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An Analysis on the Effect of Design-Based STEM Activity Development Process on Prospective Maths Teachers' Problem-Solving Skills and Scientific Creativity

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ABSTRACT

The aim of this study was to investigate the effect of design-based STEM activities developed by prospective secondary school maths teachers on their problem-solving skills and scientific creativity. An explanatory sequential mixed methods design was used in the current study, involving 45 senior students (i.e., prospective secondary school maths teachers) studying at a state university in the West Black Sea Region, Turkey during the academic year 2018/19. The participants were selected according to a purposive sampling method to be involved in our study, which was conducted during a course named "Science, Technology, and Society," and the implementation stage, of which took a total of 14 weeks, as three course hours per week. The "Problem Solving Inventory" (PSI) and "Scientific Creativity Test" (SCT) were used for the purpose of obtaining the quantitative data of the research, whereas interviews were conducted with the prospective teachers for collecting the qualitative data. The quantitative data were analyzed using a dependent t-test, while qualitative data was analyzed by descriptive analysis. A slight increase was detected in participants' problem-solving skills in relation to developing STEM activities, though not statistically significant. However, as a result of the implementation process, the scientific creativity of prospective teachers turned out to increase in such a way that it indicated a statistically significant difference.

Keywords: STEM education, design-based learning, problem-solving skill, scientific creativity, prospective maths teachers

Introduction

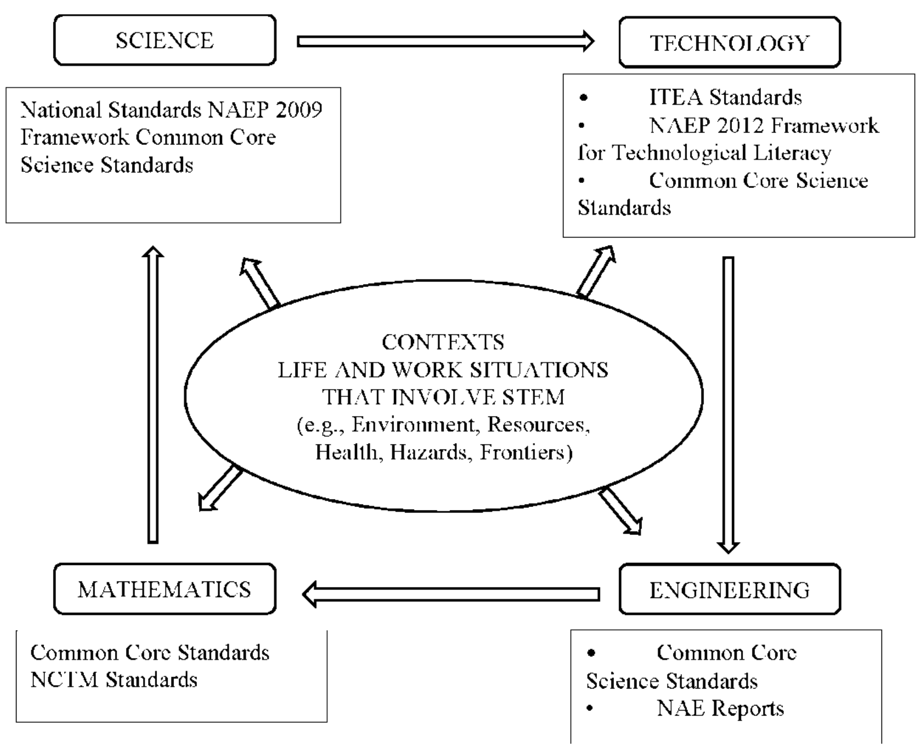
With the development of technology in recent years, the needs of countries and the workforce required to meet these needs have changed significantly. By the same token, the technological competition between countries has increased, and all developed countries have started to invest in people working in the fields of science, technology, engineering, and mathematics (STEM) (Corlu, 2014). Many researchers and industries have long emphasized that the labor supply cannot be met with the information processed and converted into products, in primary and secondary (K-12) schools. In this direction, it is recommended to re-evaluate the curricula that are currently being implemented and to focus on raising the number of people suitable for the competencies needed in today's society (Akgunduz et al., 2015; Turkish Industry and Business Association [TIBA], 2014). As a consequence, individuals are expected to think from a scientific point of view, question accordingly, think critically, develop solutions to problems, be creative and productive, and have the necessary skills to work in an interdisciplinary manner cooperatively (Akaygun & Aslan Tutak, 2016; National Research Council [NRC], 2011). In order to prepare individuals with the necessary skills, countries aim to organize their education systems in such a way that individuals can work with interdisciplinary perspectives and have 21st century skills (Demirci Guler, 2017). For this purpose, countries have initiated various reform movements in their education systems (Ministry of National Education [MoNE], 2016). STEM is one of the most popular of these reform movements (Gulhan & Sahin, 2016; NRC, 2011; Seage & Turegun, 2020).

STEM education includes knowledge, skills, and beliefs formed by the intersection of more than one of the fields of science, technology, engineering and mathematics, and where interdisciplinary studies are applied holistically (Corlu et al., 2014; Gonzalez & Kuenzi, 2012). It is the process of gaining experience by using the disciplines of science, technology, engineering, and mathematics in designing a new product or revising an existing product, as well as producing through education, by coming up with relevant solutions to problems (Thomasian, 2011). Undoubtedly, STEM education is expected to train qualified individuals by integrating engineering- and technology-related skills into the fields of science and mathematics (Bakirci & Kutlu, 2018).

The current study was guided by Bybee's (2010a) *A Framework for Model STEM Units*, in which STEM disciplines are used in an integrated way in solving a problem (Figure 1). As seen in Figure 1, there is a daily life problem involving STEM disciplines at the center of the STEM education approach. This problem situation should attract students' attention and at the same time should be appropriate to the student's level. Students use the knowledge and skills of STEM disciplines while investigating the problem.

Figure 1

A Framework for Model STEM Units (Bybee, 2010a, p.33)



The educational needs of our age have come to such an unprecedented dimension that the importance of students' vital skills and knowledge has greatly increased. STEM education and related activities enable students to acquire 21st century skills (Bybee, 2010b; Bybee, 2010c; Honey et al., 2014; Kostur, 2017). These skills remove distances in the global world by enabling individuals from different cultures (Turner, 2013). Students are supposed to work in a planned and systematic way while producing solutions to a problem in the engineering design process of STEM activities (Bybee, 2011; Guzey et al., 2014; Mann et al., 2011). Likewise, while working on the design of a new product related to the solution of problems in this process, they may prompt a new and dissimilar engineering problem to emerge at the end of the process (Lederman & Lederman, 2013; NRC, 2012).

