned the subject at the basic level asynchronously by watching the videos. Later, the researchers shared the quizzes they prepared on 'Google Forms' with pre-service teachers on Edmodo and asked them to solve the quizzes and submit them until at the end of in-class process. Thus, it was checked whether the pre-service teachers watched the shared videos and whether they prepared for the in-class process. In addition, the quizzes enabled the detection of incomplete or incorrect learning of pre-service teachers, if any. The part thus far constitutes the out-of-class process. The in-class process, which is the following process of the out-of-class was carried out synchronously via the Zoom video conference system. At the beginning of the lesson, the pre-service teachers held an average of half an hour discussions over the quiz question-answers. Thus, pre-service teachers' misconceptions were eliminated, if any. After the discussion, the Tinkercad group using Tinkercad, and the Concrete Model group using concrete materials, created 3D models related to that week's subject. Afterward, pre-service teachers reported on the models they made, and throughout this process, each pre-service teacher made a presentation on their models in line with the reports they prepared, at least once.

During the implementation process, a total of 13 models on molecular genetics were created. Below, samples of tinkercad and concrete model examples made by pre-service teachers are presented between Figures 3–8.

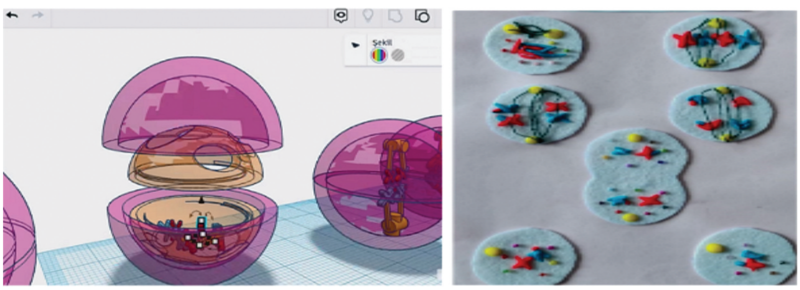

**Figure 3.** Examples of Meiosis models.

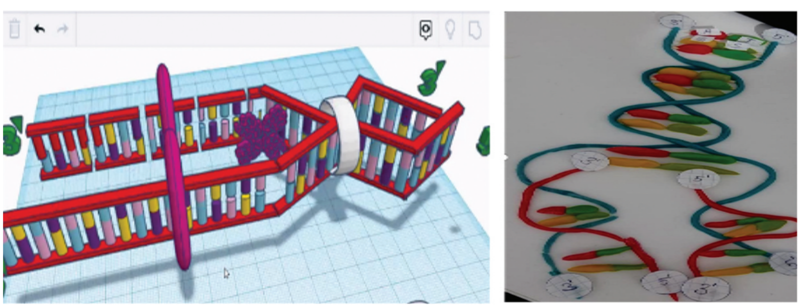

**Figure 4.** Examples of DNA replication models.

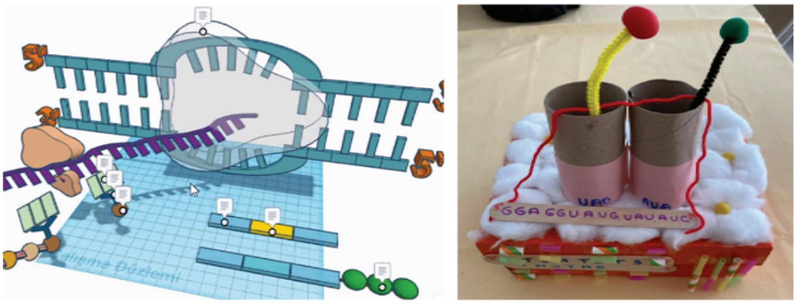

Figure 5. Examples of protein synthesis models.

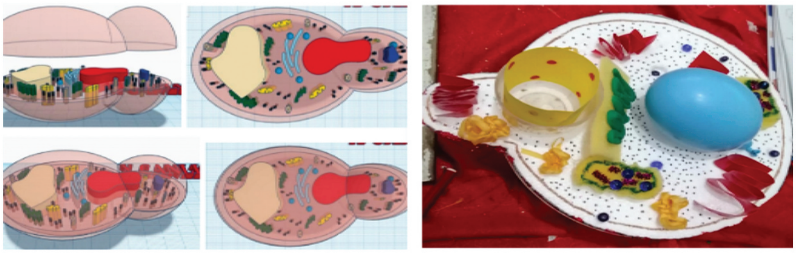

Figure 6. Examples of living models derived from mutation (On an example DNA sequence).

