International Journal of Technology and Design Education (2021) 31:95–116
https://doi.org/10.1007/s10798-019-09547-z

Exploring the effectiveness of STEAM design processes on middle school students' creativity

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Accepted: 24 September 2019 / Published online: 30 September 2019

Abstract
Creativity has an important role in many scientific processes which constitute a large and complex structure. It is difficult to identify and measure. Students' creativity can be enhanced through specific education programs. The aim of this study was to develop a science, technology, engineering, art, mathematics (STEAM) design process program for teaching 7th grade middle school students to enhance their verbal and figural creativity. The study lasted 11 weeks. Pre-test/post-test quasi-experimental method with a nonequivalent control group was used. Study Group (n = 34) was presented a teaching approach focused on STEAM education, while the control group (n = 34) was taught based on the science curriculum and science textbook. Nine different STEAM design activities were developed. The data were collected with the Torrance Test of Creative Thinking. The SPSS Program was used in analyzing the data. At the end of the study, significant differences were determined in favor of the study group in both verbal and figural creativity. As a result of the study, recommendations for implementation of STEAM design processes were discussed.

Keywords Creativity · Creative thinking · Design · STEAM · STEM

Introduction

Creativity has become an increasingly important element to ensure sustainable development (Said-Metwaly et al. 2018). For the purpose of not falling behind the modern age, improving the creativity of individuals has been one of the important tasks of education. By understanding better what creativity is in the 21st century, and by evaluating its effects on culture and economy, it is considered as a necessity to change the teaching approaches that are used in educating individuals (Conradty and Bogner 2018).

New technological developments have often been associated with the potential of having a major impact on education. One of the approaches that emerged as a result of these developments is STEM education and it has attracted considerable attention in

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recent years. STEM is an acronym consisting of the integration of Science, Technology, Engineering and Mathematics fields (Breiner et al. 2012).

STEM is a more holistic approach than any of its four constituent fields precisely because of integration among these fields. Students can explain problem situations and produce solutions to different situations with integrated STEM education. This situation makes students learn meaningfully and permanently (Wang 2012). STEM education ensures that students become innovative, inventor, self-confident, logical thinker, technology literate and better problem solvers (Morrison 2006).

STEM education enables students to produce solutions to their daily life problems by integrating the disciplines of science, technology, engineering, and mathematics. There are two different STEM integration models: content integration and context integration. Content integration means associating the contents of four disciplines together, while context integration means placing a discipline at the center, and making use of other disciplines (Moore et al. 2014).

STEM education frequently focuses on science and mathematics education, and technology and engineering fall back in this respect (Kelley and Knowles 2016). In addition, STEM lessons are frequently taught in a disconnected manner from art, creativity, and design (Hoachlander and Yanofsky 2011). Creative thinking skills must be acquired by students from pre-school education level by increasing and improving in each education level.

In recent years, the integration of art and design with STEM education has been increasing. The first STEAM education (Science, Technology, Engineering, Art and Mathematics), which initially emerged in Korea, is recognized as one of the educational methods, which may be employed to improve the creativity of students (Kim and Kim 2016). Although it is possible to see the several examples of STEAM education that date back to the earliest volumes of Industrial Arts Magazine (from 1914), and to the design and building of ancient architecture, the name STEAM was officially included in the report of the Korean Ministry of Education in 2011 (Choi et al. 2017). Even if it is not called STEAM, there is a historical literature of the integration of mathematics, science and technology and engineering has been core to technology education and industrial arts. There have also been movements to integrate art into this already integrative area, and “unified arts” turned up documents such as “A Unified Arts Experiment” published in The School Review in (1944).

Creativity is being sensitive to problems, missing points, lack of knowledge, elements that cannot be found, to inconsistencies, and determining difficulties, finding solutions to problems, finding and developing hypotheses by making predictions, changing them when they do not work, choosing and testing the right solution, retesting and then revealing the results (Torrance 1974). The definition of creativity consists of two main elements; novelty and appropriateness (Atkinson 2000). Creative thinking skills are the ability of individuals to use their minds freely to produce new ideas, new possibilities, and new inventions. It may be in the form of real or abstract ideas (Daud et al. 2012). Recent educational reforms emphasize the importance of STEAM education in increasing the creativity of students (Kim and Kim 2016).

With the increasing interest in STEAM education, a number of studies have generally investigated the perceptions and practices of teachers on STEAM education (e.g. Herro and Quigley 2016; Park et al. 2016; Wang 2012; Wang et al. 2011). These previous studies showed that STEAM education is necessary. In studies that were conducted with students, it was investigated how STEAM education affected the motivation, learning, and problem-solving skills of students (e.g. Choi et al. 2017; Herro et al. 2017; Noh and Ahn 2012;

Thuneberg et al. 2018). However, some studies found a significant gap between students' creativity and the process of STEAM design education.

