



A STEM-Driven 3D Modeling Experiment with Tinkercad and Tangible Materials: A Comparison of TPACK and Engineering Design in Terms of Self-Efficacy

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Abstract

The aim of this study was to explore the impact of models individually prepared by preservice teachers for the topic of solar and lunar eclipses on their STEM-technological pedagogical content knowledge self-efficacy and their perception of self-efficacy in engineering design skills. In this context, our exploration was carried out in 2×2 factorial experimental design with 31 preservice science teachers in their last year of training. Accordingly, 16 preservice teachers were assigned to a modeling group that would use tangible materials and 15 preservice teachers to a group that would use Tinkercad. Data for the study were collected in the form of a pre- and posttest with the STEM-Technological Pedagogical Content Knowledge (STEM-TPACK) Self-Efficacy Scale and the Engineering Design Skills Self-Efficacy Perception Scale. The data were analyzed with the ANOVA test for two-way mixed measures. Our findings revealed a significant difference in the participants' STEM-TPACK self-efficacy in favor of the Tinkercad group. On the other hand, no significant difference was found in the perception of self-efficacy between the two groups in terms of engineering design skills. Our conclusion was that while the preservice teachers' perception of self-efficacy in engineering design skills could be improved with the help of both digital and tangible materials, it was important to note that their self-efficacy with respect to technological pedagogical content knowledge needed to be bolstered with updated programs.

Keywords Science education · Models · Design · Preservice teachers

Introduction

STEM (science-technology-engineering-mathematics) education has become one of the most important concepts to draw wide interest in science education (Gao et al., 2020; Montgomery & Fernández-Cárdenas, 2018). STEM is based on an approach to solving real-life problems by

constructing a framework integrating science, technology, engineering and mathematics (Jamali et al., 2023). The goal of STEM activities is to provide students with the opportunity to create designs and carry out experiments, experience various processes, and develop the skills needed to collect, interpret and analyze data, at the same time forming associations with scientific knowledge and acquiring the competencies of thinking and working like a scientist (Hiđde & Aktamış, 2022). In the STEM approach, students create products using engineering design. These products can be modeled using both physical materials and digital programs like Tinkercad. In this context, there are many concepts that can be modeled in science education. The atom, DNA, and the cell are examples of such concepts. Additionally, astronomy concepts can be modeled with physical materials or the Tinkercad program. Indeed, the solar system, the Milky Way galaxy, and solar and lunar eclipses are all suitable subjects for modeling within the scope of astronomy. On the other hand, studies have mostly concentrated on the areas

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of science and mathematics in STEM education (Ching et al., 2025; Hourigan et al., 2022; Ortiz-Revilla et al., 2022) while the steps involving engineering and technology have been given less attention (Ching et al., 2025; Giffney & Lane, 2025; Ortiz-Revilla et al., 2022). This might result from the fact that science and mathematics are fundamental components of the science education curriculum (Moore & Smith, 2014; English, 2016). However, creating models for engineering and design applications makes up a significant part of STEM (Hallström et al., 2023; Hallström & Schönborn, 2019). It may therefore be said that teachers have more self-efficacy in teaching the disciplines of science and mathematics thanks to their training. On the other hand, engineering and technology are disciplines that have only recently been added to programs and for this reason occupy less space in the programs. Consequently, the fact that the integration of engineering and technology is lagging can be associated with science teachers' lack of sufficient knowledge of engineering design in the context of STEM (Aydin-Günbatar et al., 2025; Brink et al., 2022; Radloff & Capobianco, 2021). In addition to these factors, teachers might have difficulty in learning and applying digital technologies in digital modeling (Koehler & Mishra, 2005). Due to all of the above, teachers tend to neglect technology and engineering applications as compared to the other two disciplines of STEM education. As a result, while science and mathematics teaching programs continue to demand attention in terms of requirements and evaluation processes, various difficulties are still being encountered in applications and evaluations in the fields of technology and engineering. It is important, however, to effectively use all four STEM steps in the teaching process if STEM education is to achieve maximum impact (Forde et al., 2023; National Research Council [NRC], 2011).

As discussed above, STEM education requires the effective teaching of all four disciplines and therefore sufficient attention should also be paid to engineering design processes. Engineering encompasses the design process by integrating science, mathematics, and technology. It operates within certain limitations to solve problems and meet specific needs (Fan et al., 2021). Fan and Yu (2017) have stated that the process of engineering design critically depends on the higher thinking skills leading to problem analysis, finding ways of arriving at solutions, and optimization. Researchers have reported in studies that the integration of engineering design processes into STEM education is an effective method of giving students the opportunity to more thoroughly understand problems in the real world (Dominguez et al., 2024; Hallström & Ankiwicz, 2023; Sung & Kelley, 2022; Xi et al., 2024). There are various steps involved in the engineering design process (Hynes, 2012; Lie et al., 2021; Mesutoglu & Baran, 2020; Wendell

et al., 2019). Most of the steps that are currently a part of the engineering design process, however, begin with an identification of the problem and continue by developing designs and prototypes that lead to the best solution. In this respect, it would not be wrong to say that modeling is an important and inevitable part of the process of engineering design. Teachers of STEM-oriented classes are expected to teach their students STEM concepts and skills with the help of 3D (three-dimensional) modeling and computer-assisted design (CAD) (Douglass & Verma, 2022; Sungur Gül & Ateş, 2023; White & Newby, 2024). A goal of preservice teacher education in this context should be to provide preservice teachers with the competencies needed in using technology in STEM-driven courses. While there are many CAD applications available for use in STEM education, Tinkercad is the application that we used in this study.