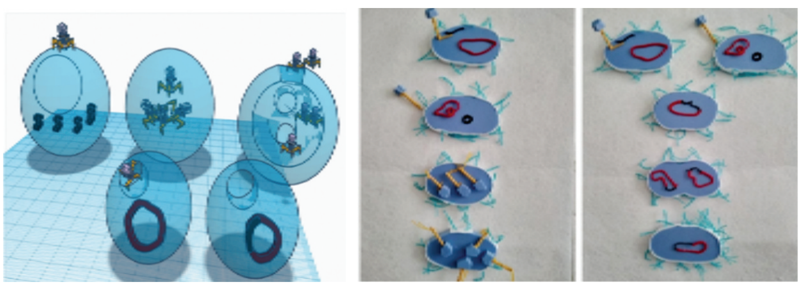

Figure 7. Examples of viral life cycle models.

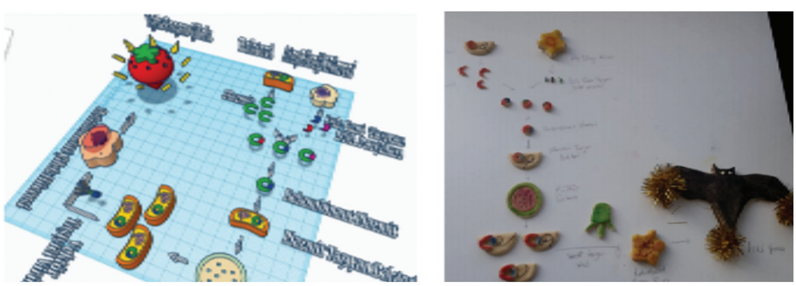

Figure 8. Examples of the generation of transgenic organism models.

### Data collection tools

At the beginning and end of the study, Purdue Spatial Visualization Test developed by Bodner and Guay (1997) and adapted into Turkish by Sevimli (2009) was used to measure changes in participants' spatial abilities. The reliability coefficient of the original test was 0.90, and the value of the adapted version was calculated as 0.84. The reason for choosing this test was that it was designed to measure participants' spatial skills in different ways, and it measures them with high reliability. In addition, semi-structured interviews were conducted with 24 participants to analyze their experiences about the implementation process with the interview form created by the researchers in line with the opinions of two experts. Before the interview, the participants were informed about the study, they were asked for permission by stating that audio and video recordings would be taken during the interview, but the data obtained as a result of the interview would be confidential and limited to this study. It was also guaranteed by the researchers that their identities would remain confidential. Afterward, interviews were held by video conference method and audio, video recorded with the permission of the participants. Each interview lasted approximately 40 minutes.

### Data analysis

Dependent samples *t*-test, independent samples *t*-test and ANCOVA analysis were applied to provide a comparison between the groups and within groups by using the mean scores obtained by pre-service teachers before and after the implementation. In addition, the Cohen *d* effect size value was calculated in case of a significant difference in the test results.

Content analysis was used in the analysis of the data obtained from the interviews. As a result of the analysis, the codes were grouped under four themes, and they are presented in tables.

## Results

### Results regarding the effect of 3D modelling performed using Tinkercad and concrete materials on spatial ability in the context of Fc

As a result of the normality test performed on the data ($p > 0.05$), it was determined that the data were eligible for the use of parametric tests. Therefore, in this section, the findings obtained as a result of comparing the results of the PSVT applied to the pre-service teachers before and after the implementation with the dependent samples *t*-test, and ANCOVA are contained.