The fact that STEM is generally interpreted as science or mathematics and does not connote technology or engineering is an issue that needs to be resolved (Bybee, 2010a). Although some educators regard engineering as least relevant to K-12 students, STEM education is actually based on engineering (Basham & Marino, 2013). Engineering education can be provided by integrating the engineering field into the fields of science, technology, and mathematics with appropriate activities (NRC, 2010). In order to achieve such integration, the most suitable way is to carry out the activities within the scope of design-based learning (Felix & Bandstra, 2010). However, design-based learning, which supports STEM education and creates an efficient and constructive learning environment, enables students to become creative individuals who can reveal their knowledge and skills in the design process, analyze and evaluate the results in the application process, and share their opinions (Kolodner et al., 2003). Besides that, students become more creative as they present original, new, and distinct products during STEM activities (Charyton, 2015; Larkin, 2015). The reason for this is that creative thinking is included in the engineering design process in STEM activities (Court, 1998).

Design activities form the focus of design-based learning (Fortus, 2005). In the event that students draw on the concepts and skills of science and mathematics while solving engineering problems, it is more likely that they will be able to find solutions more easily (Ercan & Sahin, 2015). According to Crismond (2001), a design-based learning environment is a setting in which students can contribute positively to their problem-solving, decision-making, and collaborative working skills. In particular, it is well known that many mathematics topics are perceived to be generally abstract and difficult to grasp. For this reason, authentic activities are needed in order to teach abstract concepts by establishing a relationship with real-life learning (Acikgoz, 2006; Brown et al., 1989). Similarly, planning the Maths teaching process with design-based activities and performing concrete activities may improve teaching. Akgunduz et al. (2015) emphasized that interdisciplinary approaches should be adopted in teacher education and that curricula should be organized within the scope of STEM education.

The literature shows that research on STEM focuses mostly on science (Akgunduz, & Akpinar, 2018; Bakirci & Kutlu, 2018; Capraro & Slough, 2008; Gulen, 2016). Nevertheless, despite the presence of some studies on STEM in Maths education, it has still been emphasized that the number of such studies should be increased (Akaygun & Aslan-Tutak, 2016; Delen & Uzun, 2018). The development of 21st century skills along with metacognitive knowledge and skills is especially accentuated in the Maths curriculum (MoNE, 2018).

It is, therefore, of great importance for prospective Maths teachers to carry out performances related to STEM education. From this point of view, this study aimed to investigate the impact of the implementation process of design-based STEM activities developed by prospective secondary school Maths teachers on their problem-solving skills and scientific creativity. The prospective teachers' views were also taken at the end of the activity development process. To this end, the research question for this study is "How does the design-based STEM activity development process affect prospective Maths teachers' problem-solving skills and scientific creativity?" The sub-problems that were sought to be answered, in line with the problem statement of the study, are as follows:

- Research Question 1: How does the design-based STEM activity development process affect prospective Maths teachers' problem-solving skills?
- Research Question 2: How does the design-based STEM activity development process affect prospective Maths teachers' scientific creativity?

Problem-Solving Skills

The concept of "problem" is defined in various ways in many different sources. Yavuz et al. (2010) defined this concept as the difficulties faced by people with results which cannot be predicted. Dewey (1997), on the other hand, defined the problem as anything that preoccupies and challenges the minds of individuals. Considering the definitions for the "problem", these authors seem to have a negative connotation in human life. However, the real problem is not the problem itself, what matters is the act of coming up with a solution to the problem (Ozer et al., 2009).

There are various classifications of problems in the literature. However, the most used classification belongs to Jonassen and Kwon (2011), who divided problem types into well-structured and ill-structured. Well-structured problems are mostly questions at the end of units or chapters in Science and Maths lessons, whereas ill-structured problems are those frequently encountered in daily life (Yua et al., 2010). Because daily life problems are embedded in the lives of individuals, individuals try to cope with them and need to solve them (Tambychik & Meerah, 2010).

Problem solving is learned from a very early age, and problem-solving skills are developed at school age (Miller & Nunn, 2003). According to Heppner and Krauskopf (1987), problem-solving skills refer to developing cognitive, affective, and behavioral responses in order to adapt to internal or external stimuli. According to Dewey (1997), the problem-solving process starts with a problem and ends with defining the problem, giving suggestions to present possible solutions, collecting appropriate data, testing hypotheses, solving the problem, and reporting the results.

Individuals need to possess problem-solving skills in order to solve the problems they encounter throughout their lives (Ekici-İnel & Balim, 2013; Jonassen, 2002). Considering the importance of problem-solving skills in human life, it is necessary that such skills be taught to students at a very early age. In this regard, it is often emphasized that students are able to develop 21st century skills and solve problems related to daily life thanks to STEM education (Dewaters & Powers, 2006; Tseng et al., 2013). Capraro and Slough (2008) emphasized that STEM education enables students to learn and solve problems related to daily life.

A number of scales and tests exist in the literature to determine students' problem-solving skills (e.g. Ekici-İnel & Balim, 2013; Hawkins et al., 2009; Heppner & Peterson, 1982; Pekbay, 2017; Sezgin, 2011; Wakeling, 2007; Yaman & Dede, 2008). However, such scales are based on social problem-solving skills rather than daily, life-based problem-solving skills. In addition, it is seen that the most used scale about problem-solving in the literature is the Problem Solving Inventory (PSI) developed by Heppner and Peterson (1982).

Scientific Creativity

Creativity includes the process of creating an original product in every area where a problem needs to be solved (Cellek, 2002). In other words, individuals produce new and different products by coming up with solutions to existing problems (Gardner, 1997; Plucker et al., 2004). Wallas (1926) summarizes the creative process in four stages: preparation, incubation, illumination, and validation. In the preparation stage, which is the first stage of the process, individuals define the problem and try to seek solutions. They present new syntheses and ideas for the problem in the incubation stage. They come up with a solution to the problem in the illumination stage, and the solutions found to the problem are verified and the deficiencies are met during the verification, which is the last stage. Creativity is especially active while creating a new and original product, by drawing on the knowledge that exists in an individual during the problem-solving process (Dogan, 2011; Paulus, 2000; Torrance, 1968).

Creativity of individuals can be expressed as the ability to create original products at the end of a process or the creation process itself. However, if this skill aims to find a solution to a scientific problem in a process with certain limits, it denotes scientific creativity (Liang, 2002). Creativity and scientific creativity are regarded as different concepts in the literature (Liang, 2002; Lin et al., 2003). Scientific creativity refers to generating an original product in a field of STEM, or owning a scientific skill in the related field (Rawat, 2010). Hu and Adey (2002) emphasized that scientific creativity is a process that includes the practice of solving scientific problems. The authors stated that scientific creativity is a developmental process that includes scientific knowledge. Scientific creativity should not only embody a technical product made with scientific knowledge, but also a process designed to solve a scientific phenomenon or problem (Aslan, 1994; Atasoy et al., 2007; Hu & Adey, 2002). Aiming at coming up with a new and different solution to a scientific problem, individuals should use scientific methods, especially along with innovative solutions and scientific creativity (Harlen, 2004; Meador, 2003).

Hu and Adey (2002) proposed a creativity model in which scientific creativity is defined and criteria are specified. This model consists of three dimensions: creative process, creative character, and creative product. The creative process dimension of the model consists of divergent thinking and imagination. Divergent thinking is the ability to produce various answers with a multidimensional perspective in solving a problem. Imagination, which is the most significant feature of creativity, is to design a mental setting or phenomenon with known objects and ideas (Hu & Adey, 2002; LeBoutillier & Marks, 2003).