Tinkercad is known to be especially useful and effective in creating abstract models and teaching abstract concepts (Barbosa et al., 2024). Also, CAD applications are efficacious in aiding preservice teachers to develop various competencies with respect to their knowledge of technological pedagogical content (TPACK) (Wan & Ivy, 2021). Teacher education programs stress the importance of keeping up with developing technologies and developing the competence to use technology. The need to enable preservice teachers with the skills to integrate technology into their teaching and develop their competence with regard to TPACK must not be dismissed (Chai, 2019). It must also be accepted that they need these same skills for STEM education. This is of particular importance in teaching astronomy since the use of technology is considerably prevalent in teaching this course. Teachers must therefore have the needed skills for this competence.

Concepts in astronomy include applications in modeling, simulation and problem-solving; they lend themselves with ease to the use of technology and integration with engineering design (Plummer & Maynard, 2014). However, studies have indicated that understanding concepts in astronomy is among the leading challenges that students face (Hiçde & Aktamiş, 2022; Salimpour et al., 2023; Trumper, 2003, 2006). Indeed, students have difficulty forming their own ideas about phenomena such as *eclipses* that they may observe in daily life but they may not know why these events occur. The effectiveness of using 3D designs such as those utilized in engineering when teaching macro concepts has been emphasized in the literature (Arcand et al., 2020; Keating et al., 2002; van Joolingen et al., 2015). By its own nature, STEM education facilitates the use of modeling in engineering and in turn makes it easier for students to understand concepts in astronomy (Acut & Latonio, 2021; Başpınar et al., 2024). Just as CAD-produced models can be used in teaching astronomy concepts, so can models made

from actual tangible materials. Comparing the effectiveness of models made from various types of technological models and those made from concrete materials can provide educators with an idea of how to formulate their teaching plans.

Research Rationale and Questions

As expressed above, paying less attention to the engineering and technology steps in STEM education is problematic. Based on this premise, this study investigates how preservice teachers' self-efficacy in STEM-TPACK and their perceptions of engineering design skills self-efficacy are influenced by 3D solar and lunar eclipse modeling activities using either Tinkercad or tangible materials. Thus, the study aims to identify which approach more effectively enhances these competencies and informs STEM instructional strategies. The participants in the investigation are individuals who will be providing STEM education as future educators. It is expected for this reason that the preservice teachers who will personally participate in STEM activities will gain the experience they can transfer to their prospective professional life (White & Newby, 2024; Yesilyurt et al., 2021). Additionally, preservice teachers need to benefit from current technologies in engineering design as well as develop self-efficacy in engineering design processes and STEM-TPACK.

In their review of studies based on modeling, Kiroğlu et al. (2021) reported that when science preservice teachers used physical models instead of simulations to explain the phases of the moon and eclipses, they were more effective in producing scientific responses. Garofalo (2025) found that students who worked with 3D physical models when learning about DNA were better at providing more scientific answers to questions compared to those who were using digital simulations. Although such studies have investigated how traditional physical and modern digital models impact students' scientific responses, there is a gap in the literature that indicates a lack of comparative studies on the effect of the various models on preservice teachers' self-efficacy in terms of STEM-TPACK and engineering design skills. It is therefore expected that the present study will contribute to the current literature by presenting a comparison of the effects of physical and digital models on preservice teachers' self-efficacy in engineering design skills and STEM-TPACK.

The study thus seeks answers to the following research questions:

1. Is there a significant difference in the preservice teachers' STEM-TPACK self-efficacy according to whether they participate in the Tinkercad or tangible material modeling group?

2. Is there a significant difference in the preservice teachers' perception of their self-efficacy in engineering design skills according to whether they participate in the Tinkercad or tangible material modeling group?

Background and Literature Review

Using Technology in STEM Education

Parallel to rapid developments in information and communication technologies, the possible benefits of educational technologies in STEM education are a topic that is stressed in the literature (Wu & Anderson, 2015). It can be said that improving academic achievement and engineering skills are among the benefits of digital technologies (Şen et al., 2020). Tinkercad is at the forefront of the digital applications used in designing 3D models. In their study, Kaya et al. (2019) observed that preservice teachers' self-efficacy in effectively teaching engineering in science classes improved in classes where 3D printing was employed. To the contrary, however, there are studies that reveal that creating models with Tinkercad have only a limited effect on increasing the self-efficacy of preservice teachers in teaching processes (White & Newby, 2024). It is anticipated that researching the effect of using different technological application processes in STEM education from different perspectives will expand the conversation in this area.

Engineering Design Skills

Engineering design skills are needed for solving problems that students encounter in everyday life (DiFrancesca et al., 2014; Thibaut et al., 2018). Engineering design skills are just as important as the other steps of STEM and must not be overlooked. However, the general viewpoint is that engineering design is usually needed to support the teaching of science and mathematics (Gao et al., 2020). The fact that the engineering design process requires the use of mathematics and science even before students produce their final models is overlooked. Students need these disciplines to experiment and explore the functionality of the design and its effectiveness in problem-solving (Kelley & Knowles, 2016).

Besides being used in the engineering design process in order to better explain scientific theories and increase teaching productivity (Greca & Moreira, 2000), models and modeling simplify complex concepts and are learning tools that motivate students by making ideas more concrete. This stimulates active participation and gives students the opportunity to gain more experience while also increasing the effectiveness of the teaching process

(Harrison, 2001). Concrete 3D design models help students grasp concepts and represent key engineering products in STEM education. It is known that a large part of modeling activities carried out in science and technology classes are performed with electrical devices or other concrete materials (Lin et al., 2021). Abdinejad et al. (2021) state that with the use of technological tools, visualization and modeling work have an important potential to overcome the limitations of traditional concrete modeling methods. Garofalo (2025) asserts that students find it difficult to learn abstract STEM concepts and suggests that various physical and digital modeling techniques be used inside the learning environment.