### Results regarding comparison of groups' purdue spatial visualization test pre-and post-test means

The dependent samples *t*-test results regarding the PSVT, which measures groups' spatial abilities regarding before and after the implementation are presented (Table 2)

The *t*-test results (Table 2) indicated a statistically significant difference between the pre- and post-test mean scores of the Tinkercad group, with $t(24) = -6.02$, $p < 0.05$. When the Cohen *d* ($d = -1,20$) effect size value calculated as a result of the *t*-test analysis was

**Table 2.** Dependent samples T-test Results of the Purdue Spatial Visualization Test.

| Groups | Purdue Spatial Visualization Test | *N* | Mean | *T* | SD | *P* |
|---|---|---|---|---|---|---|
| Tinkercad | *PSVT pre-test* | 25 | 16.28 | −6.02 | 24 | 0.00 |
| | *PSVT post-test* | 25 | 23.56 | | | |
| Concrete Model | *PSVT pre-test* | 32 | 12.71 | −5.13 | 31 | 0.00 |
| | *PSVT post-test* | 32 | 17.78 | | | |

**Table 3.** Groups' adjusted post-test means for the purdue spatial visualization pre-test.

| Groups | *N* | Mean | Adjusted Mean |
|---|---|---|---|
| Tinkercad | 25 | 23.56 | 22.15 |
| Concrete Model | 32 | 17.78 | 18.88 |

**Table 4.** ANCOVA results regarding adjusted post-test means for groups' pre-test means.

| Source | Sum of Squares | SD | Mean Square | *F* | *p* | Partial Eta Squared |
|---|---|---|---|---|---|---|
| PSVT pre-test | 798.56 | 1 | 798.56 | 25.35 | .00 | .32 |
| Group | 135.44 | 1 | 135.44 | 4.30 | .04 | .07 |
| Error | 1701.07 | 54 | 31.50 | | | |
| Total (Corrected) | 2968.32 | 57 | | | | |

examined, it is understood that this difference is very large. Similarly, was reached that the Concrete Model group's difference between the pre- and post-test mean scores was significant in favor of the post-test, with $t(31) = -5.13$, $p < 0.05$. The Cohen's $d$ ($d = -0.91$) effect size value indicates that this difference is very large. These results demonstrate that 3D modeling using Tinkercad or concrete material in biology lectures has a significant effect on spatial ability.

## *Results regarding comparison of groups' purdue spatial visualization test post-test means*

Since found a statistically significant difference between the pre-test results of the groups, ANCOVA analysis was performed, after determining that the homogeneity of the variances ($p > 0.05$), the homogeneity of the regression slopes ($p > 0.05$), and the linearity assumptions between the variables were met. The ANCOVA analysis results which were conducted to test the significance of the difference between the adjusted post-test means of the groups (Table 3) are presented in Table 4.

As seen in Table 3, the difference between the adjusted post-test mean scores of the Tinkercad group and the Concrete Model group was 3.27 and was found this difference was statistically significant in favor of the Tinkercad group, with $F(1–57) = 4.30$, $p < 0.05$ (Table 4). The partial eta squared value indicates that the effect size of the groups on the post-test is medium ($\eta 2 = 0.07$). These results demonstrate that 3D modeling with Tinkercad is significantly more effective in improving spatial ability than concrete materials.

## *Interviews*

The collecting data from the interviews with the 24 participants were coded under four themes. To keep the identities of the participants confidential, pre-service teachers' names were coded based on their groups with numbers 1–12 such as T1, and CM1.

## Contribution of out-of-class process and activities on learning

The theme and related codes created based on the answers given by the participants to the questions under the title of 'Out-of-Class Process' in the interview form are shown in Table 5.

As seen in Table 5, eleven (91.7%) participants from both groups stated that out-of-class processes and activities have made their learning permanent. For example, CM2 stated that she recalled the subjects she learned during the implementation process by repeating them only once.

Receiving answers from the participants were examined, it was concluded that eleven of them thought that reinforcing the subject using various activities was an important factor in permanent learning. For example, T3 stated that the quizzes shared during the out-of-class process helped to reinforce the subject and that she comprehended the parts that she did not comprehend before during the quiz answering process. Another participant, T5 pointed out the contribution of being able to repeat the contents shared out-of-class whenever and as much as they want on their learning.

