Integrating STEM into Mathematics Teacher Candidate Education: Experiences, Challenges, and Reflections

Handan Ürek[1] Ayşe Tuğçe Bodur[2] Mevhibe Kobak Demir [3]

To cite this article:
Ürek, H., Bodur, A. T., & Kobak Demir, M. (2025). Integrating STEM into mathematics teacher candidate education: Experiences, challenges, and reflections. *e-Kafkas Journal of Educational Research*, *12*, 660-681. doi:10.30900/kafkasegt.1688807

Research article **Received**:01.05.2025 **Accepted:**15.12.2025

Abstract

The integration of STEM education into mathematics teacher preparation programs has become increasingly vital to equip future educators with interdisciplinary skills required for 21st century learning environments. Considering this situation, this study explores the experiences, challenges, and reflections of mathematics teacher candidates during a STEM-based activity which was designed within the scope of teacher education. In this direction, a case study was conducted with 19 mathematics teacher candidates from a state university in Türkiye. Data were collected through a Product Evaluation Rubric, Product Evaluation Form, and an Opinion Form developed by the researchers. Obtained data was analyzed by means of qualitative approaches. The findings revealed that although all participants were conceptually familiar with STEM, they lacked prior experience in a practical STEM activity. After their participation in the current study, it was determined that most of the participants asserted positive opinions about the activity such as creating solutions to the problems and enhancing their creativity. Also, the participants expressed strong intentions to incorporate similar activities in their future classrooms. On the other hand, the participants reported several challenges that they faced such as design-related difficulties and technology-related difficulties during the activity process. In the future, it is recommended to conduct further STEM education studies with different designs involving mathematics teacher candidates to present information-rich data to the field to enhance the professional development of mathematics teachers.

Keywords: STEM education, mathematics teacher candidates, case study, professional development, interdisciplinary teaching.

[1] Author, Balıkesir University, Balıkesir, Türkiye
[2] Author, Balıkesir University, Balıkesir, Türkiye
[3] Corresponding Author, mevhibekobak@balikesir.edu.tr Balıkesir University, Balıkesir, Türkiye

Introduction

Today, the aim of educational activities goes far beyond teaching students only theoretical knowledge (Partnership for 21st Century Skills, 2010). In this context, it has become prominent to train students who can transfer what they have learned to their daily lives and relate it to different disciplines (Smith et al., 2022). Also, the targets of education involve equipping students with the skills to adapt to the age they live in (Bozkurt Altan, 2017). In the digital age we live in, the interdisciplinary approach used for the aforementioned purposes is STEM (science-technology-engineering-mathematics) education (Akaygun & Aslan-Tutak, 2016). Based on the principle of solving real-world problems, STEM education aims to equip students with the knowledge, skills, critical thinking ability, and creativity required to solve complex problems related to different disciplines (Maass et al., 2019). At the same time, this process often involves the use of engineering design and applications (Guzey et al., 2017). Thus, students can evaluate a problem situation from daily life with a more comprehensive perspective and develop solutions to this problem like an engineer. Another aim of STEM education is to train qualified individuals by directing students to have careers in these fields and to provide economic value to their countries (Corlu et al., 2014). Even if students who receive STEM education do not have a career in this field in the future, they can transfer the benefits of the skills they have acquired through STEM education to their daily lives (Benken & Stevenson, 2014). Therefore, STEM education needs to be given at an early age, starting from the primary school level (Liu, 2020). Thus, students' interest can be attracted to these fields. This situation can be achieved by training qualified teachers who will provide STEM education to the students at different grade levels.

Considering their critical roles, sufficient importance should be given to STEM education in teacher candidate training. Indeed, STEM education makes various contributions to teacher candidates such as developing problem-solving skills (Alan et al., 2019; Özçakır Sümen & Çalışıcı, 2022), innovation skills (Hacıoğlu, 2021), and tendency to use technology in their future classes (Ürek & Çoramık, 2023). In addition, studies show that teacher candidates increase their academic achievement (Özçakır Sümen & Çalışıcı, 2022) and develop their conceptual understandings through STEM applications (Altunışık et al., 2023; Ozkizilcik & Cebesoy, 2024). Furthermore, considering that teacher candidates will be able to implement STEM applications in their own classrooms in the near future, they need to be equipped with the necessary skills in this field. On the other hand, it can be asserted that the courses related to STEM education are limited in teacher training programs (CoHE, 2018). For example, an examination of the undergraduate mathematics teacher education program shows that there is no course directly related to STEM education. The subject of STEM can be addressed within the scope of the courses "Mathematics Teaching" and "New Approaches in Mathematics Education". A similar deficiency is also encountered in the studies conducted with teacher candidates in this field. Although STEM education is important for students at all educational levels, Wilson et al. (2022), who reviewed articles in three different journals on the subject of STEM education, reported in the results of their content analysis that this line of education is predominantly provided for students in precollegiate programs.

Taking into account the abovementioned literature, it can be asserted that there is a need to address college level participants and teacher candidates more frequently in terms of STEM education studies. Accordingly, Sungur-Gul and Tasar's (2023) study indicated that teacher candidates need education in various dimensions of STEM education such as theoretical structure of STEM, sample STEM activities and STEM learning methods. However, when the studies conducted with teacher candidates in the literature are examined, it is seen that studies on STEM education for mathematics teacher candidates (Bergsten & Frejd, 2019; Geiger et al., 2018; Poonpaiboonpipat, 2021, Yıldırım & Sidekli, 2018) seem to be fewer than those conducted for science teacher candidates (Alan et al., 2019; Awad & Barak, 2018; Aydin-Gunbatar et al., 2018; Douglass & Verma, 2022; Ozkizilcik & Cebesoy, 2024; Siew et al., 2015; Sungur Gül & Saylan Kırmızıgül, 2023). However, STEM education encompasses four disciplines: science, mathematics, engineering and technology. Mathematics is one of the fundamental disciplines of STEM education. Also, it can be seen in the cluster analysis by Zhang and Zhu (2023) that the keyword "STEM mathematics education" comes after the keyword "science teacher candidates" in the listing of articles the authors selected from the Web of Science Core Collection database. Based on this discovery regarding one of the fundamental areas in STEM education, mathematics, it is apparent that there is a need for effective STEM education applications especially designed for mathematics teacher candidates. That is why the current study focuses on mathematics teacher candidates.