Technological Pedagogical Content Knowledge (TPACK)

STEM education, encompassing integrated pedagogical content knowledge, content knowledge and various technological applications, presents a pedagogical problem for many preservice teachers since they may not have sufficient engineering knowledge or familiarity with design-based thinking patterns (Chai et al., 2019). Meanwhile, teachers are expected to be familiar with the course content they teach and know how to integrate technology into the syllabus (Mishra & Koehler, 2006). The use of technology is an inevitable part of STEM education and engineering design skills. In this context, the technological, pedagogical and content knowledge teachers possess will impact their classroom applications of STEM education. The Technological Pedagogical Content Knowledge (TPACK) framework proposed by Mishra and Koehler (2006), while made up of Content Knowledge (CK), Pedagogical Knowledge (PK), and Technological Knowledge (TK), also encompasses four intersecting components based on these three factors—Technological Content Knowledge (TCK), Technological Pedagogical Knowledge (TPK) and Technological Pedagogical Content Knowledge (TPCK or TPACK) (Sun et al., 2024).

The TPACK framework helps teachers design science activities and effectively integrate technology into the classroom (López et al., 2025; Polly et al., 2020). TPACK also contributes to improving teachers' self-efficacy in the use of technology (Kim & Youn, 2025). It is reasonable then to state that TPACK is of vital importance in STEM education. TPACK is regarded as the fundamental knowledge needed to increase teachers' STEM competencies (Chaipidech et al., 2021; Love & Hughes, 2022; Srisawasdi, 2012). Furthermore, Weidlich and Kalz (2023) state that TPACK has a significant impact on teachers' willingness to integrate digital technologies into their teaching.

Preservice Teacher Training

Studies have shown that the quality of preservice teacher training is instrumental in helping preservice teachers develop their teaching skills (Haverly & Davis, 2024; Menon & Sadler, 2016; Yesilyurt et al., 2021). Moreover, it is of importance that preservice teacher education ensures that they gain sufficient experience in the use of technology (Yildiz Durak, 2021). This will facilitate their handling of problems they might encounter in their teaching. This view is supported by Velthuis et al. (2014), who report that preservice teachers who have taken science content and field-specific courses in the first years of their preservice teacher training display higher levels of self-efficacy. Also, Jaipal-Jamani and Angeli (2017) have determined that preservice teachers who have made use of robotics in their STEM courses show increased levels of self-efficacy and higher comprehension levels of science concepts. It was found in other studies that inquiry-based teaching using 3D models reduced preservice teachers' anxieties about teaching, increased their competencies in science teaching, enhanced their interest in the sciences, and improved their engineering design skills (Haverly & Davis, 2024; Menon & Sadler, 2016; Yesilyurt et al., 2021). In the context of preservice teachers' conceptual development, it is stated that the use of 3D models is useful in deepening preservice teachers' conceptual understanding. This is particularly needed in astronomy since concepts in this discipline are inevitably abstract and need 3D spatial reasoning (Küçüközer, 2008). At the same time, it has been pointed out that 3D models can impact preservice teachers' self-efficacy in teaching their courses (Li et al., 2019; White & Newby, 2024).

Studies show that teachers are not sufficiently knowledgeable about students' alternative concepts when teaching astronomy concepts (Rodrigues et al., 2023). In fact, it is known that inservice and preservice teachers tend to have many different misconceptions (Ogan-Bekiroglu, 2007; Rodrigues et al., 2023; Trumper, 2006). The extent of the training that teachers have had in teaching astronomy plays a role in how much they learn needed concepts and how they will be able to teach these concepts in the future. Studies also indicate, however, that traditional methods of teaching astronomy fall short in terms of reaching projected goals (Kang et al., 2024; Şensoy & Yeşil, 2025). Kim and Youn (2025) point to the need for more applied studies to determine how developing virtual reality materials for teaching topics in astronomy can impact preservice teachers' TPACK skills. Also, there is a positive relationship between the self-efficacy levels of preservice teachers and their willingness to use technology in their classes (Joo et al., 2018). Canlas et al. (2024) state that preservice teachers' self-efficacy perception levels increase with their acceptance of technology

and the more they use its benefits. Therefore, technological applications should be included in astronomy instruction and the effects of these on prospective teachers should be discussed. It is for these reasons that the present study on the use of physical and digital models in astronomy will add a new perspective to ongoing research in this area.

Method

Research Model

A 2×2 factorial experimental design was used in the implementation of this study in two different groups in order to determine whether the applications employed made a difference in the participants' perception of their self-efficacy with respect to their use of STEM-TPACK and their engineering design skills. In this design, Factor 1 defines the type of modeling (Tinkercad vs. Tangible Material), Factor 2 the means of measurement (Pretest vs. Posttest).

Study Group

The study group consisted of a total of 31 preservice science teachers of whom 26 were women, 5 were men. All of the participants were randomly selected from senior-year preservice teachers attending the Science Teacher Education program of a university in western Türkiye who agreed to participate in the research. The literature indicates that a power analysis must be performed for many statistical tests in order to determine sample size (Faul et al., 2009). The Central Limit Theorem requires that when sample size exceeds 30 ($df \geq 30$) the distribution of the sample mean is considered a normal distribution for practical purposes, meaning that the assumption of normality in parametric tests remains independent of the original distribution (Kwak & Kim, 2017). Additionally, when other conditions are met (e.g., homogeneity of variances, equality of covariances), this permits the use of a 2×2 factorial design. In addition, the literature reveals some studies of a similar methodological nature that have worked with a limited number of participants. For example, Delmas et al. (2018) used the two-way mixed ANOVA for a single group of 14 participants while Tan et al. (2023) made use of this method with 19 in the experimental group, 19 controls, a total of 38 participants. Meanwhile, McDuffie et al. (2018) reported on a study they conducted using the two-way mixed ANOVA with a smaller sampling of 10 in the experimental group and 10 in the control group. It can be accepted therefore that the 31-participant sample consisting of two groups in the present study is sufficient in practical terms.