T4 drew attention that the quizzes referred them to research to detect and correct their incomplete information as follows:

> You created the content of the quiz questions in a way that will allow us to summarize the subject. You generally asked us to explain, not to give short answers. Therefore, we have already tried to give sufficiently detailed answers to the questions there. We researched where we lacked in answering the question, and we completed them. So we learned better. (T4)

Many of the participants stated that in terms of aspects the length of content, etc. was sufficient content shared in the out-of-class process, and that these contents were effective to summarize the subject, learn easier and, understand better.

**Table 5.** Contribution of out-of-class process and activities on learning.

| | | Pre-service Teachers | | | |
|---|---|---|---|---|---|
| | | Tinkercad Group | | Concrete Model Group | |
| Theme | Categories and Codes | f | % | f | % |
| | Impact on Learning Style | | | | |
| Contribution of out-of-class process and activities on learning | Permanent learning | 11 | 91.7 | 11 | 91.7 |
| | Learning with Fun | 4 | 33.3 | 2 | 16.7 |
| | Easier Learning | 8 | 66.7 | 7 | 58.3 |
| | Individual Learning | 1 | 8.3 | 0 | 0 |
| | Skills Gained in the Process | | | | |
| | Referral to Research | 11 | 91.7 | 9 | 75.0 |
| | Systematic Study | 4 | 33.3 | 2 | 16.7 |
| | Providing Learning Support | | | | |
| | Opportunity to Unlimited Repetition/Ability to Replay and Pause | 6 | 50.0 | 3 | 25.0 |
| | Detecting and Correcting Incomplete Information | 4 | 33.3 | 7 | 58.3 |
| | Reinforcement | 7 | 58.3 | 4 | 33.3 |
| | Preliminary to the Lesson | 1 | 8.3 | 3 | 25.0 |
| | Reducing Cognitive Load | 0 | 0 | 2 | 16.7 |
| | Impact on Content | | | | |
| | Substantial Content | 5 | 41.7 | 3 | 25.0 |
| | Content in Sufficient Length | 4 | 33.3 | 6 | 50.0 |

Note: $N_{Tinkercad} = 12$, $N_{ConcreteModel} = 12$.

## *Advantages of in-class process and 3D modeling*

The categories and codes created from the answers given by the participants to the questions about in-class process and 3D modeling are shown in Table 6.

As seen in Table 6, a total of twenty-one participants, eleven (91.7%) from the Tinkercad group and ten (83.3%) from the Concrete Model group, stated that the in-class process and 3D modeling ensure permanent learning. For example, T2 stated the effect of in-class process and 3D modeling on permanent learning by concretizing the subject as follows:

> So, for example, you know meiosis by heart, but it does not come to your mind... Concepts are always in your mind, but for example, nothing comes to your mind, or when said DNA replication, maybe before that period, I could not think of anything clear, but now I think of something that opens like a zipper. Because we knitted them loop by loop, we placed them one by one . . . on my mind now . . . (T2)

**Table 6.** Advantages of In-class Process and 3D Modeling.

| | | Pre-service Teachers | | | |
|---|---|---|---|---|---|
| | | Tinkercad Group | | Concrete Model Group | |
| Theme | Categories and Codes | F | % | F | % |
| Advantages of in-class process and 3D modeling | Impact on Learning Style | | | | |
| | Permanent learning | 11 | 91.7 | 10 | 83.3 |
| | Learning with Fun | 7 | 58.3 | 2 | 16.7 |
| | Easier Learning | 8 | 66.7 | 8 | 66.7 |
| | Addressing Various Learning Styles | 5 | 41.7 | 2 | 16.7 |
| | Skills Gained in the Process | | | | |
| | Questioning | 1 | 8.3 | 3 | 25.0 |
| | Concretization | 10 | 83.3 | 11 | 91.7 |
| | Creativity Development | 3 | 25.0 | 6 | 50.0 |
| | Developing Spatial Ability | 9 | 75.0 | 6 | 50.0 |
| | Learning To Use Tinkercad | 11 | 91.7 | 0 | 0 |
| | Tinkercad Ease of Use | 9 | 75.0 | 0 | 0 |
| | Improving Dexterity | 0 | 0 | 4 | 33.3 |
| | Considering Everything as Material | 0 | 0 | 4 | 33.3 |
| | Increased Communication | 12 | 100.0 | 12 | 100.0 |
| | Increased Responsibility for Learning | 6 | 50.0 | 1 | 8.3 |
| | Providing Learning Support | | | | |
| | Detecting and Correcting Incomplete Information | 10 | 83.3 | 11 | 91.7 |
| | Seeing Others' Perspectives | 3 | 25.0 | 3 | 25.0 |
| | Reinforcement | 4 | 33.3 | 6 | 50.0 |
| | Integrating into Other Courses | 5 | 41.7 | 1 | 8.3 |
| | Increasing Classroom Participation | 1 | 8.3 | 1 | 8.3 |
| | Impact on the Affective Field | | | | |
| | Motivating | 3 | 25.0 | 2 | 16.7 |
| | Interesting | 2 | 16.7 | 3 | 25.0 |
| | Valuing | 0 | 0 | 1 | 8.3 |
| | Positive Attitude Development | 5 | 41.7 | 7 | 58.3 |
| | Understanding the Importance of Material Selection | 0 | 0 | 1 | 8.3 |
| | Raising Awareness | 0 | 0 | 3 | 25.0 |
| | Impact on Content | | | | |
| | Substantial and Useful Content | 3 | 25.0 | 0 | 0 |
| | Active Learning Activities | 3 | 25.0 | 4 | 33.3 |