A review of the literature reveals that several STEM education studies conducted with mathematics teacher candidates are based on the lesson plans prepared by the teacher candidates (Bergsten & Frejd, 2019; Poonpaiboonpipat, 2021; Yıldırım & Sidekli, 2018). These studies are reported to contribute to mathematics teacher candidates' understanding of the concept of STEM education (Bergsten & Frejd, 2019; Poonpaiboonpipat, 2021), development of their 21st century skills (Bergsten & Frejd, 2019), mathematics literacy self-efficacy and technological pedagogical content knowledge (Yıldırım & Sidekli, 2018). On the other hand, these applications were reported to cause no significant improvement in the mathematical thinking of the participants (Yıldırım & Sidekli, 2018). Geiger et al. (2018), however, developed an online learning module on mathematical modeling for teacher candidates in their study. This module was based on the mathematical literacy model and focused on the relationship between mathematical modeling and STEM disciplines. The researchers obtained positive results from this module and also emphasized the need for further development of the module with the participation of more stakeholders. Besides, various challenges encountered by teacher candidates in the aforementioned STEM education-based study processes are discussed in the research (Geiger et al., 2018; Poonpaiboonpipat, 2021; Yıldırım & Sidekli, 2018).

One of the challenges teacher candidates face in STEM education applications is concerned with the engineering design process (Barbosa et al., 2024; Poonpaiboonpipat, 2021; Ürek & Çoramık, 2023). Engineering design constitutes a significant part of STEM applications. As a result of this design process, a model of the product to be developed can be created. In this regard, designs can be made using technology or hands-on applications. Thus, physical (Karaismailoglu & Yildirim, 2023; Ürek et al., 2025) or digital models (Dertli & Yıldız, 2025; Karaismailoglu & Yildirim, 2023; Küçük et al., 2024; Pabuçcu Akiş & Demirer, 2023; Şen et al., 2020; Tüysüz et al., 2024; Ürek et al., 2025) can be created. In the context of digital modelling, Tinkercad is a free web application that provides the opportunity to create three-dimensional (3D) designs (Autodesk, 2024). STEM education benefits from this approach. By using these types of technologies towards a specific aim in education, students are introduced to real-life situations in a low-risk and entertaining environment (Beheshti et al., 2024). The technological opportunities that lead the way to spatial-mathematical learning experiences using Tinkercad are elements of design known as adding, dimensioning, combining, aligning, cutting, rotating, measuring, and 360° viewing (Sun, 2023). Moreover, Tinkercad is capable of connecting with 3D printers, which can produce concrete materials through the use of ink, toner and filament instead of paper (Şen et al., 2020).

The use of Tinkercad appears in various studies in the literature that have been conducted with middle school students (Dertli & Yıldız, 2025; Küçük et al., 2024; Şen et al., 2020; Tüysüz et al., 2024) and high school students (Pabuçcu Akiş & Demirer, 2023). However, there are fewer studies which involve teacher candidates (Karaismailoglu & Yildirim, 2023; Ürek et al., 2025). In some of these studies, designs have been transformed into products with the help of 3D printers and in this context, we can see that students created products such as scales (Şen et al., 2020), bottles of cologne (Pabuçcu Akiş & Demirer, 2023) and cold storage rooms (Dertli & Yıldız, 2025). Some of the models described in studies appear to have been left in digital form (Karaismailoglu & Yildirim, 2023; Küçük et al., 2024; Sungur Gül & Saylan Kırmızıgül, 2023; Tüysüz et al., 2024; Ürek et al., 2025). Besides, the activities reported in the literature have resulted in positive feedback from the students (Dertli & Yıldız, 2025; Karaismailoglu & Yildirim, 2023; Pabuçcu Akiş & Demirer, 2023; Şen et al., 2020; Tüysüz et al., 2024). On the other hand, Küçük et al. (2024) reported a comparison they made between traditional teaching applications and those conducted with Tinkercad in two fifth grade classes, stating that there was no significant difference between the groups in terms of either spatial thinking skills or computational thinking skills (Küçük et al., 2024). This study makes use of both digital and physical modelling with the use of Tinkercad and hands-on applications by mathematics teacher candidates.

Current Study

The aim of this study is to develop, implement, and evaluate a STEM-based activity for mathematics teacher candidates. In this context, it is aimed to examine teacher candidates’ experiences and reflections about the activity as well as the challenges they faced during the activity process. Also, the products which were developed by the teacher candidates were investigated in detail.

In view of the limited resources available in the literature on STEM activities for mathematics teacher candidates, our study aimed to make a contribution to the field by providing a detailed example of an activity that can be used in this context. At the same time, activity-based studies offer various advantages to teacher candidates embarking on their professional lives (Jeong et al., 2020; Ürek & Çoramık, 2023; Yıldırım, 2021). In fact, it has been reported that teachers' perceptions, their knowledge and the level of their comprehension of STEM play an important role in their effective use of STEM education in their own classes (Bell, 2016). Teacher candidates gain a host of knowledge about current methods and techniques in the formal education they receive during their undergraduate training. It is true, however, that they may not be able to have the opportunity of being actively involved with any one of these methods. By offering a means of having teacher candidates participate in a STEM activity, this study offered them the opportunity to become more acquainted with STEM education, which was another goal of our research.

The research questions to which answers were sought were:

- What were the teacher candidates' prior knowledge and experience of STEM education before participating in the activity?
- What kind of products did the teacher candidates develop over the course of the activity?
- What were the teacher candidates' opinions about the activity following their participation in the activity?

Method

Research Design

This study employed a qualitative case study design. This methodological approach is particularly appropriate for research that aims to gain an in-depth, holistic understanding of a complex phenomenon within its real-life, contemporary context (Yin, 2018). A case study is defined as an empirical inquiry into a "bounded system", which can be an individual, a group, an event, or, as in this instance, a specific program or activity (Creswell & Poth, 2018; Stake, 1995). The "case" in this research is the bounded system of 19 mathematics teacher candidates participating in a structured, two-week STEM-based activity designed and implemented by the researchers. This design was chosen over other qualitative approaches because the study's focus was not on the isolated, lived experience of an abstract phenomenon (as in phenomenology), but rather on the comprehensive, real-world processes, challenges, and outcomes of a specific educational intervention (Yin, 2018). A key strength of the case study design is its capacity to utilize multiple sources of evidence to facilitate data triangulation (Stake, 1995). Accordingly, this study utilized a Product Evaluation Rubric, a Product Evaluation Form, and an Activity Opinion Form to build a rich, detailed, and credible account of the candidates' experiences and reflections during the STEM activity.