The reason the study group was chosen from among preservice teachers in their last year of training was because these participants were more experienced than other class levels to handle STEM education and the required preparatory work such as designing activities, materials and lesson planning. In line with the objective of the study, 15 participants were assigned to the group who would be modeling using Tinkercad. These participants were chosen from among the students who owned laptops. The remaining 16 participants were assigned to the group who would be working with concrete materials. Ethical approval was obtained from Balıkesir University, Science and Engineering Sciences Ethics Commission (on the session dated 16.12.2024 and numbered 2024/10) for the conduct of the study and participants gave their informed consent. In addition, participant protection was ensured by maintaining confidentiality in the presentation of the data.

Data Collection Instruments

Two different data collection instruments were used in the study. The first of these was the STEM-Technological Pedagogical Content Knowledge Self-Efficacy Scale (STEM-TPACK-SS) originally developed by Chai et al. (2019) and adapted into Turkish by Aktaş and Özmen (2024). This scale is of the Likert type and contains a total of 24 items distributed in four subscales. There are no negative statements in the scale. Cronbach's alpha coefficient, calculated for the data from the overall scale, is reported to be 0.95 (Aktaş & Özmen, 2024).

The second data collection tool was the Engineering Design Skills Self-Efficacy Perception Scale (EDSSPS) developed by Kahraman et al. (2024). The EDSSPS consists of 35 items and is a 4-point Likert-type of scale. There are no negative statements in the scale. McDonald's omega (ω) reliability coefficient for the overall scale has been expressed as 0.971 (Kahraman et al., 2024).

The Study Process

The study activity was held for two class hours a week for a total of four weeks. Figure 1 summarizes the research process.

The activities shown in Fig. 1 were carried out separately by each group in the study (Tinkercad Group & Tangible Materials Group). Accordingly, both groups started out with taking the pretest. Then, the participants were further informed about the study and were told that they would be asked to design models for solar and lunar eclipses. Additionally, the Tinkercad group was provided with training on how to use this program. In the second and third weeks, the

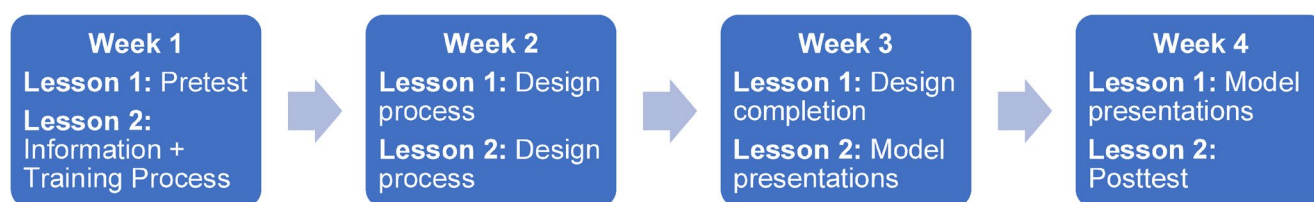


Fig. 1 Activities in the study process

participants in both the Tinkercad and the Tangible Materials group individually designed their models.

The researchers distributed worksheets to the groups to use during the process. Both groups were given worksheets with the same content. The items in the worksheet are presented in the Appendix 1. The first item on the worksheet queried the participant on which concepts came to mind when they heard the word “eclipse”. The responses to this question were collected using the “Mentimeter” platform. The participants were then asked how they could make a visual presentation on the topic of “eclipses” to middle school students. The participants were thus invited to focus on the teaching of the concept and offered motivation to achieve effective teaching. The preservice teachers were expected to provide responses on using appropriate models. They were then presented with the materials they would be using and guided into the activity. The participants were first asked to draw the model they would be designing on the topic of eclipses. At this point, the researchers reviewed the participants’ drawings and provided verbal feedback. The participants then listed the materials they would be using on the worksheets and designed their models according to their modeling method (Fig. 2). They were again provided with verbal feedback at this design stage. Lastly, the participants were asked to provide the aspects of the model they wished to expand upon. The worksheet was thus completed with a subjective review of the activity.

As can be seen in Fig. 2a, the preservice teachers in the tangible material group worked with materials such as playdough, cardboard, sponges, tape, paste and scissors, producing models of the Sun, Earth and Moon. Thus, the participants first created their drawings on the worksheet, then designed and produced their Sun, Earth and Moon models. Finally, they completed their models by placing these celestial bodies in a position to reflect an eclipse. They then observed the play of light and shadow that they created using a flashlight. Meanwhile, scenes of the activity of the other Tinkercad group can be seen in Fig. 2b. These participants were also guided by the same worksheet. The design stage, however, was carried out digitally. The distances between the celestial bodies and their sizes were based on Tinkercad’s background proportional scaling feature and axial tilts were based on the program’s angle measurement function. Labels, arrows and other indications were added

to the models digitally. This model could not be illuminated as it was in the physical model.

In order to observe how each preservice teacher’s skills developed in the design process, the participants were asked to work individually instead of in small committees. Lastly, each of the participants showed the models they had produced to their classmates. The participants then received simple verbal feedback from their classmates, and the group discussed the pluses and minuses of the designs. The activity ended with the administration of a posttest.

Data Analysis

Quantitative data were obtained from the study. The responses to the STEM-TPACK-SS were scored on the range of “I definitely agree=6” to “I definitely disagree=1”. The responses to the EDSSPS were scored on the range of “I definitely agree=4” to “I definitely disagree=1”. Since there were no negative statements on either measure, no reverse scoring took place. There was also no missing data.