Creativity and innovation is important for society (Feist 1999) and play key roles in design processes (Forbes 2008). The art aspect of STEAM was often named as "creativity" in education; and it was emphasized that STEAM education developed creativity (e.g. Kim and Park 2012; Land 2013; Sousa and Pilecki 2013); however, there were no extensive studies in the literature on whether STEAM education influences creativity directly or not.

Creativity is very difficult to measure. Two important methods are commonly used to measure creativity: divergent thinking testing and creativity trait testing (White et al. 2012). Creativity trait testing is based on the hypothesis that creative people share a common set of personality traits (Feist 1999). Divergent thinking testing determines various, sometimes seemingly irrelevant, thought flows that produce innovative solutions to a problem. Torrance developed two divergent thinking tests, the most widely used and also supported by a wide range of validity assessment data (White et al. 2012). Verbal creativity is the ability or abilities measured on the Torrance Tests of Creative Thinking developed by Paul Torrance (1966), containing the following five subtests: ask and guess activity, product improvement activity, unusual uses activity and just suppose activity. Figural creativity is the ability or abilities measured on the Torrance Tests of Creative Thinking developed by E. Paul Torrance (1966), containing the following three subtests: picture construction activity, incomplete figures activity and repeated figures activity.

Although there have been serious increases in recent years in the number of experimental studies in which creativity has been investigated (Runco and Jaeger 2012), studies that examine the effect of STEAM education on the creativity of students are very few. In this limited literature on creativity in STEAM education, Oh et al. (2013) examined the effects of STEAM education program on the creativity of sixth-grade students. In the study that was conducted by using the mathematical-based educational software called Scratch, hands-on activities were not performed. The researchers found that the program that was applied had a positive effect on the figural creativity of the students. Kim et al. (2014) reported that STEAM education had a positive effect on the creativity and interest of sixth-grade students. In this study, the STEAM education program was applied in line with the Preparation–Development–Implementation–Evaluation (PDIE) procedure model. In the literature, no studies were detected examining the effects of the STEAM design process, which is performed by hands-on activities on direct, figural and verbal creativity of students by using easily available daily materials instead of computer software.

One of the most important issues to be considered in education is the development of appropriate instructional design in which teachers can transfer the content and processes available to students. Although the contribution of art to other disciplines is not ignored, the subjects on teachers' preparedness and appropriate curriculum resources are of importance. The challenges experienced by the integrated STEM education are many; adding a fifth dimension increases the complexities that are experienced by educators (English 2017). For this reason, it is considered that preparing a proper teaching design will be effective in eliminating this complexity and in applying an appropriate STEAM education. This study contributes to the STEAM literature in two ways. The first one is that it claims to prove that STEAM education improves creativity. There were no comprehensive studies that examined the effects of STEAM education on verbal and figural creativity with direct hands-on activities in the literature. Secondly, the STEAM design process is explained in detail, which will be guiding for the practitioners. This study was conducted by the following research question:

How do STEAM design processes affect students' creative thinking?

(a) How do STEAM design processes affect students' verbal creative thinking?
(b) How do STEAM design processes affect students' figural creative thinking?

Creativity in art and science

Creativity is an important characteristic of a scientific viewpoint. Problem-solving skills, establishing hypotheses, conducting experimental processes, and being able to think differently are necessary for scientific creativity (Lin et al. 2003). Creative skills are designing ideas, modeling, playing, realization and establishing connections. Innovation, idea-product invention and idea solutions are developed with these creative skills (Kim and Park 2012). Creativity in art and scientific creativity have similar characteristics such as having basic knowledge of the field, recognizing connections, making interruptions and having an imagination (Innamorato 1998), so these two types of creativity are related (Jacob 2001). Scientists are creative in seeing the world in new ways, testing and expressing when they are constructing theories, analogies, models, and similar explanatory tools. However, it is not clear what creativity means in the context of the school (Newton and Newton 2009).

Science and art are generally regarded as divergent fields: while one represents rationality and logical reasoning, the other one is considered basically as aesthetic. Both art and science include creativity, but it is more related to art than science (Kind and Kind 2007). Although the activities of artists and the research activities of scientists are different from each other in terms of objectives, tools, methods, and results, they both necessitate imagination, observation, and creativity (Kim 2012). Art encourages creative thinking and provides a better understanding on the visual world (Eisner 2002), and supports the development of basic skills like art, image production, and drawing, and contributes to the development of the whole brain to improve learning (Sousa 2006).

Studies in the field of neuroscience and different learning styles show that humans have the ability to learn through visual, auditory and kinesthetic clues. While artistic questioning encourages meticulousness and creativity, it also allows that a teacher teaches in more than one way, which creates more nerve paths and increases the probability of keeping the information in the mind (Land 2013). Art has its own unique beneficial aspects, and some scientists act cautiously in realizing learning in other disciplines through art. Positive qualities associated with art, such as creativity, imagination and critical thinking, are not only specific to art (Jacob 2001).