Whether or not an idea is the product of creative thinking can be understood by evaluating the dimensions of fluency, flexibility, and originality that define the character of the ideas (Hu & Adey, 2002). Fluency includes producing more than one idea, flexibility includes producing different ideas with the same stimulus, and originality refers to producing new and original ideas (Guilford, 1986; Hu & Adey, 2002; Torrance & Goff, 1989). In the dimension of fluency, individuals express their ideas verbally or in different ways by producing a large number of ideas and offering a variety of suggestions for possible solutions to a problem (Hu & Adey, 2002; Jaarsveldt, 2011).

On the other hand, in the dimension of flexibility, people can easily adapt to different situations or environments by evaluating the situation from different perspectives and producing different and exceptional ideas (Hu & Adey, 2002; Kontas, 2015). Whereas in the dimension of originality, individuals put forward an idea or product that has not been tried or produced before, make innovative attempts while looking for a solution to the problem, and offer an original solution that has not yet been produced either (Hu & Adey, 2002; Jaarsveldt, 2011). In the dimension of generating a creative product within the creativity model in science, the products to be made as a result of creative thinking should be technical products. Scientific knowledge in relation to such products must be set forth, must correspond to a scientific phenomenon, and must be designed to solve a scientific problem (Hu & Adey, 2002; Ustundag, 2014).

Combining the creative design process with the engineering design process is of particular importance in that it contributes to individuals' creative thinking skills (Hacioglu, 2017). Especially for the case of secondary school students, the engineering design process improves scientific creativity and problem-solving skills (Samuels & Seymour, 2015). STEM education also includes a process that contributes to students' creative thinking while seeking solutions to problems (Charyton, 2015; Havice, 2015). Hence, it is necessary to be open to innovations offered through activities and performances that develop students' creative thinking skills in teaching environments.

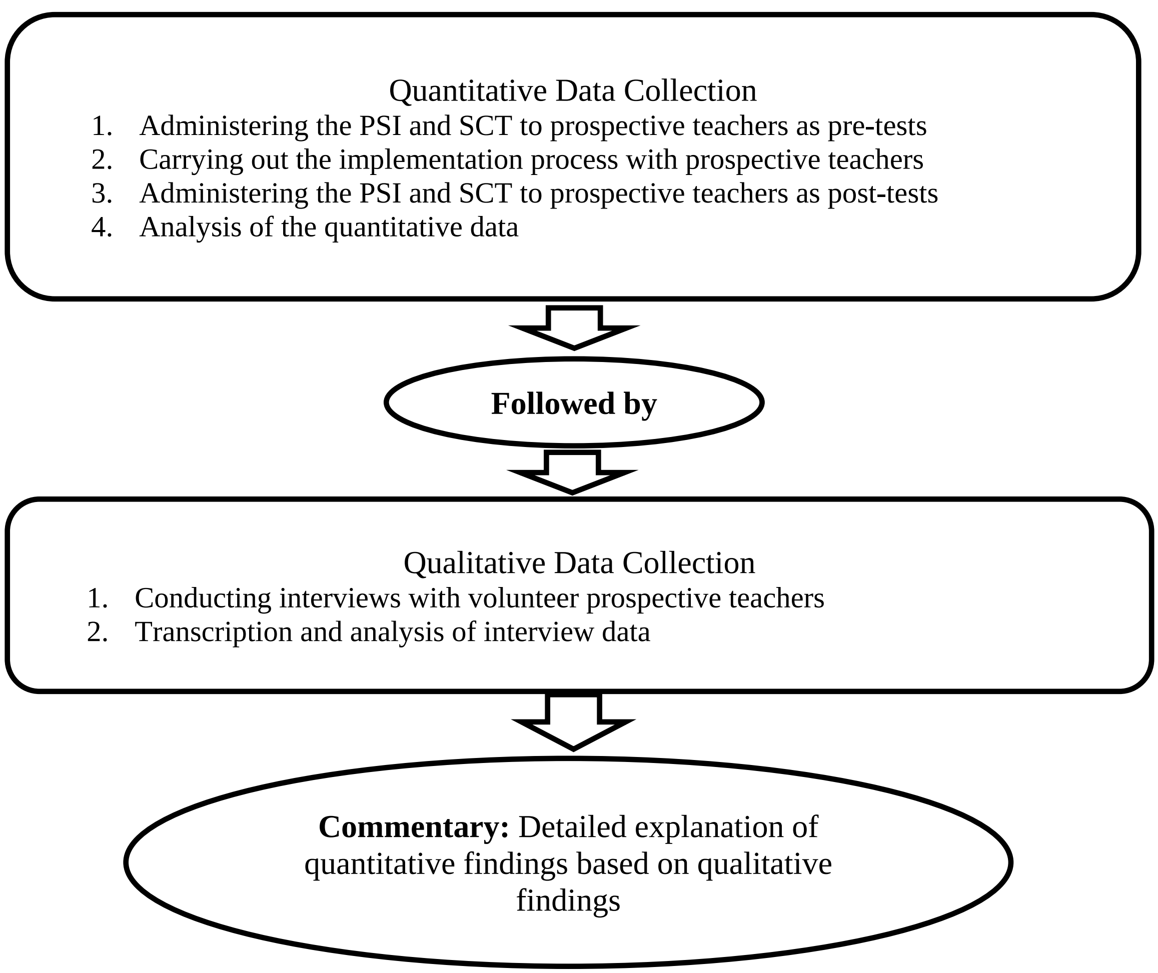
Method

Research Design

The present study involves the "explanatory sequential mixed methods design", in which qualitative and quantitative data are collected in stages (Creswell & Plano Clark, 2011). In the first stage, quantitative data are collected and analyzed, while in the second, qualitative data are collected and analyzed. In fact, qualitative data are used to explain and support the interpretation of quantitative data. In social sciences, the use of either quantitative or qualitative approaches may prove insufficient, especially in defining complex problems, as well as concluding and interpreting data. In such cases, mixed methods research designs allow researchers to have a more detailed examination and explanation of the problems (Creswell, 2005). The reason for choosing a mixed methods design in this study is to explain the research problems in line with qualitative and quantitative data. Figure 2 shows the schematic representation adopted for this research.

Figure 2

Schematic Representation of the Research Method (This Figure was Adapted to the Current Research, Inspired by the Explanatory Sequential Mixed Method Design as Indicated by Creswell and Plano Clark (2011))



Participants

The study was conducted with the participation of a total of 45 prospective secondary school Maths teachers (38 females, seven males) with an age range of 20-23, who were senior students at a state university in the West Black Sea Region in the academic year of 2018/19. Prospective teachers took the "Science, Technology, and Society" course for the first time and were not knowledgeable about integrated STEM education before. Participants from whom quantitative data were collected were selected using a purposive sampling method. The study group, in which the qualitative data of the research was collected, consisted of six pre-service teachers using maximum diversity sampling, one of the purposive sampling methods. The aim here was to create a relatively small sample and to reflect the diversity of individuals for the problem studied in this sample at the maximum level (Yıldırım & Simsek, 2011). The prospective teachers to be interviewed were selected according to the differences in their participation in the activity process. This method allowed for the obtainment of rich information and to investigate the situations in detail, depending on the purpose of the research (Buyukozturk et al., 2019).