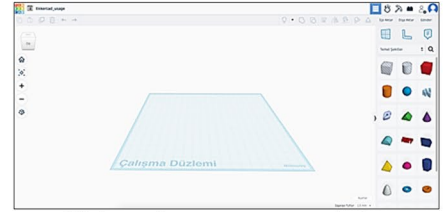
The two-way ANOVA for mixed measures was used in the data analysis. Mixed designs include the combination of at least two independent variables with repeated measures (Field, 2009). It is thus possible, as in this study, to test independent measurements conducted in two separate modeling groups (Tinkercad vs. Tangible material) in terms of pretest and posttest using repeated measures over time. This is why this model was used in this research. The SPSS 24 program was used in the analysis. A 0.05 level of significance was accepted in all of the analyses.

For the analysis model, some prerequisite analyses were performed. In this context, the data sets obtained from the pre- and posttest were tested for normal distribution. To this end, the Shapiro-Wilk test results were examined since the number of participants was below 50. Accordingly, the results of the STEM-TPACK-SS pretest for the tangible materials group were $W=0.956, p=.595$ and $W=0.929, p=.266$ for the Tinkercad group. The results of the posttest were $W=0.949, p=.480$ for the tangible materials group and $W=0.929, p=.266$ for the Tinkercad group. The same analyses were performed for the pretest results of the EDSSPS; the findings were $W=0.952, p=.520$ for the tangible materials group and $W=0.951, p=.548$ for the Tinkercad group. The posttest results for the same scale were $W=0.937, p=.316$ for the tangible materials group and

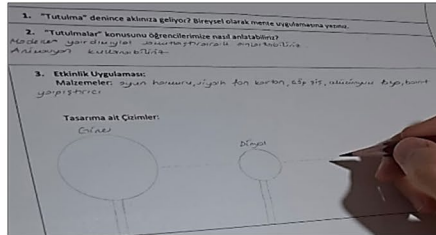
Fig. 2 Stages related to the pre-service teachers' study process. **(a)** Tangible materials group, **(b)** Tinkercad group



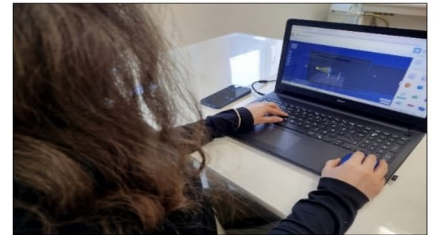
Tangible materials used in the activity



Tinkercad program screenshot



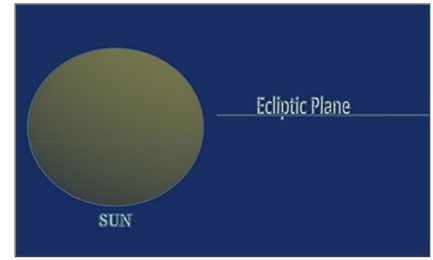
A drawing for physical modeling



Modeling with Tinkercad program



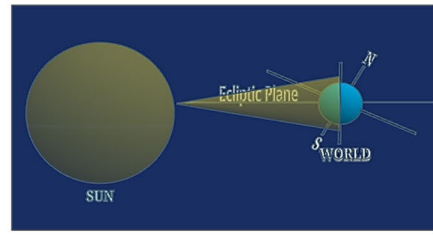
A stage from physical modeling with tangible materials



A stage from digital modeling with Tinkercad program



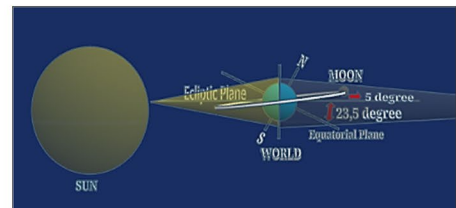
Another stage from physical modeling with tangible materials



Another stage from digital modeling with Tinkercad program



The final state of the physical model showing the lunar eclipse
(a) Tangible materials group



The final state of the digital model showing the lunar eclipse
(b) Tinkercad group

Table 1 Descriptive statistics for STEM-TPACK-SS and EDSSPS scores at pretest and posttest

| Scales | Group | Pretest | | | Posttest | | |
|---------------|--------------------|---------|--------|-------|----------|--------|-------|
| | | n | Mean | SD | n | Mean | SD |
| STEM-TPACK-SS | Tangible Materials | 16 | 97.50 | 10.71 | 16 | 100.56 | 13.33 |
| | Tinkercad | 15 | 98.53 | 14.90 | 15 | 111.27 | 13.75 |
| EDSSPS | Tangible Materials | 16 | 103.63 | 12.97 | 16 | 111.38 | 13.08 |
| | Tinkercad | 15 | 106.53 | 11.19 | 15 | 112.60 | 13.37 |

Table 2 Results of levene's test for variance homogeneity for STEM-TPACK-SS and EDSSPS scores at pretest and posttest

| Measurement | F | df1 | df2 | p |
|-------------------------|-------|-----|-----|-------|
| STEM-TPACK-SS pre-test | 1.380 | 1 | 29 | 0.250 |
| STEM-TPACK-SS post-test | 0.115 | 1 | 29 | 0.737 |
| EDSSPS pre-test | 0.189 | 1 | 29 | 0.667 |
| EDSSPS post-test | 0.017 | 1 | 29 | 0.897 |

Table 3 Results of the test for equality of covariance for STEM-TPACK-SS and EDSSPS scores

| | STEM-TPACK-SS Scores | EDSSPS Scores |
|---------|----------------------|---------------|
| Box's M | 3.651 | 1.527 |
| F | 1.126 | 0.471 |
| df1 | 3 | 3 |
| df2 | 177952.753 | 177952.753 |
| p | 0.337 | 0.702 |