Study Group

The study group consists of 19 mathematics teacher candidates, 10 males and 9 females, studying at the faculty of education of a state university in the west of Türkiye. The study group was determined by criterion sampling, one of the purposive sampling methods. Criterion sampling requires the inclusion of all situations that meet the determined criteria in order to reach the best data source suitable for the research purpose (Patton, 2014). In this framework, the participants included in the study group are studying in the sixth semester of their undergraduate education and have completed the compulsory courses in their programs, namely "Mathematics Learning and Teaching Approaches", "Algorithm and Programming", "Instructional Technologies", "Problem Solving in Mathematics" and "Mathematics Teaching 1". In addition, the participants are taking the courses "Mathematical Modeling" and "Mathematics Teaching 2" in the semester in which the application was carried out. These criteria were deemed essential as they ensured participants possessed the prerequisite knowledge for the STEM activity. Specifically, courses such as "Mathematics Learning and Teaching Approaches" and "Problem Solving in Mathematics" provided the essential pedagogical and content knowledge. Simultaneously, courses like "Algorithm and Programming" and "Instructional Technologies" equipped the candidates with the basic technical and design-oriented skills required to engage with the 3D modeling (Tinkercad) and technology integration components. The sixth semester marks a point in their program where they possess this sufficient foundational knowledge but have not yet begun their final-year teaching practicum.

The researchers informed all students taking the "Mathematics Teaching 2" course about the study's purpose and procedures. It was emphasized that participation was entirely voluntary and would not affect their course grades in any way. The 19 students who expressed interest and agreed to participate constituted the study group. Ethical approval was obtained from the Science and Engineering Ethics Commission of Balıkesir University (Approval No: E-19928322-302.08.01-374173). All participants provided written informed consent after being assured of confidentiality and their right to withdraw at any time.

Data Collection Tools

Product Evaluation Rubric: While providing individuals with sufficient detail to evaluate themselves in the process of completing and improving a task during self-evaluation, rubrics also support STEM classes as a peer assessment tool by evaluating the work of other students working on different aspects of the STEM project (Bender, 2016). In this study, a "Product Evaluation Rubric" was used for the peer assessment of the products developed by the groups. This rubric was originally developed by the researchers following a comprehensive review of relevant literature on STEM product assessment. To ensure content validity, the draft instrument was reviewed by two field experts. Based on their feedback, the wording of the items (e.g., 'the inclusion of the engineering design process' and 'affordability and usability') was clarified, and the final version of the rubric was implemented after achieving full consensus from the experts on its clarity and relevance. The rubric consists of five items that could be scored between '1' (e.g., Poor) and '5' (e.g., Excellent).

Product Evaluation Form: In this study, the "Product Evaluation Form", consisting of four open-ended questions, was used as a qualitative tool to facilitate groups' self-evaluation of their own products . The form was developed by the researchers and reviewed by two field experts to ensure both content validity and comprehensibility. Based on their feedback, minor wording adjustments were made to ensure the questions would elicit the intended technical reflections. The form was deliberately designed to complement the "Product Evaluation Rubric" rather than merely "support" its findings. While the rubric captured quantitative, external peer-assessments of the final product, this form was intended to yield qualitative data on the internal design process. Specifically, its purpose was to obtain detailed, in-depth information regarding the candidates' technical self-reflection. Accordingly, the four questions focused on the groups' solution paths, their purposeful use of geometric shapes, their rationale for determining length measurements, and the aspects of their products they wished to develop. This provided a depth of process-oriented data on the groups' specific mathematical and engineering reasoning that the rubric alone could not capture.

Activity Opinion Form: This form, consisting of eight open-ended questions, was used to obtain participants' summative opinions and reflections about the entire activity. To ensure content validity and comprehensibility, the draft form, which was developed based on a literature review, was then reviewed by the same two field experts who validated the other instruments. Feedback from the experts regarding the clarity and relevance of the questions was incorporated to finalize the form. Its purpose was not to function as a pre/post-test to measure changes in attitude or deep cognitive learning outcomes. Instead, this form was designed to capture participants' summative reflections on the entire experience, and its questions were directly aligned with the study's primary aims . Specifically, the questions focused on participants' prior STEM knowledge, their general opinions of the activity, the difficulties they encountered during the process, the interdisciplinary connections they made (particularly relating mathematics) and their willingness to apply such activities in their future careers. Therefore, this form was not intended to be the sole source of "in-depth" data. It served as a crucial triangulation tool. The qualitative data from this form provided a holistic, reflective context that, when combined with the quantitative peer-assessment data (from the Rubric) and the technical self-reflection data (from the

Product Form), enabled a rich, in-depth understanding of the candidates' experiences within this case study.

Implementation Process

The activity was held for three class hours a week (3 x 50 min) for a total of six class hours in two weeks. The researchers supervised the process. Figure 1 describes the research process:

Week 1

- Lesson 1: Information of STEM education
- Lesson 2: Tinkercad training
- Lesson 3: STEM activity: Designing on Tinkercad, feedback

Week 2

- Lesson 4: STEM activity: Making a product with concrete materials
- Lesson 5: STEM activity: Filling out Product Grading Forms + Presentations of the products + Filling out Product Grading Rubrics
- Lesson 6: Filling out Product Grading Rubrics and Opinion Forms

Figure 1. The Implementation Process

In the first two hours of the process, the teacher candidates were given preparatory STEM and Tinkercad training. The designing part of the activity started in the third class hour. For this, the teacher candidates worked in four groups. Accordingly, the first (G1), second (G2) and fourth (G4) groups comprised five participants and the third (G3) group comprised four teacher candidates. The activity implemented in our study was developed by the researchers, who based it on a design-based teaching approach. In the introduction to the activity, the teacher candidates were asked a question to test the extent of their knowledge and whet their curiosity: "Have you ever played court tennis?" After the teacher candidates responded to this question, a video was shown on the sport of court tennis and its scoring. Another question was then posed: "How do we collect the balls that fall on the court in tennis?" Following the teacher candidates' responses, a video was shown on different techniques of collecting tennis balls from the court with baskets and other means. Worksheets were distributed to the groups and the participants started the problem-solving stage as shown in Figure 2.

> Ms. Melissa has been playing court tennis as a professional with her friend for seven years. But she has to bend down continuously to pick up the limited number of balls that fall while she's playing. One day, as she was bending down, she heard a crack and found it hard to get back up. When she went to the hospital, the doctor told Ms. Melissa that she had a slipped disc and shouldn't bend down anymore. How can you help Ms. Melissa continue to play tennis under these circumstances?