Implementation Process

The implementation process of the research was carried out in the "Science, Technology, and Society" course taught as an elective in the Mathematics Teaching Curriculum. It was completed in a total of 14 weeks, three course hours per week, and the stages of the implementation are given in Table 1.

Table 1

Implementation Process and Stages for the Prospective Teachers

Week	Implementation
1	Getting to know you, introduction to the course, creating groups, and administering pre-tests
2	Informing about the concepts concerning STEM Education and its history
3	Informing about the curricula and STEM
4	STEM teaching-learning models: Explaining the 5E Learning Model
5	STEM teaching-learning models: Informing about Project-Based and Problem-Based Learning
6	Introduction to the engineering design process
7	Example Activity 1: Barbie Bungee Jumping
8	Example Activity 2: Rafting Competition
9	In-Class STEM Activities (implementation process for the prospective teachers)
10	In-Class STEM Activities (implementation process for the prospective teachers)
11	In-Class STEM Activities (implementation process for the prospective teachers)
12	In-Class STEM Activities (implementation process for the prospective teachers)
13	Presentation of Projects
14	Conducting post-tests and interviews

General information about the process was shared and the PSI and "Scientific Creativity Test" (SCT) pre-tests were administered in the first week (instruments described below) of the implementation process. The participants were given theoretical information about STEM education between the second and sixth weeks. The theoretical information about STEM is given according to

Bybee's (2010a) theoretical framework. At the same time a problem situation from daily life took place in the center, both in the activities carried out by the researchers and in the activities designed by the preservice teachers. In the seventh and eighth weeks, preservice teachers took part in the sample activities as a group, as planned by the researchers, within the scope of the engineering design process introduced by Hynes et al. (2011). In the seventh week, prospective teachers were informed about the requirement to prepare acquisition-oriented STEM activities in the following weeks in line with the secondary school mathematics curriculum, as presented in the sample activities. The STEM activity expected to be designed by prospective teachers was to include one or more acquisitions in the secondary school mathematics curriculum, and to prepare the activities as design-based. What was expected of the project was the design of a product that could solve a problem encountered by prospective teachers in daily life. The participants were also required to use the engineering design process introduced by Hynes et al. (2011), when designing their products.

This model is composed of a non-linear loop between the stages, in which there can be a transition from any stage to the next. Having been used in many fields, this model can also be adapted to the process of STEM activities. The engineering design process proposed by Hynes et al. (2011) consists of nine stages, for which the descriptions are given as follows.

1. *Identifying the need or problem:* This stage is important in that the problem is determined and the design is planned in detail (Atman et al., 2014). A list of necessary materials is created in line with the criteria or limitations specified for the product to be created during the planning process (English et al., 2017; Kolodner et al., 2003; Mentzer, 2011). It is indispensable to specify the limitations and criteria for the purpose of solving a problem and creating a product with the desired features, that is, coming up with a solution corresponding to the need (Brunsell, 2012). Students create a plan for solving a given problem at this stage of the engineering design process. They also plan an implementation process to create a product in consideration of the problem's limitations and criteria (Hynes et al., 2011).
2. *Researching the need or problem:* At this stage, students conduct research to develop different solutions to the problem. They explore what can be done to improve the solution they have come up with (Hynes et al., 2011; Kolodner et al., 2003). The limitations of the problem in relation to possible solutions are clearly determined (NRC, 2012). Students brainstorm and offer possible solutions to the problem.
3. *Developing possible solutions:* Here, the creativity of individuals stands out and individuals offer creative solutions (Wendell et al., 2010). Since there is more than one solution in the engineering design process, the students brainstorm about these solutions with their groupmates (Brunsell, 2012). The ideas put forward with the aim of solving the problem are evaluated. The solutions created are recorded with drawings or writings (Hynes et al., 2011).
4. *Selecting the best solution:* The students evaluate the solution proposals by taking into consideration the limitations and criteria, and come to a conclusion accordingly (Brunsell, 2012; NRC, 2012). The most suitable idea for the solution is selected while making a decision. However, in the case of the presence of ideas which do not meet the criteria, it is necessary to decide which criterion is more important or dispensable among them. In other words, the chosen proposal may not meet the solution exactly, yet the most appropriate one should be decided in accordance with the criteria (NRC, 2012). In this process, students can get help from their teachers before reaching a decision within the group (Hynes et al., 2011).
5. *Constructing a prototype:* A concrete prototype is created as a model or presentation for problem-solving. The prototype not only offers a solution to the problem, but also allows the implementation of theoretical knowledge (NRC, 2012). Students create a prototype product that corresponds to their specific solution. They also realize their mistakes so that they can develop their solutions while making their prototypes (Hynes et al., 2011).

6. Testing and evaluating the solution: The prototype is evaluated and tested according to the set criteria (Brunsell, 2012; Hynes et al., 2011; NRC, 2012). Students test and evaluate their designs with their teachers. Upon the evaluations, they improve and correct their prototypes in line with the given criteria so that they can successfully finalize their designs (Hynes et al., 2011).
7. Communicating the solution: The prototype and design process are shared. This sharing is important, both in terms of giving feedback to improve the prototype and promoting the product (Brunsell, 2012; NRC, 2012). Students present their designs to other classmates. Consequently, they can get feedback from their classmates to improve their designs. Thanks to such feedback, they receive suggestions from their classmates about the limitations and solutions of the problem (Brunsell, 2012; Hynes et al., 201).
8. Redesigning: The design is rearranged in line with the feedback given at the end of the submission of the solution. In addition, students work and make improvements to ensure that their designs are successful, and to eliminate the deficiencies in their designs (Hynes et al., 2011).
9. Completing the decision: Students decide that the design made is the most appropriate solution for the problem (Hynes et al., 2011).

Prospective teachers carried out the design-based STEM activities in groups of five to six students between the ninth and twelfth weeks with their classmates. In the thirteenth week, the projects prepared by each group were presented. In the last week, the PSI and SCT post-tests were re-administered and prospective teachers were interviewed voluntarily.

Data Collection Tools

In the present study, the PSI and SCT were conducted to collect quantitative data, and the participants were interviewed to collect qualitative data.

Problem-Solving Inventory

The PSI, developed by Heppner and Peterson (1982) and adapted into Turkish by Sahin et al. (1993), was used to measure prospective teachers' problem-solving skills. The scale consists of 35 items. Sahin et al. (1993) calculated the Cronbach's alpha reliability coefficient as .88 for the overall inventory. The scale was composed of six sub-dimensions, which include being impulsive, reflexive, avoidant, monitoring, problem-solving confident, and planful. The alpha coefficients of these subscales were found to be .78, .76, .74, .69, .64, and .59, respectively. In the present study, the Cronbach's alpha reliability coefficient of the problem-solving scale was found to be .89, with coefficients obtained for the sub-dimensions calculated as .74, .90, .70, .87, .86, and .80, respectively. The PSI was a six-point Likert type scale. According to the PSI, the low scores obtained from this scale indicated that the perception of problem-solving skills increased. The problem-solving levels indicated by the scores obtained from the scale were: Very high 1.00-2, High 2.01-3, Medium 3.01-4, Low 4.01-5, and Very low 5.01-6. Sample items are given below.