Table 4 Results of reliability analysis of STEM-TPACK-SS and EDSSPS scores (Cronbach's alpha coefficients)

| Scales | Tangible Materials Group | | Tinkercad Group | |
|---------------|--------------------------|----------|-----------------|----------|
| | Pretest | Posttest | Pretest | Posttest |
| STEM-TPACK-SS | 0.857 | 0.937 | 0.934 | 0.949 |
| EDSSPS | 0.936 | 0.936 | 0.952 | 0.972 |

$W=0.912$, $p=.146$ for the Tinkercad group. Furthermore, we found that skewness and kurtosis coefficients for all the data sets were in the range of -1.5 - $+1.5$. Therefore, it was seen that all the data sets showed normal distribution.

Descriptive statistics for the preservice teachers' scores on the scales can be seen in Table 1.

It can be seen in Table 1 that the preservice teachers displayed different mean scores on the pre- and posttests of both the STEM-TPACK-SS and the EDSSPS. The results of the tests for variance homogeneity and equality of covariance are shown in order in Tables 2 and 3.

It can be seen in Table 2 that there is variance homogeneity for each data set.

An examination of Table 3 reveals that the data sets obtained in the study display equality of covariance. Since these conditions were met, the two-way ANOVA for mixed measures was deemed appropriate to use to compare the preservice teachers' scores on the pre- and posttests in terms of the variables examined. In the analyses performed with the two-way ANOVA for mixed measures, effect sizes were calculated with the partial eta-squared value (η_p^2). Cohen's (1988) values were accepted in interpreting the size of partial eta-squared. Accordingly, 0.01 indicated a small effect size, 0.06 was accepted as moderate, and 0.14 was accepted as a large effect size.

Cronbach's alpha coefficient was computed in the context of reliability testing. Cronbach's alpha coefficients calculated with the help of SPSS 24 for each data set are shown in Table 4.

All the Cronbach's alpha coefficients in Table 4 are above 0.70 and therefore point to the reliability of the data analysis.

Findings

Findings on the Self-efficacy of the Preservice Teachers in STEM-Technological Pedagogical Content Knowledge

The two-way ANOVA for mixed measures was used to analyze the changes in the pretest and posttest scores of the preservice teachers participating in two different modeling groups in terms of their STEM-TPACK self-efficacy. Our findings can be seen in Table 5.

According to Table 5, the STEM-TPACK self-efficacy scores of the participating preservice teachers in the two

Table 5 Effect of the modeling group on the preservice teachers' STEM-TPACK self-efficacy scores

| Source of Variance | Type III Sum of Squares | df | Mean Square | F | p | η_p^2 |
|--------------------|-------------------------|----|-------------|--------|--------|------------|
| Between Subjects | 8725.968 | 30 | | | | |
| Group | 533.299 | 1 | 533.299 | 1.888 | 0.180 | 0.061 |
| Error | 8192.669 | 29 | 282.506 | | | |
| Within Subjects | 3277.806 | 31 | | | | |
| Measure | 965.839 | 1 | 965.839 | 14.364 | 0.001 | 0.331 |
| Group*Measure | 362.032 | 1 | 362.032 | 5.384 | 0.028* | 0.157 |
| Error | 1949.935 | 29 | 67.239 | | | |
| Total | 12003.774 | 61 | | | | |

Table 6 Effect of the preservice teachers' modeling group on their perception of their engineering design skills

| Source of Variance | Type III Sum of Squares | df | Mean Square | F | <i>p</i> | η_p^2 |
|--------------------|-------------------------|----|-------------|--------|----------|------------|
| Between Subjects | 7925.000 | 30 | | | | |
| Group | 66.133 | 1 | 66.133 | 0.244 | 0.625 | 0.008 |
| Error | 7858.867 | 29 | 270.995 | | | |
| Within Subjects | 2237.905 | 31 | | | | |
| Measure | 738.969 | 1 | 738.969 | 14.402 | 0.001 | 0.332 |
| Group*Measure | 10.969 | 1 | 10.969 | 0.214 | 0.647 | 0.007 |
| Error | 1487.967 | 29 | 51.309 | | | |
| Total | 10162.905 | 61 | | | | |

different types of modeling groups displayed a significant difference, $F(1, 29)=5.384$, $p<.05$). Also, the effect size ($\eta_p^2 = 0.157$) was large. In looking at the pre- and posttest scores, we saw that the Tinkercad application was more effective (Table 1).

Findings on the Self-efficacy Perception of Preservice Teachers Regarding their Engineering Design Skills

The change in the participating preservice teachers' perception of self-efficacy in engineering design skills in the two different modeling groups was also compared with the two-way ANOVA for mixed measures. The findings are shown in Table 6.

According to Table 6, it was found that there was no significant difference between the preservice teachers' perception of self-efficacy in engineering design skills, $F(1, 29)=0.214$, $p>.05$). Accordingly, the effect size ($\eta_p^2 = 0.007$) was small. We observed that in both the Tinkercad group and the tangible materials group, the preservice teachers' perception of their self-efficacy in engineering design skills displayed a similar change. This is supported by the participants' pre- and posttest scores (Table 1).

Discussion and Conclusions

In the present study, preservice teachers were divided into two groups and asked to design their treatment of solar and lunar eclipses, a subject that they would be teaching in the future. While one of the groups used tangible materials available in everyday life to design a 3D model, the other group made use of the Tinkercad program, commonly employed in STEM education, and created visual models, recording their designs as computer files. In both groups, the participants showed the products of their work to their classmates and discussed the finished product with them. In this context, the self-efficacies of preservice teachers in two fields, STEM-TPACK and engineering design skills, were discussed.