Note: $N_{Tinkercad} = 12$, $N_{ConcreteModel} = 12$.

As a result of the interviews, nine participants from both groups stated that they learned by having fun. For example, T9 pointed out that she developed a positive attitude toward the lesson.

A total of twenty-one participants pointed out the fact that they detected and corrected incomplete or incorrect information with the in-class process and 3D modeling, while seven participants stated that various learning styles were addressed in this process.

As seen in Table 6, 91.7% of the Tinkercad group stated that one of the most important contributions of this process is learning to use the Tinkercad program. For example, T7 emphasized that they can model anything they want in Tinkercad as they do in their minds, nine participants emphasized that Tinkercad is a program that everyone can easily use, and T4 Tinkercad contributes to their learning by both having fun and simplifying it. Another participant, T1 stated that she could make a 3D model using only a computer and the internet.

Also, CM5 from the Concrete Model group pointed out the importance of material selection in concrete modeling, CM1 pointed out that her dexterity developed, she developed a positive attitude towards modeling, and she considered everything as a material over time. Similarly, CM4 stated that she views everything around her as material:

> . . . While I was walking, I was thinking like 'Oh, I can use this as a material', here we have really come to such a level. (CM4)

Participants stated that their creativity also improved in this process. While the participants in the Tinkercad group expressed this through the modeling processes and the model they created in Tinkercad, those in the Concrete Model group mentioned that their creativity improved on material selection.

In order to determine which modeling is more advantageous, the participants were asked which group they would prefer to be in if they had the chance to participate in this implementation again. All of the Tinkercad group (100%) said they would like to be in the Tinkercad group again. Eight of the participants in the Concrete Model group stated that they wanted to be in the Concrete Model group again, others said that the Tinkercad group attracted their attention. For example, T12 stated that Tinkercad is better in terms of 3D thinking, imagining, and working. On the other hand, for example, CM2 mentioned that his dexterity was not good and stated that he would prefer Tinkercad if he had the chance to choose a group again.

As shown in Table 6, all participants stated that their communication developed during this process. For example, CM7 emphasized that the classroom atmosphere they missed during the pandemic process was created in this process. Also, one of the participants, T11 uttered her satisfaction with the rapid feedback from the researchers:

> . . . I mean, sometimes you even replied to my e-mail within three minutes. I was shocked how. It is definitely nice to be able to communicate in this way, and it is really nice to be able to communicate with my other friends as well. It is absolutely also great to be able to hear our voices, especially during this distance learning period . . . (T11)

## Disadvantages of in-class process and 3D modeling

The codes that emerged as a result of the interviews with the participants were presented under the theme of 'Disadvantages of In-Class Process and 3D Modeling' in Table 7.

As seen in Table 7, six participants from the Tinkercad group mentioned that the in-class process did not have any disadvantages. While T4 from the other members of the group saw the lack of time as a disadvantage while modeling, T9 and T7 stated that the process's disadvantage was that the modeling took too much time. Eight participants from the Concrete Model group mentioned that modeling takes too much time.