"When I have a problem, I try to think of all the ways I can solve it."

"I usually act on the first idea that comes to mind."

Scientific Creativity Test

The original form of the SCT was developed by Hu and Adey (2002), whereas its Turkish adaptation was made by Kadayifci (2008). The original test consisted of seven open-ended questions and was prepared in conformity with the dimensions of scientific creativity. The factor analysis of the original test indicated a single factor and the Cronbach's alpha reliability was calculated as .89. The test translated by Kadayifci (2008) was then administered to 57 students and the Cronbach's alpha reliability coefficient was found to be .74. In the present study, the Cronbach's alpha internal consistency coefficient of the scale administered to 45 prospective teachers was found to be .83. Based on the responses given in the SCT, the scores were evaluated according to the flexibility, fluency, and originality sub-scores. In the scoring of the SCT, the responses given by the students were determined as "raw ideas." Ideas pointing to the same issue, but expressed in different ways were combined to obtain "organized ideas." Analyses were made taking into account the "organized ideas", while creating the student scores. In scoring the questions, the researchers evaluated the raw ideas and the organized ideas together, and decided in collaboration to reach a consensus. Sample items are given below.

Question 1: Write down the possible scientific uses of a piece of glass.

Question 4: Imagine that there is no gravity and describe what the world would be like.

Interviews

In the present study, qualitative data were obtained from interviews conducted with the prospective teachers regarding the STEM activity development process following the implementation process. Interviews with the respondents were conducted in a semi-structured manner, as the questions were flexible, allowing the ability to ask additional questions to the interview questions (Merriam, 2009; Yildirim & Simsek, 2011). In order to ensure the content validity of the interview questions, two science education experts as well as an assessment and evaluation expert were consulted. The interviews aimed to reveal how the problem-solving skills and scientific creativity of the participants changed during the development of STEM activities. The sample question planned for the interview is presented below.

Question: What are your views with respect to the STEM activities you performed during the implementation process?

Alternative Question: What are your views with respect to the product designs you made during the implementation process?

Six prospective teachers who participated in the implementation process were interviewed in the face-to-face interviews, which were tape-recorded and then transcribed. The interviews lasted 30-40 minutes and were conducted on a voluntary basis. The participants were selected by using maximum variation sampling, taking into account the scores they received from the tests and their participation in the implementation process.

Data Analysis

The data obtained from the PSI and SCT were analyzed using IBM SPSS Statistics 21. In order to determine whether or not the data obtained from these tools showed a normal distribution, the data were analyzed with the Kolmogorov-Smirnov Test for normality. Since the p value was greater than .05 with the Kolmogorov-Smirnov Test for normality for the pre-test and post-test scores, it can be assumed that the groups have a normal distribution. According to these results, it can be considered that the scores obtained through the data collection tools show a normal distribution (Buyukozturk, 2011). In this context, a dependent *t*-test was used to examine whether or not there was a statistical difference between the pre-test and post-test scores obtained through the quantitative data collected from the group.

In the current study, the data obtained from the interviews with prospective teachers were analyzed with descriptive analysis. In the descriptive analysis method, the data are systematically grouped and explained clearly with cause-and-effect relationships, without the need for digitization or without any concerns for generalization (Yildirim & Simsek, 2011). In other words, researchers organize and interpret their questions within the framework of themes and concepts. In this regard, the data are interpreted and presented according to the themes specified before the analysis (Strauss & Corbin, 2015; Yildirim & Simsek, 2011). The present study applied a descriptive analysis process as explained by Yildirim and Simsek (2011) in four steps. The themes of the research were specified in the first step, while in the second step, the data were meaningfully correlated and organized within the scope of the themes. In this context, the conversations in the audio recordings, that is the interview data, were transcribed in written documents on paper. Sections that were irrelevant to the themes in the cited text were omitted. The data were explained in the third step, while they were interpreted through the findings in order to attach relevant meanings in the fourth step. In the commentary, direct quotations were included to emphasize the cause-and-effect relationship, and the plots were clearly presented. Common views and striking data were conveyed by including direct quotations, and all participants were given code names (S1, S2, S3,…). The raw data were analyzed with the joint decisions of the researchers, and the analysis process was carried out with their participation as well.

Validity and Reliability of the Research

Data were collected at different times and with different data collection techniques in order to increase the internal validity of the research. The internal consistency coefficient (Cronbach's alpha) calculations were made for the PSI and SCT scales to ensure reliability and validity in the quantitative part of the research. Because the study was carried out in an elective course in the curriculum, the participants were familiar with the researchers and regarded them as the experts of the course. The researchers already had previous academic studies on STEM and acted as a guide during the implementation process.

In the qualitative part of the study, participant confirmation was gathered in order to ensure reliability and validity, and to enable the transferability of the study, besides the researchers taking part together in the analysis of the data. It was made sure that there was long-term interaction to ensure the credibility of the research (Yildirim & Simsek, 2011). That is to say, the long-term interaction of the researchers with the participants increased the credibility. After the data recorded during the interview process were converted into written documents, the consent of the students who participated in the interview was obtained as to whether the data was correct or not. Besides that, the implementation process, the time of data collection, and the participants were described in detail in the research, and the interview data were presented with direct quotations.

Results

The results are presented in line with the sub-problems of the study.

Research Question 1: How Does the Design-Based STEM Activity Development Process Affect Prospective Maths Teachers' Problem-Solving Skills?

In the present research, a dependent *t*-test was used to examine whether there was a statistical difference between prospective teachers' PSI pre-test and post-test scores, and the results are given in Table 2.

Table 2

Dependent t-Test Results Related to PSI Scores

Variable	Measure	N	$\bar{x}$	S	SD	*t*	*p*
Problem-solving skills	Pre-test	45	2.70	0.53	44	1.30	0.20
	Post-test	45	2.58	0.63			

As can be seen in Table 2, no significant difference was found between the pre-test and post-test scores of problem-solving skills ($t_{(44)}$=1.30, p>.05). The post-test average scores of the participants regarding their problem-solving skills ($\bar{x}$=2.58) are lower than those scores indicated in their pre-tests ($\bar{x}$=2.70). Despite the lack of a significant difference between prospective teachers' post-test and pre-test scores, there ended up being a decrease, demonstrating that prospective teachers tended to improve their problem-solving skills at the end of the implementation process.

A dependent *t*-test was used to examine whether there was a statistical difference between the prospective teachers' scores obtained in the PSI in relation to the sub-dimensions, including being impulsive, reflective, avoidant, monitoring, problem-solving confident, and planful in the pre-tests and post-tests. Table 3 shows the relevant results.