Figure 2. The Problem to Solve on the Worksheet

Once the problem seen in Figure 2 was conveyed to the teacher candidates, they were asked to follow the engineering design steps set down by Brunsell (2012) and Wendell et al. (2010) and later revised by Ercan (2014). According to this model, the first step is to define the problem. Then, the groups brainstorm to develop solutions to solve the problems and are asked to write down their ideas. Later, the researchers reviewed the groups' ideas together with the groups to arrive at the most appropriate solution. Each group created a 3D model for the solution on the Tinkercad program (Figure 3). The researchers reviewed the models and gave the groups feedback. This completed the lessons for the first week. The teacher candidates were given one week before the next lesson to create a concrete model of their idea with tangible materials.

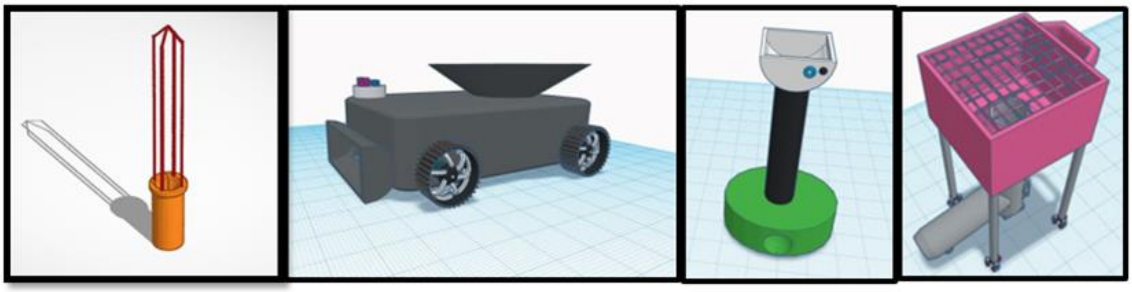

Figure 3. The Sample Models Created by the Teacher Candidates on Tinkercad

In the first lesson of Week 2, each group built their model with concrete materials. Waste materials were utilized for this part of the activity (Figure 4). At the same time, the groups were asked to fill out the Product Evaluation Form to evaluate their own product.

Figure 4. The Process of Creating a Product with Concrete Materials

In the last two hours of the activity, the groups introduced the products they had developed to their classmates (Figure 5). All of the groups then evaluated and graded the products introduced to them.

Figure 5. Process of Introduction of the Teacher Candidates' Products

Data Analysis

Data analysis was conducted using a mixed-methods approach, which is well-suited for a case study design as it facilitates a comprehensive triangulation of data (Yin, 2018). The analysis was systematically structured to address the primary aims of the study. First, to address the aim of evaluating the products presented by the teacher candidates, the quantitative data from the Product Evaluation Rubrics were analyzed. This analysis was not merely "descriptive statistics"; it specifically involved calculating the mean scores, standard deviations, minimums, maximums, and ranges for the peer assessments of the group products. This provided a statistical overview of product performance against the established criteria. Second, to address the aims of examining candidates' experiences, perceptions, and the activity's effects on their professional development, qualitative content analysis was applied to the data from the Activity Opinion Form. This analysis was also used on the Product Evaluation Form to provide a deeper understanding of the product evaluation results.

The qualitative content analysis followed the systematic stages outlined by Merriam (2009). This process involved more than just open coding; it followed a clear interpretive structure. Initially, two researchers independently read all participant responses to gain a holistic understanding. Following this, they engaged in open coding to create an initial list of codes directly from the data. The analysis then proceeded iteratively: related codes were grouped to form descriptive categories (e.g., technology use, collaborative work). These categories were then interpreted, compared, and clustered to identify the overarching themes presented in the findings (e.g., positive experiences, design-related difficulties). To ensure the trustworthiness and inter-rater reliability of this qualitative process, procedures outlined by Miles and Huberman (1994) were followed. As the goal in this qualitative study was to achieve a deep, shared understanding rather than just a minimum statistical threshold, a numerical coefficient was not the primary focus. Instead, a rigorous 100% consensus approach was adopted. The two researchers independently coded the data, then met for multiple rounds of systematic comparison and dialectical discussion. During this process, every discrepancy was debated and resolved. This consensus-based method, which ensures all final codes, categories, and themes were fully agreed upon by both researchers, was deemed more robust for this case study than a singular numerical coefficient, which can sometimes mask underlying interpretive differences. Finally, key findings were reinforced with direct quotations. Direct quotes in the qualitative data were presented by coding them as P1 for the participants and G1 for the groups.

Findings

Findings on Participants' Prior STEM Knowledge and Experiences

The findings obtained from the opinions of mathematics teacher candidates show that all 19 participants had knowledge about STEM education before the STEM activity they attended, and the vast majority of them acquired this knowledge during their undergraduate education (f=14). In addition, it was found that the candidate coded P14 encountered STEM applications in high school. This participant stated that 'There was a STEM class in the high school I graduated from'. Also, there were teacher candidates who attended a conference about STEM (P1) and participated in a STEM-related project work (P3).

When the opinions of the teacher candidates about STEM were evaluated, it was found that the participants mostly highlighted the interdisciplinary aspect of STEM (f=7). Accordingly, the view of the participant coded P4 was as follows: 'STEM is a study that is based on constructivism with an innovative perspective in education and includes technology, science, engineering and mathematics'. This statement shows that STEM is associated with the constructivist approach and it has interdisciplinary dimension. Another view which emphasized that STEM allows adapting to the requirements of the age and includes 21st century skills was as follows: 'I think that STEM generally includes 21st century skills, and it is related to engineering etc. fields of daily life, and is an education that will enable us, and even go beyond, to keep up with the times while training the students of the future.' P2

The evaluation of the participants' STEM experiences prior to their attendance in the current study showed that despite having knowledge about STEM, the vast majority of the participants (f=15) did not participate in a STEM activity before this activity. The opinions of two teacher candidates who previously participated in a STEM activity are as follows: 'I designed bridges and roofs using engineering and mathematics.' P11 'When I was in high school, we designed a robot that included robotic coding.' P14

Findings Related to the Products Designed by the Participants

The concrete products created by each group were evaluated and graded by the participants who were not members of that group. The results of this assessment can be seen in Table 1.