T6 and T9 from the participants uttered increased learning responsibility as the process's disadvantage. Two participants of the Concrete Model group expressed that they had problems due to their availability of the home.

The most common problem regarding the concrete modeling process is the supplying materials, which 58.3% of the group mentioned. Three participants of the Concrete Model group explained that since the modeled phenomena and events are abstract, thinking about how accurately they can do it while concreting them made the process difficult. Two participants also uttered that they sometimes had difficulties in terms of prolonging the time of creating a model from the materials they chose or being insufficient in producing the model they wanted.

## Contribution of 3D modeling using Tinkercad and concrete material to spatial ability

The codes created in line with the answers given to the questions about the effect of the implementation on the spatial abilities of the participants and the test measuring their spatial abilities are presented in Table 8.

As seen in Table 8, twenty-one participants stated that they gained speed in 3D thinking and implementing with 3D modeling. For example, T9 stated that she improved in using the Tinkercad program and accelerating in 3D modeling as follows:

> At first, rotation, etc. I was never able to. I was constantly remaking them one by one, but then it got very simple… I combined different shapes and made much more complex and beautiful models. In other words, I think that I have both accelerated and become more professional. I think that the development of my three-dimensional thinking skills affect this. (T9)

**Table 7.** Disadvantages of in-class process and 3D modeling.

| | | Pre-service Teachers | | | |
|---|---|---|---|---|---|
| | | Tinkercad Group | | Concrete Model Group | |
| Theme | Categories and Codes | F | % | f | % |
| Disadvantages of in-class process and 3D modeling | No | 6 | 50.0 | 0 | 0 |
| | Time | | | | |
| | Limited Time | 1 | 8.3 | 1 | 8.3 |
| | Time Consuming | 2 | 16.7 | 8 | 66.7 |
| | Implementation Intensity | | | | |
| | Increased Responsibility for Learning | 2 | 16.7 | 0 | 0 |
| | Home Availability | 0 | 0 | 2 | 16.7 |
| | Concrete Modeling Process | | | | |
| | Concretizing the Abstract | 0 | 0 | 3 | 25.0 |
| | Dexterity | 0 | 0 | 1 | 8.3 |
| | Supplying Material | 0 | 0 | 7 | 58.3 |
| | Selecting Material | 0 | 0 | 2 | 16.7 |

Note: $N_{Tinkercad} = 12$, $N_{ConcreteModel} = 12$.

**Table 8.** Contribution of 3D modeling using Tinkercad and concrete material to spatial ability.

| | | Pre-service Teachers | | | |
|---|---|---|---|---|---|
| | | Tinkercad group | | Concrete Model group | |
| Theme | Codes | F | % | f | % |
| Contribution of 3D modeling using Tinkercad and concrete material to spatial ability | Accelerating 3D Thinking and Implementing | 9 | 75.0 | 12 | 100.0 |
| | Noticing Spatial Ability Development in Daily Life | 5 | 41.7 | 6 | 50.0 |
| | Accelerating in 3D Modeling | 5 | 41.7 | 1 | 8.3 |
| | Solving the PSVT Easier and Faster | 9 | 75.0 | 7 | 58.3 |
| | Improving in Using Tinkercad | 6 | 50.0 | 0 | 0 |
| | Developing a Different Perspective to the Environment | 2 | 16.7 | 1 | 8.3 |
| | Changing Strategy While Solving the PSVT | 1 | 8.3 | 0 | 0 |
| | Making More and More 3D Models | 0 | 0 | 4 | 25.0 |

Note: $N_{Tinkercad} = 12$, $N_{ConcreteModel} = 12$.

Although all of the participants had a hard time at first, sixteen participants noticed that they accelerated in the second solution of the PSVT as T4 stated:

> At first, I just did it by trusting my own inner voice . . . I could not build it in my head, but after making this modeling, we worked in Tinkercad in three dimensions, and we realized some things. That is why I solved it by saying that 'if this is the case, I think it should definitely be like this'. I solved it more consciously and faster . . . It really made me realize before and after the implementation. (T4)

When the participants were asked whether there was a difference in their spatial abilities when they looked at their daily life, eleven participants explained that they felt the difference through examples.