Table 3

Dependent t-Test Results of the Sub-Dimensions of the PSI

Variables	Measure	N	$\bar{x}$	S	SD	*t*	*p*
Impulsive	Pre-test	45	3.10	0.76	44	0.77	0.45
	Post-test	45	2.90	0.81			
Reflective	Pre-test	45	2.2 9	0.90	44	0.38	0.71
	Post-test	45	2.21	1.06			
Avoidant	Pre-test	45	2.15	0.78	44	-0.22	0.83
	Post-test	45	2.18	1.12			
Monitoring	Pre-test	45	2.19	0.81	44	-0.08	0.94
	Post-test	45	2.20	1.06			
Problem-solving confident	Pre-test	45	2.46	0.86	44	1.38	0.18
	Post-test	45	2.22	0.92			
Planful	Pre-test	45	2.51	0.90	44	1.78	0.08
	Post-test	45	2.18	0.95			

As shown in Table 3, the sub-dimensions of the PSI include the following constructs: impulsive ($t_{(44)}$= 0.77, p>.05), reflective ($t_{(44)}$= 0.38, p>.05), avoidant ($t_{(44)}$= -0.22, p>.05), monitoring ($t_{(44)}$= -0.08, p>.05), problem-solving confident ($t_{(44)}$= 1.38, p>.05), and planful ($t_{(44)}$= 1.78, p>.05), with no significant difference between pre-test and post-test scores. In the sub-dimension of being impulsive, the pre-test scores ($\bar{x}$=3.10) are moderate, while the post-test average scores ($\bar{x}$=2.90) are high. Results show that in the sub-dimension of being impulsive, post-test mean scores ($\bar{x}$=2.90) are lower than the relevant pre-test scores ($\bar{x}$=3.10); in the sub-dimension of being reflective, post-test mean scores ($\bar{x}$=2.21) are lower than the relevant pre-test scores ($\bar{x}$=2.29); in the sub-dimension of problem-solving confidence, post-test mean scores ($\bar{x}$=2.22) are lower than the relevant pre-test scores ($\bar{x}$=2.46); and in the sub-dimension of planful approach, post-test mean scores ($\bar{x}$=2.18) are lower than the relevant pre-test scores ($\bar{x}$=2.51).

The difference between the prospective teachers' post-test and pre-test scores showed a decline in the sub-dimensions of being impulsive, reflective, problem-solving confident, and planful, though not statistically significant. These results show that prospective teachers tended to improve their skills in these dimensions at the end of the implementation process. On the contrary, in the sub-dimension of avoidance-approach, post-test mean scores ($\bar{x}$=2.18) were found to be higher than the relevant pre-test scores ($\bar{x}$=2.15), whereas in the subscale of monitoring, post-test mean scores ($\bar{x}$=2.20) were higher than the relevant pre-test scores ($\bar{x}$=2.19). The difference between the post-test and the pre-test scores in the sub-dimensions of being avoidant and monitoring showed a slight increase, although not statistically significant. In general, these results show that prospective teachers' tendency of improvement decreased in these dimensions at the end of the implementation process.

In the interviews, the prospective teachers emphasized that the implementation process positively affected their problem-solving skills, and that the activities carried out during the problem-solving process turned out to be fun and improved their problem-solving abilities since the fields of STEM were combined within the implementation process. In this context, S1 said:

> I believe that STEM education is an efficient process. It enables students to develop different solution strategies by learning to think in a uniform and certain pattern to solve problems with certain methods. I had a lot of fun, especially while thinking about the solution of the problems in the activities. During the activities, I created a hypothesis through trials. Afterwards, testing was a really exciting process.

Moreover, S5 said that the activities helped improve problem-solving skills while looking for solutions to the problems encountered in teaching abstract subjects of mathematics, given as follows:

> As Maths is a course comprising abstract expressions, adapting it to daily life problems and making concrete designs helped my problem-solving skills improve. In the process of developing an activity by associating the abstract topics of Maths with daily life, thinking about 'How can I do it? or What can I do?' had a positive effect on me since I had to solve the problem.

S3 emphasized that the practices affected the prospective teachers' perspective and ability to solve problems in the following statements:

> I think STEM aims to generate solutions to daily life problems by using science, technology, mathematics and engineering fields together. So, I think that my perspective on problems and my ability to solve problems have improved as a result of the activities we have done. During the design process of the activities, we constantly encountered problems that we had never thought of. We needed to find urgent solutions to those problems. Therefore, we always thought from a multi-dimensional perspective and came up with solutions.

Another respondent, S2 stated that STEM activities would contribute to the problem-solving abilities and other skills of not only prospective teachers, but also younger students and said:

> To me, coming up with solutions to daily life problems by using science, technology, mathematics, and engineering in the implementation process, helps develop necessary skills

for creative thinking and problem solving, as well as engineering. I think I have improved myself especially when thinking about problem-solving. Since problems are often encountered suddenly, it is likely that the first system that comes to mind at that moment is developed in this framework. Testing whether the developed solution is suitable or not shows that the process should actually be planned. What is more, the use of these disciplines together in the education of young students and the fact that the problems include daily life problems enable them to both enjoy the lesson and think creatively.

Research Question 2: How Does the Design-Based STEM Activity Development Process Affect Prospective Maths Teachers' Scientific Creativity?

In the present study, a dependent *t*-test was used to examine whether or not there was a statistical difference between prospective teachers' pre-test and post-test scores obtained from the SCT. Results are given in Table 4.

Table 4

Dependent t-Test Results of Scientific Creativity Test Scores

Variable	Measure	N	$\bar{x}$	S	SD	*t*	*p*
Scientific	Pre-test	45	9.45	1.86	44	-2.88	.01
Creativity	Post-test	45	10.64	2.10			

As is seen in Table 4, the difference between prospective teachers' scientific creativity pre-test and post-test mean scores is statistically significant ($t_{(44)}$= -2.88, p<.05). Since the group's SCT post-test mean score ($\bar{x}$=10.64) was higher than that of the pre-test ($\bar{x}$=9.45), such a difference can be considered to be in favour of the post-test averages.

A dependent *t*-test was used to examine whether there was a statistical difference between the pre-test and post-test scores in the constructs of flexibility, fluency, and originality, which stand for the sub-scores in the SCI Test. Results are given in Table 5.

Table 5

Dependent t-Test Results of Scientific Creativity Test Sub-Scores

Variable	Measure	N	$\bar{x}$	S	SD	*t*	*p*
Fluency	Pre-test	45	3.02	.80	44	-1.87	.07
	Post-test	45	3.36	.85			
Flexibility	Pre-test	45	3.80	.88	44	-3.53	.00
	Post-test	45	4.44	1.05			
Originality	Pre-test	45	2.63	.56	44	-1.78	.08
	Post-test	45	2.84	.53			

As can be seen in Table 5, the difference between the pre-test and post-test mean scores of prospective teachers in terms of flexibility ($t_{(44)}$= -3.53, p<.05) sub-score is significant on the side of the post-test, yet the difference between those scores for the fluency ($t_{(44)}$= -1.87, p>.05) and originality ($t_{(44)}$= -1.78, p>.05) was not significant. Nevertheless, the fluency post-test mean score ($\bar{x}$=3.36) of the group was found to be higher than that of the pre-test ($\bar{x}$=3.02), the flexibility post-test mean score

($\bar{x}$=4.44) was higher than that of the pre-test ($\bar{x}$=3.80), and the originality post-test mean score ($\bar{x}$=2.84) also turned out to be higher than that of the pre-test ($\bar{x}$=2.63).