Table 1.
Results of the Peer Grading of the Group Designs

Grup	min	max	range	Mean	*SD*
G1	17	25	8	20.29	2.23
G2	14	25	11	21.57	2.95
G3	18	25	7	22.00	2.50
G4	5	25	20	17.21	6.71

According to Table 1, the mean scores given to the designs of G1, G2 and G3 were close to each other, varying between 20.00-22.00. We observed that the score for G4 was below this range. While G3 displayed the highest score, G4's mean score was the lowest. In other words, the teacher candidates had assessed G3 to be the group to create the product that more closely matched the criteria, declaring as well that G4 had created the product that least matched the criteria.

The results of the separate assessment of each group's scores derived from the items on the rubric in the peer evaluation can be seen in Table 2.

Table 2.
Group Gradings of Rubric Items

Items	Mean *(SD)*				
	G1	G2	G3	G4	Average
I1: The design is original.	4.29 (0.91)	4.57 (0.65)	4.60 (0.51)	3.64 (1.34)	4.29 (0.99)
I2: The design can be applied to real life.	3.79 (0.80)	4.50 (0.76)	4.40 (0.74)	3.29 (1.38)	4.00 (1.04)
I3: The design is useful and cost-effective.	3.57 (0.94)	4.50 (0.85)	3.47 (1.19)	3.14 (1.35)	3.66 (1.05)
I4: The design reflects the engineering design process and incorporates technology.	4.29 (0.82)	3.50 (0.85)	4.73 (0.59)	3.50 (1.45)	4.00 (1.07)
I5: The design presents a solution appropriate to a real-life problem.	4.36 (0.63)	4.50 (0.65)	4.80 (0.41)	3.64 (1.50)	4.33 (0.91)

According to Table 2, while G3 displayed the highest grade in terms of originality of design, ($M = 4.60, SD = 0.51$), G4's grading was the lowest in this category ($M = 3.64, SD = 1.34$). In terms of applicability to real life, the highest grading for the design was given to G2 ($M = 4.50, SD = 0.76$); the lowest grading in this category belonged to G4 ($M = 3.29, SD = 1.38$). The appropriateness of the design's practicability and cost effectiveness were also similar. In keeping with the nature of STEM education, another important competency to be expected in designs is whether or not the product reflects the engineering design process and incorporates technology. In this context, the highest grading was given to G3's design ($M = 4.73, SD = 0.59$) while the lowest belonged to G2 ($M = 3.50, SD = 0.85$) and G4 ($M = 3.50, SD = 1.45$). In the last item on the rubric, which was related to presentation of appropriate solutions of real-life problems, G3 was rated as exhibiting the most appropriate solution ($M = 4.80, SD = 0.41$) while G4's design was found to offer the poorest solution ($M = 3.64, SD = 1.50$).

A review of the explanations provided by the groups on the Product Evaluation Form regarding the teacher candidates' process of design development is present in Table 3.

Table 3.
Details of Designed Products

Groups	How Did You Determine Your Path to the Solution?	Which Geometrical Figures Did You Use?	What Did You Take as a Reference Point for the Dimensions of the Product?	What Were the Aspects of the Design that You Wanted to Develop?
G1	-Vacuum mechanism -Basket on top -Sensor to sense the balls -Motor to carry the balls to the basket	-Rectangular prism -Cylinder -Cone	-Dimensions of the tennis court	-Dimensions -A different design instead of the vacuum mechanism -Sensor system -Wheels compatible with different surfaces
G2	-Rubber barrier to collect balls and prevent their escaping -Four cylindrical sticks at equidistance reaching upward so that the individual does not have to bend down -Hinged connection to let collected balls out when capacity is reached	-Cylinder	-Dimensions of a tennis ball -Average person's leg length	-Extendible body suitable for athletes of different heights
G3	-Vacuum mechanism	-Cylinder -Sphere	-Average person's height	-Dimensions adjusted to a person's height -A different concept to prevent balls from falling from the collection basket -Mechanism for objects outside of balls
G4	-Vacuum mechanism -Fans -Basket on top to collect balls	-Cube -Circle -Cylinder -Cone	-Dimensions of a tennis ball -Average person's height	-Operable without human assistance

In the review of Table 3, we saw that when the participants were asked how they arrived at a method of solving the problem, the method the groups used to prevent players from bending down was mostly to design a vacuum mechanism (G1, G3, G4). The following quotation underlines why this design was chosen: 'To not have Ms. Melissa exert herself to bend down all the time to catch the tennis balls, we developed a robot that vacuumed the fallen balls from the ground with the help of fans suitable to her height and collected them in the basket.' (G1) Another result that can be seen in Table 3 was that each group's design contained a common geometrical form–the cylinder. On the other hand, there were groups that made use of other geometrical forms (G1, G3, G4). For example, G1 described the stages of their design process and how they used different geometrical forms by saying 'To create the main body, we tapered the corners of a rectangular prism. We formed the opening of the machine with half of a cylinder. We made an aperture using a small rectangular prism to shape an opening for the balls to go through. To collect the tennis balls in the upper area, we took a cone and cut off the base a little and then used a small cone to empty it. We added four wheels to make the machine mobile.'

The responses given to the question "What Did You Take as a Reference Point for the Dimensions of the Product?" indicated that the groups had taken the actual dimensions of a tennis court (G1), the dimensions of a tennis ball (G2, G4) and the average height of a human being (G2, G3, G4) as their reference points. Differing from the other groups, G1 expressed their reference point for the dimensions of their design as the length of a tennis court: 'We adapted the dimensions of the design according to the standard dimensions of a tennis court. Since a court is 23.78 m (78 ft) long, and 10.97 m (36 ft) wide, we calculated that our robot would be 0.6 m long and 0.4 m wide.' Stating that they had taken the actual dimensions of a tennis ball and the average height of a human being as reference points, G2 stated that their goal was not to have the tennis player bend over: 'We decided on 26 cm for the first area and 52 cm for the third area. The specifications for the areas were determined on the basis of the length of the diameter of a tennis ball. The total length of our product was 78 cm. This measurement is the ideal length for an average person's height. These dimensions were chosen so that the tennis player would not have to bend over to pick up the balls.'

In the review of the aspects of the designs that the groups wished to develop, we saw that G1 felt they could improve the dimensions of the product, use wheels that were compatible on every surface and also make improvements in the sensor system. G1's suggestion is as follows:

> A change in dimensions can be optional. Another type of system can be used instead of a vacuum system. The sensor system can be developed further if it proves to be inefficient. The wheels can be developed to be more compatible with different surfaces.