> For example, yesterday I used Google Maps. I can go much better than before, I never understood before . . . I mean, I have seen that my spatial ability has improved by experiencing it in my daily life. (CM6)

## Discussion and conclusion

The results of the study revealed that 3D modeling performed in the context of the FC model, regardless of the using Tinkercad or concrete materials, improved the pre-service teachers' spatial abilities. For example, Waller, Hunt, and Knapp (1998) argued that virtual environments have the potential to be an effective learning environment for the spatial ability's development, in their study examining the transferability of spatial knowledge acquired through virtual environment applications to real life. In this study, there was a significant increase in the spatial ability means of the Tinkercad group at the end of the implementation compared to before implementation, which supports Waller et al. The same is true for the concrete model (Olkun 2003). In the current study, the significant development in the spatial abilities of the participants and the large calculated effect sizes reveal the effectiveness of the implementation process. Also, studies show that computer software develops spatial ability more than the use of concrete materials (Baki, Kosa, and

Guven 2011). Similarly, the results of this study show that the difference between the adjusted post-test mean scores of the groups is significant in favor of the Tinkercad group. These results show that 3D modeling with Tinkercad is a more effective implementation to develop spatial ability. While the participants' statements supported the quantitative results, they were toward that they realized their spatial abilities had improved in their daily lives.

Individuals can begin to apply, analyze and synthesize by examining abstract data in a visual context like the letters in DNA sequences that represent nucleotides-proteins. Visual and spatial abilities are used in the process of making sense of the given 3D visuals and modeling phenomena and events in 3D. Based on this, it can be said that spatial ability is embedded in the learning process of genetics and genetics has a spatial language. Making the models themselves allows students to use their different senses. While this situation causes more than one area of the student's brain to be stimulated, it enables them to learn by doing and living (Haury 1989). Moreover, as the participants stated, 3D modeling supports more easy and permanent learning than other learning activities in terms of concretizing abstract subjects, making sense of which part they put in their models for what and the relationship of each part to each other, etc. in the process of creating the model. Therefore, this process made the participants aware of their incomplete information and engaged the participants to question more and referred them to research. When the literature examined, it is seen that ready-made animations and simulations can be used to embody the subjects (Unal, Okur, and Kapucu 2010). Unlike these, modeling can enable the student to reach metacognitive levels and improve spatial ability better.

During interviews, we observed that one of the positive effects of this process was that the participants developed dexterity and, 3D modeling was the most enjoyable application of the implementation process for participants. The participants' difficulties in supplying materials during the implementation process also constituted the challenge of the process. This situation is thought to be caused by the curfew during the COVID–19 pandemic. Indeed, during the interviews, the participants emphasized that they could have made much better models if the implementation process did not take place during the pandemic. On the other hand, some participants evaluated this situation differently and started to consider everything as material.

In order to determine which modeling is more advantageous for the participants, the question was asked during the interviews which group they would prefer to be in, if they had the chance to choose. Most of the participants' answer was 'Tinkercad'. While people make 3D models using concrete materials, they create their models by combining certain materials from certain aspects. The 3D modeling process with Tinkercad is more complex than that. There are basic shapes in Tinkercad. Users create and combine different shapes by making various arrangements over basic shapes. With the manipulation of these, they create models with complex structures. While creating concrete models, individuals rotate and position the concrete materials they take in their hands very quickly and without thinking (Gutiérrez 1996). Contrary to concrete modeling, in Tinkercad, individuals have to rotate the shapes that bring their models together in the required direction and angles in the x, y, and z planes, and size and place the shape they rotate in a way that fits the other parts of the model in all three planes. They need to consider coordinates in the modeling process and using coordinate spatial relations is more complicated (Lopez, Postma, and

Bosco 2020). During the implementation process, the participants in the Tinkercad group stated that they had difficulties in the beginning, but they mastered it over time. Therefore, it is not surprising that the Tinkercad group's spatial ability has increased further compared to the Concrete Model group. As a matter of fact, the participants in the Tinkercad group stated that they felt that they were working more in three dimensions in this process. Participants also stated that they modeled in Tinkercad in a shorter time and easier than concrete modeling. Because the problems such as the selection of suitable materials for the model and the supplying materials have been eliminated. Especially in the pandemic or distance education process, Computer-aided modeling can come to the fore in eliminating the difficulties encountered in 3D modeling with concrete materials. Thus, we can integrate the technology that attracts the attention of today's learners into the learning process.