In the interviews, prospective teachers stated that the STEM activities-based implementation process helped improve their scientific creativity by offering them a different perspective. Regarding this, S2 said:

> We were able to integrate different areas and observe the effect of these four different areas on each other, which gave me a different perspective since such a process revealed creative ideas, enabling me to think of different ways while creating new designs. We developed many ideas while designing the activities. During the implementation, I gained experiences that I can apply to improve the creativity of students, especially in my future teaching career.

In an attitude to support such views, S1 said:

> STEM activities enable and develop skills such as creative thinking, self-expression, and entrepreneurship. It also stimulates a sense of doing research and curiosity. When I become a teacher in the future, I will definitely use them because they will develop both my students' creativity and my own creativity as well as other skills.

In addition, S4 emphasized that STEM activities, in a way, represent normlessness; that they are original and a process which triggers the power of thinking, thereby supporting creative thinking:

> I can say that STEM activities improved my creativity. If I had to describe the implementation process, I can say that learning how to design is different and interesting, besides being partly out of norms. You feel inadequate when you fail to produce new ideas. Permanent learning takes place as it leads you to think creatively. It has also contributed to our own self-improvement, as we develop activities that generate solutions to problems especially by using the power of thinking. I mean, it is a unique, different, and solution-oriented process.

S6 pointed out the idea that STEM activities developed imagination as well as creativity, and taught how such applications should be done:

> The blending of mathematics, engineering, science and technology fields and the way they are used in education gives the opportunity to develop imagination and work in these fields. By establishing an effective bond in these areas, I saw how I could use my imagination in activities and my imagination could develop even at this age. While carrying out our activities in the classroom, we were able to come up with much more creative products without being bound by a specific directive.

Furthermore, S5 stressed that creative solutions to problems can be produced by thinking multi-dimensionally during the activities, and said:

> This process showed me that planning and doing an activity is not difficult, and that students can learn permanently and produce creative solutions to problems. During the implementation process, I both had fun and learned to produce practical solutions. Work sharing in group work enabled me to improve my skills for thinking multi-dimensionally and to approach events from different perspectives. It also had a significant and positive impact on my analytical and practical thinking.

Discussion and Conclusion

This study examined the implementation process of some design-based STEM activities, particularly developed by prospective secondary school Maths teachers, in terms of the impact of those activities on the problem-solving skills and scientific creativity of prospective teachers. As a result of the development process of STEM activities in this study, no statistically significant difference was found between the prospective teachers' pre-test and post-test scores for problem solving skills. In spite of the lack of a significant difference between the PSI pre-test and post-test scores, the clear decline in the post-test scores indicated that the participants' problem-solving skills had improved. Similarly, considering the impulsive, reflective, avoidant, monitoring, problem-solving confident, and planful approaches, which are the sub-dimensions of the PSI, it was concluded that there was no significant difference between the pre-test and post-test scores. However, the decline between the post-test and pre-test scores in the sub-dimensions of the PSI including the factors of being impulsive, reflective, problem-solving confident, and planful indicated that the participants showed improvement in these dimensions at the end of the implementation process. However, the increase observed between the post-test average scores and the pre-test scores in the avoidant and monitoring approaches within the inventory denotes that the development of prospective teachers in these dimensions decreased at the end of the implementation process. One of the reasons for such results could be the readiness of prospective teachers' problem-solving skills being at a high level.

Problem-solving skills can be learned and affected by interpersonal communication (Heppner & Petersen, 1982). The reason why the problem-solving skills of prospective teachers showed no significant improvement could be attributed to the lack of communication within or between groups, since this research was carried out in a crowded classroom. The results of this study indicated a similarity to those results reported by Acar (2018) and Nagac (2018) in their studies conducted with secondary school students and prospective teachers. These studies also revealed that STEM activities showed no positive impact on students' problem-solving skills. Similarly, Elliott et al. (2001) investigated the effect of STEM education on university students' critical thinking skills, problem solving skills, and attitudes towards Maths. At the end of the study, while a positive increase was found in students' attitudes towards mathematics, there was also a slight increase in their critical thinking skills, yet no increase in their problem-solving skills. Contrary to the results of this paper, Delen and Uzun (2018) reported that the process of using design-based STEM activities developed by prospective secondary school Maths teachers had a positive effect on both their problem-solving skills and their views about the process. Moreover, Ceylan (2014), concluded in a study conducted with secondary school students that STEM education had a moderate effect on students' problem-solving skills.

Different studies conducted with different age groups concluded that the activities related to STEM education improved students' problem-solving skills (Akcay, 2019; Akgunduz & Akpinar, 2018; Bal, 2018; Cho & Lee, 2013; İnce et al., 2018; Nagac, 2018; Pekbay, 2017; Ozcelik & Akgunduz, 2018; Vatansever, 2018). In addition, studies in the counselling literature have shown that design-based activity practices also positively affect students' problem-solving skills (Barak & Assal, 2018; Ceylan, 2014; Cooper & Heaverlo, 2013; Crippen & Antonenko, 2018; Dewaters & Powers, 2006; Elliott et al., 2001; Lin et al., 2015; Pekbay, 2017; Sarican & Akgunduz, 2018). A study conducted by Avsec and Kocijancic (2014) reported that engineering-based activities developed within the scope of inquiry-based learning improved students' problem-solving skills as well as their learning capacity.

Despite the lack of any statistically significant differences in the PSI, the findings obtained from the interviews with prospective teachers support the increase in the problem-solving skills of prospective teachers. Participants emphasized that their problem-solving skills improved in the process of developing design-based STEM activities. They also indicated that the activities contributed, especially in terms of problem-solving skills, gaining a different perspective, creativity, and the ability to make use of them while teaching, and that STEM education is interdisciplinary as a whole. They also emphasized that it is a practical preparation, in which different disciplines are integrated and solutions are produced, for different problems.

Generally speaking, prospective teachers stated that STEM education is a process, design, or product that integrates different disciplines (technology, science, mathematics, and engineering as a whole), requires problem-solving skills, and finds solutions to current problems and needs. In particular, students' designing with materials they may encounter in daily life enables them to establish direct relationships with daily life (Ceken, 2010). Thus, students' awareness of the environment increased during the implementation process, which they stated they associated with the topics and concepts with daily life. Similarly, Ozcakir Sumen (2018) reported that the use of STEM activities in lessons contributed to establishing an increased relationship between mathematics subjects and daily life. Additionally, Kayalar (2018) asserted that STEM activities can be conducted using simple, cheap, and recyclable materials. The author also stated that STEM activities are intertwined with daily life and that they need to be planned to meet the needs of individuals. In a similar manner, Harkema et al. (2009) noted that science and engineering exist in an integrated way in daily life, and that STEM activities should also have an emphasis on daily life.