G2 suggested that they could devise an extendible body for tennis players of different heights. G2's suggestion is as follows: 'An extendible body can be designed to accommodate tennis players of different heights.' In addition, G3 mentioned revising the product so that its dimensions prevented the collected balls from falling and the product would work with objects besides balls. G3's suggestion is as follows:

> It can be adjusted to the person's height. The balls will be collected in the upper basket and new incoming balls will be carried there. We can develop another idea to see that the balls in the basket do not fall back. Outside of this, a mechanism can be developed for other systems outside of the ball system.

G4 suggested developing a device that would operate on its own algorithm without human assistance. G4's suggestion is as follows: 'We want the robot to collect the balls by means of its own algorithm without human assistance. '

Findings from Participants' Views on the Activity

The findings concerning participants' experiences during the course of the activity are displayed in Table 4.

Table 4.
Participants' Experiences During the Activity Process

Categories	Codes	Participants
Positive	Fun	P2, P7, P10, P11, P12
	Supporting group work	P3, P5, P6, P9, P10
	Creating solutions to problems	P1, P2, P4, P9, P14
	Contributing to technology knowledge	P3, P8, P10, P17
	Developmental	P1, P12, P15
	Enhancing creativity	P5, P6, P10
	Acquiring knowledge about STEM education	P13, P19
	Allowing idea exchange	P15
	Improving hand-eye coordination	P5
	Enabling research	P11
	Changing perspectives	P16

Table 4 continuing

	Allowing design creation	P19
	Satisfying	P18
Negative	Tiring	P2, P11
	Having challenging sections	P10

As seen in Table 4, the feedback from teacher candidates regarding their experiences during the activity process were predominantly positive. Although participants like P2, who stated, 'It was a fun and tiring activity that allowed us to blend a problem we might encounter in daily life with our existing mathematical knowledge and skills' and P10, who said, 'Although it had challenging sections, I enjoyed doing it. It was an activity that developed creativity, technological relationships, and social cooperation skills...' expressed negative thoughts, it can be inferred that they generally liked the activity. The participants who emphasized positive aspects highlighted that the activity was fun, created solutions to problems, supported group work, and contributed to technology knowledge. Examples of positive views regarding the activity are as follows: 'It was an activity that could create solutions to a problem in daily life and was comprehensive and developmental as it required thinking about all situations.' P1 'In today's conditions, STEM is an essential part of education. We gained insight into the STEM skills that new generation teacher candidates and teachers need to acquire.' P13

Table 5 displays the findings concerning the contributions of the STEM activity to the participants' development.

Table 5.
Contributions of the STEM Activity to Participants

Categories	Codes	Participants
Contributions to Personal Development	Learning design program	P1, P8, P9, P12, P19
	Communication skills	P5, P6, P7
	Quick decision-making	P2, P11
	Different perspectives	P2, P9
	Developing social skills	P5
	Enhancing creativity	P10
	Product creation	P10
Contributions to Learning Environment	Collaborative work skills	P5, P6, P7, P8, P9, P13, P15
	Relating	P2, P11, P15
	Producing solutions to problem situations	P4, P11
	Three-dimensional design	P16
	Concretizing mathematics	P7
	Making mathematics fun	P7
	Contribution to group work	P9
Contributions to Teaching Career	Example for teaching career	P3, P6, P12, P13
Contributions to High-Level Cognitive Thinking	Creativity	P5, P6, P7, P8
	Multidimensional thinking	P4, P13
	Critical thinking	P5
	Problem-solving	P13
	Reasoning	P13
	Three-dimensional thinking	P3
	Practical thinking	P4

As seen in Table 5, the activity contributed to the personal development of teacher candidates, especially in learning a design program, communication skills, quick decision-making, and gaining different perspectives. Additionally, encouraging collaborative work is a significant contribution to the teacher candidates in terms of the learning environment. Participating in STEM activities provided an example for the teaching careers of teacher candidates. In terms of high-level cognitive thinking processes, the activity was found to contribute to creativity and multidimensional thinking skills. Examples of the participants' views are as follows: 'I learned a different application where we can design 3D products with the activity.' P19 'Our cooperation and communication skills developed because we worked as a group in the activity, our critical thinking skills developed because we evaluated at the end of the design, and our creativity skills developed because we designed a product.' P5 'It was an unforgettable activity process. It gave me an idea to do similar applications with students when I become a teacher in the future.' P6

The disciplines other than mathematics that teacher candidates associated the activity in producing solutions to the problem situation are presented in Table 6.

Table 6.
Disciplines Associated with the Activity in Producing Solutions to the Problem Situation

Related Disciplines	Participants
Engineering	P2, P4, P5, P6, P7, P8, P10, P11, P13, P14, P15, P17
Technology	P3, P5, P6, P8, P9, P10, P12, P13, P17, P18
Physics	P1, P2, P4, P11, P14, P17, P19
Daily Life	P3, P5, P11
Science	P6, P13
Art	P12, P15
Architecture	P7
Sports	P3
Can be Related to Every Discipline	P16

According to Table 6, the disciplines that participants related to along with mathematics during the activity process were predominantly engineering, technology, and physics. This finding aligns with the participants' pre-activity explanations regarding STEM education, where they emphasized the interdisciplinary aspect of STEM. Participants perceived STEM education as an interdisciplinary approach and believed that mathematics is a fundamental component of this approach. It can be said that the activity process reinforced or developed this perspective of the participants. They had concrete experiences by relating mathematics to different disciplines during the activity, which may have deepened their understanding of STEM education.

In the study, it was determined that all teacher candidates except for P5 and P16 encountered several difficulties during the activity process. Table 7 presents the findings regarding these difficulties.

Table 7.
Difficulties Experienced by Participants During the Activity Process

Categories	Codes	Participants
Design-Related Difficulties	Transferring mental image to design	P3, P13, P17
	Combining product parts	P10, P14, P15
	Finding ideas	P7, P13
	Mental visualization	P1
Technology-Related Difficulties	Technology use	P4, P6, P7, P8, P10, P12, P19
Material-Related Difficulties	Material supply	P1, P2, P11
	Wrong material selection	P18
	Material insufficiency	P15
	Material fragility	P9
Time- Related Difficulties	Time-consuming	P6, P11
Difficulties Related to Collaborative Work	Unequal contribution from group members	P14

Table 7 indicates that the difficulties related to design were at the forefront of the difficulties experienced by teacher candidates. This finding was followed by difficulties related to technology use and materials, which are significant components in product creation. Examples of participant views obtained in this context are as follows: 'We had difficulty in the joining the parts when creating the model. The reason was material insufficiency.' P15 'I had the most difficulty in using Tinkercad in the activity. It was a program I didn't know before. Therefore, the design initially challenged me.' P4

When the intentions of the teacher candidates to use such kind of STEM activities in their own classrooms in the future were asked, a large majority of them stated that they would like to use similar activities in their professional lives. The findings regarding their reasons are presented in Table 8.