The measurements taken before and after the design process showed a significant difference between the groups in terms of their STEM-TPACK self-efficacy. The results revealed that the applications carried out by the Tinkercad group were more effective, creating a larger effect than those of the tangible materials group. This unsurprising finding may be considered a natural result of using the contemporary design program Tinkercad. Program users are easily able to transfer the design they have in mind into the digital medium. They are also able to make any changes they desire (e.g., color, size). At the same time, the feedback received from the instructors can be immediately transferred into the design. The program enables users to redesign their projects practically and easily. Thus, it can be specified that Tinkercad facilitates each step of the modeling process as well as making it easier to go back to previous stages of the modeling process, making changes and proceeding again. However, when working with tangible materials, such processes are more challenging in terms of time, effort, and cost. All of these capabilities point to the superiority of Tinkercad compared to the method of using tangible materials for modeling. Therefore, the mentioned advantages of the program can be closely associated with the more pronounced STEM-TPACK self-efficacy the preservice teachers in the Tinkercad group gained. Similarly, Pabuçcu Akiş and Demirel (2022) reported that STEM applications that integrate 3D technologies improve students' technological competencies. On the other hand, Kim and Youn (2025) reported that while preservice teachers developed virtual reality materials for teaching topics in astronomy, they did not have the opportunity to apply these to students. The authors thus emphasize that there is a need to carry out more studies to evaluate preservice teachers' process of improving their TPACK skills. In the present study as well, the improvement seen in the preservice teachers' development of their TPACK skills as they carried out their digital modeling with Tinkercad could be evaluated from a wider perspective that would encompass their teaching in the classroom setting.

The positive outcome of the present study in terms of the STEM-TPACK self-efficacy the Tinkercad group gained through digital modeling, however, conflict with the results reported in the literature that reveal that physical modeling

is better at achieving conceptual understanding (Garofalo, 2025; Kiroğlu et al., 2021). Kiroğlu et al. (2021) have in fact associated this with the difficulty of transferring a 3D simulation to a two-dimensional screen, an action that makes it harder to think on a 3D scale. It can be seen, on the other hand, that such studies are more concentrated on the effect of different modeling methods on conceptual understanding in different topics of science. In this context, digital tools can offer various advantages in the learning and teaching process, but it must be accepted that they also bring various limitations into the picture. The conceptual understanding of the preservice teachers related to solar and lunar eclipses was not included in the scope of the research in the present study. The researchers, however, made various observations in the classroom setting to determine how the type of modeling impacted the preservice teachers' self-efficacy. Accordingly, in both groups, we saw that despite the fact that the participants were asked to work individually, there was a great deal of interaction among those who were working with tangible materials (e.g., exchanging materials, asking each other questions). Meanwhile, in the Tinkercad group, the participants were much quieter and more isolated as they worked on their computers. We noticed, however, that there were some participants that communicated with other students working on the Tinkercad program to ask for their help. It will therefore be useful to design programs that will improve preservice teachers' technological self-efficacy.

With the current digital transformation, 3D models, simulations and other technological applications have made it easier to understand and explain phenomena in astronomy and this is why it is stressed that teachers must have the competencies needed to work with technology in the classroom (Canlas et al., 2024). It is also emphasized that besides having to learn the skills specific to their disciplines, it is important that teachers have the required pedagogical knowledge that will help them teach effectively (Weld & Funk, 2005). The aim of this study was to offer preservice teachers the opportunity to improve their STEM-TPACK self-efficacy through the use of Tinkercad. Our objective was to provide these students with the Tinkercad experience, a skill that would benefit them in their future professional life. Joo et al. (2018) determined that preservice teachers appreciated the advantages of learning about the new technologies that were available and used them willingly. The preservice teachers in our study, too, appreciated the experience and skills they gained working with the topic of eclipses on Tinkercad and believed these skills would be needed when they had to apply Tinkercad and other similar tools to their upcoming professional life. Additionally, Ogan-Bekiroglu (2007) reported the results of their investigation of the impact of model-based learning on preservice physics teachers' conceptual understanding of the topics of the moon, phases of

the moon and lunar phenomena. The authors stated that scientific understanding is in fact enhanced the more authentic the model. Indeed, the scaling capability that Tinkercad provides makes it possible to reproduce celestial bodies proportionately and give them the appropriate axial tilt. It can be seen therefore that the technological assistance provided in the designing process has a positive impact on TPACK skills.

Another outcome of the study was that as a result of the applications carried out in the two different groups, the preservice teachers' perceptions of their self-efficacy in engineering design skills were similar to each other. In other words, although both groups of preservice teachers experienced an increase in their perception of self-efficacy with respect to engineering design skills during the study, this increase was not significantly different from one another. This result can be interpreted to mean that designs produced from tangible materials provided a similar impact on the preservice teachers' perceptions of self-efficacy in this skill compared to when designs were produced with the help of Tinkercad in the digital medium. This may have been because both study groups benefited from their engineering design skills as they produced their designs and were able to render original design work. In addition, both groups used worksheets in the design process. Arık and Topçu (2024) emphasize that making an in-depth review of how engineering design skills develop is based on either comparing differently structured engineering design processes or analyzing each step of each design process in detail. It may be said then that what is needed in this context is a more in-depth analysis of preservice teachers' perception of their self-efficacy in engineering design skills. For example, although Tinkercad is helpful in scaling designs, it is still not possible to realistically reproduce the sizes and distances between the Sun, Earth and Moon in a model. The size of the moon remains too small and distances between celestial bodies are not proportional in Tinkercad models. This makes it hard to carry the model to the screen and provide visibility. The same problem actually exists for solar and lunar eclipse models made with tangible materials. We find that most models depicted in textbooks pay more attention to representing the phenomenon of the eclipse rather than on attempting to reproduce actual sizes and distances (Testa et al., 2014). We observed that the study participants' self-efficacy in design seemed to be influenced by these factors and that they exhibited some degree of improvement.