Prospective teachers stated that the process was remarkable in that they generated concrete solutions in relation to the subjects of the activities during the implementation process. In other words, this process ensures that an individual is kept active in the learning process by doing and experiencing. Another study supporting these results was conducted by Dare et al. (2017) on the use of STEM activities in teaching physics concepts with sixth grade students. In this context, they used the engineering design process to solve possible problems in STEM activity plans. As a result of that study, the authors reported that student-centered approaches motivated students who found STEM activities attention-grabbing and that making designs for the field of physics made it easier for students to establish a relationship between physics and daily life in such a way that they could learn the subject well. Many studies on STEM education have concluded that STEM has a positive effect on students' conceptual and theoretical learning levels (Gulgun et al., 2017; Robinson et al., 2014; Yoon et al., 2014).

Another result of our study is the statistically significant difference in favour of the post-test, which was found between the participants' pre-test and post-test scores with respect to scientific creativity as a result of the STEM activities development process. Based on this, it could be assumed that STEM activities, conducted with the participation of prospective teachers, contribute to their scientific creativity. Similarly, there was a statistically significant difference in favour of the post-test between the pre-test and post-test scores in the flexibility sub-score of the scientific creativity test. As opposed to this, no statistically significant difference was found between the pre-test and post-test scores in fluency and originality sub-scores. However, these sub-scores were found to be higher in the post-tests than in the pre-tests.

In the STEM activity processes, the prospective teachers associated their daily life experiences with the field knowledge they had already acquired. During the implementation of the activities, they followed the changes in their ideas, commented on different ideas, and came to a conclusion by discussing the correctness and applicability of their ideas, a process which contributed to the scientific creativity of the students. The results of some studies in the literature are also similar to the results of the present study (Ceylan, 2014; Cho & Lee, 2013; Ciftci, 2018; Dogan & Kahraman, 2021; Dong-Ju et al., 2016; Kahraman, 2021; Knezek et al., 2013; Pekbay, 2017; Ryu & Lee, 2013; Siew et al., 2015; Senturk, 2017). The results of the study conducted by Ciftci (2018) with seventh grade students also indicated that STEM activities positively affected students' scientific creativity levels. Similarly, STEM activities integrated into the subject of acids and bases were found to boost students' creativity (Ceylan, 2014) and that STEM activities, especially those associated with abstract concepts, also improved students' scientific creativity (Senturk, 2017).

Given the results of the present study, the reason why the post-test results of scientific creativity as well as of its sub-scores of fluency, flexibility, and originality were high could be attributed to the use of engineering design process steps in the STEM activities conducted during the procedure. Associating the problem scenarios used in such activities with daily life experiences, and creating a solution to an existing problem can play an important role. The reason for this is that students create new products and designs by using the engineering design process and skills at the stage of producing solutions for the given problem (Bybee, 2011; Lederman & Lederman, 2013). Mauffette et al. (2004) asserted that the scenarios used in learning environments, and the problems contained in those scenarios, establish a connection in attracting students' attention, determining the boundaries of the relevant subject, and associating such experience with daily life.

In the interviews, the prospective teachers emphasized that STEM-based practices support scientific creativity and that creative ideas are put forward, since the implementation process encourages individuals to think multi-dimensionally. The STEM activity development process enabled participants to offer different solutions on the basis of original ideas. Therefore, it can be said that the problem-solving process exposed the creativity of the prospective teachers. It can also be concluded that the implementation of the activities in the classroom environment prepared the prospective teachers for their future teaching profession by enabling them to acquire the necessary skills such as relevant experience, making presentations, planning the process, classroom management, and self-confidence.

In the counselling literature, it is stated that STEM-based activities improve problem-solving skills and creativity of individuals, and their self-confidence in STEM fields (Akgunduz et al., 2015; Gulen, 2016; Moore et al., 2015; Naizer et al., 2014; Wendell, 2008). In addition, Gokbayrak and Karisan (2017) emphasized that such activities with students contribute to their mental development. For this reason, it is extremely important that the activities carried out in the teaching environments are instructive and that educational activities allow students to establish interdisciplinary relationships.

In the present study, participants found the activities conducted in relation to STEM education interesting and fun. Participants also emphasized that the activities supported learning by doing and experiencing, besides heading them towards multi-disciplinary thinking by offering different perspectives. Similarly, in many other studies, students stated that STEM-based practices are fun, enjoyable, and interesting (Cinar et al., 2016; Ozbilen, 2018). In addition, as students carry out the activities actively throughout the implementation process, they are able to use their field knowledge to solve a problem (Cepni, 2017). In this way, the students are actively involved in the process, thereby restructuring the knowledge themselves as they gain experience through learning by doing (Daniel,1993; Jones et al., 2003; Wheatley, 1991).

In the current study, the participants stated that STEM activities improved their imagination by influencing their abilities to be able to make predictions and think analytically within group work, Moreover, participants were able to associate mathematics with daily life, which provided permanent learning that was educational. Various studies in the literature also indicated that STEM-based activities encourage students learn cooperatively and develop their effective communication skills (Ceylan, 2014; Choi & Hong, 2013; Cepni, 2017; Eroglu & Bektas, 2016). Having investigated the effects of out-of-school STEM activities on students, Sahin et al. (2014) reported that students are influenced by each other and contribute to each other's development as they cooperate.

Considering the results of the research in teacher education, it is thought that there is a need for teaching environments in which individuals will actively take part in the learning process, where they can offer various solutions to the problems they encounter, where they can make original and innovative designs, and display their creativity. This study presents an innovative perspective on STEM-focused science and mathematics education teacher preparation. It is thought that the application process and results of the study will contribute to the field.

Recommendations

The following recommendations can be made based on the results obtained from this research: In this study, the designs for the relevant activities were created in the classroom environment by making use of the materials available, and within the time limit for which the activities were being conducted. Similar activities can be conducted with the participation of students in the form of assignments, or projects as an out-of-school activity, so that there will be no limits in terms of time and materials. The activities within the scope of this research were carried out in the classroom environment, which was organized in accordance with the activities throughout the implementation process. However, another important factor is that STEM activities should be easily implemented and suitable environments should be arranged for students to work in groups. In this context, workshops or laboratories can be organized in schools for the implementation of STEM activities. Thus, students can be provided with suitable settings where they can create their own designs and products.

This study was carried out in a crowded classroom with 45 prospective teachers. In the future, further studies can be conducted in classes or in groups with fewer people. In addition, this study was carried out with prospective Maths teachers only. The content of the study can be used to conduct other studies with prospective teachers studying in different departments with updated curricula. Thus, it will be possible to achieve interdisciplinary work with a variety of prospective teachers. The applicability of STEM activities developed by prospective teachers can be tested using quantitative and qualitative methods. Also, more STEM education courses can be prepared and offered to prospective Maths teachers. In-service professional development on STEM education can be provided for Maths teachers. This study examined prospective Maths teachers' problem-solving skills and scientific creativity. Many other skills may be examined in future studies, and different tests may be used to measure the problem-solving skills and scientific creativity of prospective teachers.

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