Table 8.
Findings Regarding the Reasons Participants Want to Use Similar Activities in Their Professional Lives

Categories	Codes	Participants
Learning-Teaching Approaches and Methods	Collaborative learning	P6, P7, P9
	Active participation	P10, P12
	Suitability for constructivist approach	P2
	Fun	P5, P12, P16, P18
	Attracting attention	P3
	Connecting	P19
Cognitive/Psychomotor Skills	Self-regulation skills	P6
	Psychomotor skills	P7
	Cognitive skills	P7
	Research skills	P9
Creativity	Enhancing creativity	P1, P6
	Problem-solving	P4
	Imagination	P16
Technology	Keeping up with developing technology	P3
	Keeping up with the times	P8
Personal Development	Socialization	P7
	Broadening horizon	P5, P15
	Skill development	P15
Understanding of Mathematics Education	Seeing that mathematics is not just about numbers	P15

According to Table 8, teacher candidates preferred to use STEM activities similar to the one in this study in their future professional lives was primarily due to the contributions of the activity to learning-teaching approaches and methods. In addition, other related reasons included the contribution to cognitive/psychomotor skills, creativity, personal development, and the inevitability of technology. Also, one of the important findings was that the activity provided a different understanding for the participants by showing that mathematics is not just about numbers.

Discussion, Conclusion, and Suggestions

The present study indicates that many teacher candidates participating in the activity had knowledge about STEM from their undergraduate education but lacked practical experience. This result is supported by the literature which indicates that the majority of participants heard about the concept of STEM before the study they attended about STEM education (Çavuş et al., 2021; Rifandi et al., 2020). On the other hand, most teachers have no prior interdisciplinary STEM education experience (Tosmur-Bayazıt, 2018) and teacher candidates need role models for successful STEM implementations (Ryu et al., 2019). In addition, it was determined that teachers find the STEM education they receive at the undergraduate level inadequate (Yıldırım, 2018). Accordingly, these findings imply the significance of the effective STEM education applications with teacher candidates during their undergraduate education as in the current study. Thus, teacher candidates' STEM awareness can be raised (Güleryüz, 2020; Kalemkuş, 2020; Özçakır Sümen & Çalışıcı, 2022; Siew et al., 2015). Besides, the current study shows that teacher candidates had positive perspectives towards STEM education and mentioned constructivism, interdisciplinary learning, adaptation to the requirements of the age and 21st century skills in terms of their preconceptions of STEM education. Yet, it is believed that transforming these positive views into experience is more substantial for the individuals who will be teachers in the near future. Indeed, it is pointed out that a teacher's perception and knowledge level regarding STEM is directly related to the practices they implement in their own classrooms (Bell, 2016). On the contrary, when teachers lack sufficient knowledge and understanding of STEM, it is pointed out that their students' learning potential will also be limited. So, this paper focuses on a group of teacher candidates participating in a STEM activity and evaluates their opinions, experiences, and reflections from several aspects.

In the current study, mathematics teacher candidates worked in small groups, designed materials to collect tennis balls easily on the ground with the help of Tinkercad program, and then they created their products with the help of tangible substances. When the products generated in the activity are evaluated, it was found that the participants mostly highlighted "providing solutions suitable for real-life problem situations". This result is also in line with one of the mostly asserted positive aspects of the activity which was creating solutions to a problem. So, in this study, teacher candidates perceived the fundamental aim of STEM education as to generate solutions to a problem situation. A similar opinion was also found to be frequent among Indonesian (Rifandi et al., 2020) and Thai teacher candidates (Pimthong & Williams, 2020). The problem situation in this study dealt with tennis, a kind of sports. This situation was also reflected in the responses of the participants which indicated the connection of the activity with sports and daily life. So, it can be stated that consistent results were obtained in this context.

Other results of the product grading indicate that the teacher candidates found their designs to be original, real life-applicable and included engineering design and technology use. All of these points are concluded to be in line with the fundamental aims of STEM education. On the other hand, the participants were determined to give the least importance to "cost and usability of the design." This point suggests a need for improvement of the desings in several aspects. Also, this result is in line with what was obtained from the product evaluation forms of the groups. In this regard, the aspects that teacher candidates wanted to improve in their products were related to the design and the dimensions of the product rather than the solutions they offered to the problem situation. Hence, design process emerges as an issue which should be carefully considered by the researchers and the teacher candidates. On the other hand, the participants mentioned the utilization of technology and design both in terms of the contributions of the activity into their future professional lives and the challenges of the activity. Indeed, the current study involves the design applications of Tinkercad which is widely used in STEM studies. Also, it is encountered that middle school students (Dertli & Yıldız, 2025; Küçük et al., 2024; Şen et al., 2020; Tüysüz et al., 2024) and high school students use Tinkercad in such studies (Pabuçcu Akiş & Demirer, 2023). Hence, incorporating the skills to use this technological application to the teacher candidates is significant. The literature outcomes also report technology utilization among the positive aspects of STEM activities conducted with teacher candidates (Eroğlu & Bektaş, 2016; Ürek & Çoramık, 2023). As well as the positive results, the study of Awad and Barak (2018) also shows challenges faced by the teacher candidates in terms of the utilization of technology. In the current study, the participants perceive technology and design applications both as a gain and difficulty. This case signifies that learning to use and adapt technology in-class applications requires a systematic approach rather than to limit this process into a period of a STEM activity. Technology and design are fundamental dimensions of STEM activities and therefore they need to be carefully considered. So, it may be more appropriate to cover technological applications, which allow students make designs, specifically in a separate course over a longer period, such as one semester to eliminate such dilemma.

When the details of the teacher candidates' designs are evaluated, it was found that cylindrical, conical, circular, rectangular, spherical, and cubic geometric shapes were used in the designs. This situation matches with the focus of the study as the activity was structered around mathematics and mathematics teacher candidates. Indeed, Liu (2020) highlights the role of mathematics in STEM education which provides service in learning and teaching. Also, mathematics was associated with various disciplines during the activity process such as engineering, technology, and physics. Considering the holistic structure of STEM (Eroğlu & Bektaş, 2016), which enables students to relate and apply the fields of science, technology, engineering, and mathematics (Thomas, 2014), it is an expected result that teacher candidates relate mathematics, which is one of the STEM disciplines, with other fields.