Based on our experience, we think that Tinkercad, which was used differently from the others in this study, is an effective tool that can be used to develop spatial abilities similar to those used in other studies. In addition, we think that Tinkercad is an easy-to-use tool that can be used from higher education level to primary education level, as it allows the group to work on the same model remotely and to create models similar to those in people's minds as participants stated. Moreover, It is possible for users to do all of them by using only a computer and the internet. In this process, they only need skills such as spatial ability and imagination.

Based on the above results, It is understood that the learning process of the FC model is very different from the learning process of conventional learning. 'Why should we apply the FC model?' The question may come to mind. In fact, researchers have shown 'more efficient use of the class time spent by the teacher and the student', which is an answer to this question, by supporting them with their studies (Baepler, Walker, and Driessen 2014). In the conducted study learning the subject at a basic level outside of class and carrying out more challenging active learning activities in the classroom with the teacher supported that the participants learned more easily in this process. Participants were constantly exposed to biology during the FC implementation process. It encouraged the systematic study of the participants. On the other hand, it required them to spend a long time on the implementation process. This caused participants to respond during the interviews as 'increased learning responsibility' as both the most favorite and least favorite aspects of the FC model. Also, the participants stated that it is a process in which each of them finds themselves in a different activity and that even those who did not have a positive attitude towards biology before the implementation learns by having fun. Also, As Cevikbas and Kaiser (2021) stated, the FC model encourages students to engage to the lesson. A striking result of the study was that the classroom atmosphere of the participants, which they missed during the pandemic process, was created by the FC model's in-class process and there was a significant improvement in their communication. This situation shows that the practice is a compensation for face-to-face education in the pandemic. As a matter of fact, the opinions of the participants are in the same direction.

As a result of our observations and the participants' statements during the implementation, we think that the FC model's implementation is efficient. In this direction, necessary teacher training should be given on the characteristics and management of the implementation process, and it's implementation should be encouraged. This would be an alternative learning model that teachers can apply, including during the pandemic process.

This study shows that spatial ability has a substantial place in science education. Although more studies are needed on this subject, these findings are significant in that the implementation shows how spatial ability can be developed in biology, the effect of 3D modeling on learning abstract subjects like molecular genetics and presents an example of the FC model in biology. If a similar study is conducted, we suggest examining the participants' creativity. Because the statements of the participants were that their creativity improved during the 3D modeling process. Furthermore, developing teachers' spatial abilities will also affect their students' learning lives (Otumfuor and Carr 2017) and, in this regard, their future professions.

## Limitations and further reseach

This study has some limitations as well as the benefits it provides. Firstly, this study was carried out with a limited number of participants. Future studies need to be performed with larger samples. Increasing the sample size and representativeness may provide more reliable support for the findings.

Secondly, semi-structured interviews were conducted with only 24 participants to explore students' experiences during the implementation process. Also, only the Purdue Spatial Visualization Test was used in the study to evaluate the participants' spatial abilities improvement. Additional qualitative and quantitative data can be collected to fully reveal students' perceptions of the teaching approach and the development of their spatial abilities. Furthermore, the inclusion of other measurement tools in the assessment to comprehensively assess students' spatial abilities may better support the results.

Thirdly, while the study supports the emerging educational approach in science and math education, more research is needed to determine whether this teaching strategy is suitable for students from different disciplines and age groups. Therefore, future interdisciplinary research is recommended to better understand the effectiveness and applicability of this teaching method.

Finally, the teachers' spatial abilities can give an idea about their ability to carry out implementations that improve their students' spatial abilities. Further research can investigate whether the variation in teachers' spatial abilities has an effect on the development of their students' spatial abilities.

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## ORCID

Fatma Karaismailoglu http://orcid.org/0000-0002-6478-7952
Mehtap Yildirim http://orcid.org/0000-0001-7398-8396

## Ethical approval

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## Consent to participate

Informed consent was obtained from the participants.

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