While some studies assert that digital technologies are effective in developing engineering skills (Kaya et al., 2019; Şen et al., 2020), others point to the limitations of technology in improving these skills (White & Newby, 2024). What is expected of teachers in this process is that they be able to guide students effectively (Dertli & Yıldız, 2024). This can

only be achieved if teachers can first improve their own self-efficacy in STEM-TPACK and engineering design skills. Kiroğlu et al. (2021) have called attention to the role of the teacher in teaching complex subjects in astronomy such as the phases of the moon and eclipses. Moreover, García-Carmona and Toma (2024) report that preservice science teachers feel uncertain about their ability to integrate engineering applications into the teaching process and believe their self-efficacy to be poor in this area. This is why the results of the present study offer various data that will be useful for future studies in terms of integrating modeling activities into the teaching and learning process and providing teachers with insight into how to select the appropriate type of modeling.

In sum, modeling activities carried out in this study indicated a significant effect on preservice teachers' STEM-TPACK self-efficacy in favor of the Tinkercad group. On the other hand, no such differentiation was obtained between the two groups in terms of their perceptions of engineering design skills self-efficacy. This situation can also be associated with Bandura's (1977) Theory of Self-Efficacy. In his theory, Bandura explains self-efficacy as the belief an individual can effectively perform the actions necessary to achieve the desired results. In educational development, Bandura (2006) asserts three primary paths through which efficacy contributes significantly to cognitive growth and achievement. These paths are related to students' beliefs, teachers' beliefs and the faculties' collective sense of efficacy. It can be stated that the Tinkercad program used in this study positively influenced the beliefs of preservice teachers participating in the digital modeling, creating a meaningful impact on STEM-TPACK self-efficacy in favor of these participants. On the other hand, it might be asserted that the lack of any technological tools used in the tangible materials group did not foster such beliefs in this group, and this was reflected in the research results. When the research results are considered in terms of engineering design skills, it can be assessed that the modeling process had a similar impact on the self-efficacy perceptions of the participants in both groups. In this context, similar changes in participants' engineering design skills self-efficacy perceptions may be attributed to the resulting design product rather than the use of tangible materials or software during the process. In addition, the fact that all participants were educated at the same faculty and therefore the faculty provided all preservice teachers with a similar sense of collective efficacy may have created similar effects on the preservice teachers regardless of the type of modeling used.

Last, the study also has certain limitations. Firstly, the assignment of the participants into two groups could not be performed in a way that is in keeping with the nature of quantitative research. Instead, students who owned laptops were assigned to the Tinkercad group, with the remaining

students brought into the tangible material group. The researchers chose this type of allotment because laptops could not be provided to as much as half of the participants. When students were assigned to the groups in this way, we saw that those in the Tinkercad group worked with ease at their own laptops and thus completed the exercise more comfortably. Another limitation of the study is that the teaching applications dealt with only one subject for a total of six class hours. Thus, the fact that the participants showed a more limited improvement in terms of engineering skills can be associated with the relatively short duration of the activity. Adding models of constellations and planets to the solar and lunar eclipse modeling may have a greater impact on self-efficacy perceptions in engineering design skills. An additional weakness of the study was that the designs produced were limited to two different methods of modeling. The basic materials typically used in science teaching constituted the tangible materials. In the case of Tinkercad, however, with the introduction of STEM into science education, it must be said that this particular technology has become the leading and most widely used application in this field. Our study has aimed to make a comparison between two different modeling methods used in STEM education in terms of their impact on self-efficacy. It is expected that more studies with larger samplings will be carried out in this context in the future. Study outcomes can be enriched with the addition of different types of modeling.

In light of our results, the following suggestions may be made:

- The results of the study can be enriched by collecting qualitative data. For example, more effectual evidence of the development of preservice teacher STEM-TPACK self-efficacy may be examined through semi-structured interviews. Additionally, the problems encountered by both groups in the modeling process may be investigated. In this case, a study of mixed design may prove beneficial.
- The impact of the design process can be examined with lengthier studies. In this context, the preservice teachers can be asked to produce more than one design in more than one subject.
- The level of modeling factors in the study can be increased by adding a third method to the study. Different materials such as Lego building blocks can be useful, for example. It may also be suggested that in the case of this type of three-arm comparisons, the study group can be expanded.
- To further and more effectively support the development of preservice teachers' engineering design skills, hybrid studies may be carried out in a third group or in the Tinkercad group. In the light of the importance of

hybrid studies in today's world, the activity process may be monitored remotely to gain deeper understanding of how it impacts the engineering design skills of preservice teachers.

Appendix 1. The Items in the Worksheet

Introduction of the activity.

- a) Which concepts come to mind when you hear the word "eclipse"? Use the Mentimeter platform to give your answers.
- b) How can you make a visual presentation to support your students' learning when teaching the subject of "Solar and Lunar Eclipses"?

Designing stage of the activity.

- iii) Please, make a drawing for your model.
- iv) What materials do you plan to use in the model you will create?
- v) Make your model and finalize it.

Evaluation of the activity.

- f) Which aspects of your model would you like to improve or change? Why?

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Data Availability Data and material related to the study are available upon request.

Declarations

Ethical Approval Ethical approval was taken from Science and Engineering Ethics Commission of Balikesir University (E-70465693-108.01-440763).

Informed Consent All participants took part in the study voluntarily and they could withdraw from the study at any time.

Competing Interests The authors have no competing interests.

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