Other results of the study indicate that teacher candidates' opinions and experiences during the activity process were generally positive. In this context, various advantages and contributions of the activity were determined among participants' responses. For example, the positive experiences of the participants included being fun, enhancing creativity, and supporting group work. The literature also reports that such kind of STEM activities are fun (Çavuş et al., 2021; Özkan & Topsakal, 2017; Sarı & Katrancı, 2020; Tosmur-Bayazıt, 2018; Ürek & Çoramık, 2023). This finding was consistent with another outcome of the study which indicated that teacher candidates plan to use similar activities in their future classes. Thus, the conducted activity presents a good example for the teacher candidates' professional development. Another positive aspect of the activity, enhancing creativity was also mentioned among the contributions of the activity to the participants in terms of their future professional lives. This result is noteworthy and consistent with the literature (Ceylan et al., 2018; Çavuş et al., 2021; Çınar & Terzi, 2021; Gülhan & Şahin, 2018). The participants used their creativity to generate products to find solutions to collect tennis balls on the ground in different ways in this study. Moreover, the participants stated that the activity contributed to their communication skills as supported by other research through STEM education (Choi & Hong, 2013; Sarı & Katrancı, 2020). On the other hand, despite stating among the positive aspects, working in groups was also asserted as a challenge of the activity in line with the literature (Sarı & Katrancı, 2020; Tosmur-Bayazıt et al., 2018). In this regard, group work was perceived both as an advantage and challenge of the activity by the participants. So, future studies might deal with this issue in detail.

As well as various positive aspects of the activity, the participants asserted time-related difficulties in the study which were parallel with the previous studies' results (Çınar & Terzi, 2021; Eroğlu & Bektaş, 2016). Moreover, the current study showed material-related difficulties similar to the STEM studies conducted with teacher candidates (Ürek & Çoramık, 2023), elementary school students (Sarı & Katrancı, 2020), and high school students (Tosmur-Bayazıt et al., 2018). These results support the findings of the current study. Although STEM education can be conducted with economical materials (Stohlman et al., 2012), Çınar and Terzi (2021) attribute the difficulties related to material shortage in STEM applications to the effort to design a complex product. In addition to different grade level students, in-service teachers were reported to face such challenges when designing STEM learning environments (Çınar & Terzi, 2021; Eroğlu & Bektaş, 2016). Hence, teacher candidates' experiences might reduce having material-related difficulties in the future. On the other hand, the literature depicts difficulties related to noise and chaos (Çınar & Terzi, 2021), subject mastery (Eroğlu & Bektaş, 2016), and mathematical calculations in STEM education (Ürek & Çoramık, 2023). These outcomes might be related to the structure of the STEM activity, types of implementations, experiences of the researchers and characteristics of the participants. Therefore, such issues may not have emerged in the current study.

Finally, although the participants faced difficulties during the activity, they stated that the activity had positive implications for their future lives. Thier reasons included various positive effects on learning-teaching approaches and methods, cognitive/psychomotor skills, personal development and understanding of mathematics education. Also, the study indicated that the majority of teacher candidates would like to use similar activities in their professional lives which is consistent with the literature (Çavuş et al., 2021; Rifandi et al., 2020; Yıldırım, 2019). However, Brown et al.'s (2011) study with science, mathematics, and technology teachers showed that although teachers were aware of the importance of STEM, they gave limited place to its application in their lessons. Considering the challenges encountered in the STEM activities and opinions of in-service teachers, it is necessary to eliminate such problems in the field and trigger successful implementations. For these reasons, it is believed that increasing the STEM awareness of teachers and teacher candidates, informing parents and administrative units about this, providing the necessary materials, and designing curricula and classroom sizes suitable for STEM approaches are critical for the effective implementation of STEM activities.

Limitations and Further Research

This study is limited to the application of a single STEM activity on a group of mathematics teacher candidates. This situation results from the restricted number of mathematics teacher candidates to whom researchers can easily access. Also, the current study presents the details of qualitative data obtained prior to and following the STEM activity implementation on these participants. On the other hand, the study process might be enriched with the application of several STEM activities for the teacher candidates over a longer period of time. Also, quantitative data can be collected and experimental studies can be designed with the involvement of experimental and control groups. Thus, various comparisons can be conducted regarding different variables.

In the light of the study results, the following recommendations can be listed:

- More studies with different designs might be conducted with mathematics teacher candidates to present information-rich data to the field. Several research can also be conducted in the form of experimental studies to make comparisons between the groups.
- Different variables such as motivation, attitudes and self-efficacy can be addressed in the future quantitative studies which focus on practical STEM education.
- A course which directly addresses STEM education might be placed in mathematics teacher education programs in Türkiye.
- Specific courses might be placed in all teacher education programs considering technological applications which can also be utilized in STEM education.
- Although several teacher candidates perceive the conducted STEM activity as a gain in terms of making group work, their abilities to work in groups should be enhanced. In this regard, detailed studies might be conducted to determine the problems that hinder teacher candidates' colloboration with each other.
- Teacher candidates should be provided with more opportunities to participate in practical STEM activities to make them gain more knowledge, skills, and experiences in this context. Thus, time- or material-related problems might be eliminated.
- The results of the current study regarding the contributions of the activity to the professional lives of the participants can be examined with long-term follow-up studies.

Acknowledgment

Ethics Statement: In this study, we declare that the rules stated in the "1964 Declaration of Helsinki and its later amendments" and "Higher Education Institutions Scientific Research and Publication Ethics Directive" are complied with and that we do not take any of the actions based on "Actions Against Scientific Research and Publication Ethics". At the same time, we declare that there is no conflict of interest between the authors, which all authors contribute to the study, and that all the responsibility belongs to the article authors in case of all ethical violations.

Author Contributions: First Author: Conceptualization, methodology, supervision, writing and editing. Second Author: Application process, data collection, data analysis, and writing. Third Author: Data analysis, supervision, writing, reviewing, and editing.

Funding: This research received no funding.

Institutional Review Board Statement: Ethical approval was taken from Science and Engineering Ethics Commission of Balıkesir University (E-19928322-302.08.01-374173).

Data Availability Statement: Data generated or analyzed during this study should be available from the authors on request.

Conflict of Interest: There is no conflict of interest.

Generative Artificial Intelligence Statement: The manuscript was entirely developed without AI-generated content.

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