The idea that science is a creative effort is indisputable. Scientific ideas are the things created by the mind (Hadzigeorgiou et al. 2012). Inspiration and imagination are common for scientists and artists alike, and the boundaries between art and science are eliminated in the creation process, and the aesthetic has a central role (Miller 2001). The creativity process (e.g. preparation, incubation, illumination, and verification) is similar to the steps that are involved in the scientific method (i.e. observation, hypothesis, experiment, and verification) (Gallagher 1985).

Despite the great number of similarities, the differences between art and science must also be emphasized. Science is considered as a serious intervention that is interested in understanding the facts that are considered critical for the future by working with meticulous rational research and logical theory. However, it is believed that art is concerned with beauty, not reality; art is subjective and personal, but nor is it an absolute necessity for the future (Eisner and Powell 2002). In addition, there is always a validation process in science, which is not found in the art (Hadzigeorgiou et al. 2012).

Combining art and science encourages students in learning each discipline, and develops the lifelong skills and creative perspectives of students outside the classroom (Belardo et al. 2017). Combining these two areas activates both cognitive and affective processes simultaneously especially in studies requiring extensive knowledge and skills. As a result, the teaching and learning processes are empowered effectively both for teachers and students (Steele and Ashworth 2018). For this reason, the importance of creativity in learning, productivity and developing the mind cannot be ignored (Conradty and Bogner 2018). With the latest scientific interventions based on the assumption that creativity has brought new motivations to science education, STEAM (science, technology, engineering, art and mathematics) education has emerged by ensuring the integration of creativity and science (Burnard 2015).

A place for art and STEAM

STEAM education consists of the learning experiences, which increases their motivation for scientific and mathematical learning, establishes connections between real life to arouse their interests, and helps students to understand how to learn and focus (Bybee 2010). In other words, STEAM means the transition from "what to be taught" to "what I shall experience", and in this way, emphasizes content, design and emotional convergence (Choi et al. 2017). The main factors of STEAM education are context, creative design, and emotional touch (KOFAC 2012). STEAM training is considered as a way of encouraging interdisciplinary creativity and creative thinking (Wynn and Harris 2012).

STEAM education comes to the forefront by conceptualizing in the form of (1) project-based learning, (2) technology in the context of creativity and design, (3) approach to question a problem by using multiple ways, (4) science, technology, engineering, art/human sciences and mathematics, which are required by the problem (5) cooperative problem solving (Herro and Quigley 2016).

Thanks to the advantages of art, STEAM education offers many opportunities for students to develop themselves in several fields. These advantages are the development of cognitive growth, enhancement of long-term memory, increasing social growth, reducing stress, increasing attractiveness in subject areas, and encouraging creativity (Sousa and Pilecki 2013). STEAM education was supported to emphasize the ability to understand imagination and artistic emotions of students as well as to understand scientific contents (Jho et al. 2016). When students start to understand and increase their interest in mathematics and science, STEAM education is taken as one of the educational methods which students can use to improve their creativity and to achieve the purpose of creativity and character education through convergence (Kim and Kim 2016).

The purpose of STEAM education is to integrate science, technology, engineering and mathematics with basic capacities called 4C (Creativity, Communication, Convergence, and Caring) (Choi et al. 2017). Art embraces these four skills and provides teachers and their students with many opportunities for being involved in complex and integrated teaching and learning, especially when they are integrated with STEM fields (Steele and Ashworth 2018). The first reason that an art component is needed in STEAM education is that art encourages creative thinking in science via creativity, imagination, communication, and sensitivity (Noh and Ahn 2012). The second reason is that the skills and artistic sensitivities of individuals are combined in science and technology (Choi et al. 2017).

STEAM education, which supports logical and mathematical thinking, offers opportunities for activities that include creativity, expression, and visual aspects of design and engineering tasks to explore science and mathematics. Creativity in STEAM education means producing ideas and strategies, which are critical in thinking as an individual or as a community and producing reasonable explanations and strategies that are consistent with relevant data (Manches and Plowman 2017). STEAM focuses on becoming globally competitive through creative problem-solving, decision-making, artistic knowledge, and expertise in science education (Baek et al. 2011).

With the addition of the art field, researchers tried to determine the differences between STEM and STEAM. This conflict between STEM and STEAM stems partly from the innovation and deficiency research and conceptual understanding of STEAM. Although STEM focuses more on mathematics and science, STEAM focuses on design, computer graphics, art exhibition, art as an expression and even involves creative problem-solving that solves problems while exploring solutions (Herro and Quigley 2016). STEM encourages teamwork more than cooperation. STEAM, on the other hand, deals with art that involves design in a wider sense while researching and designing solutions (Jolly 2014). STEAM may also include design education elements in which creative processes are used “to examine the aesthetics and benefits of the elements in our daily life” (Vande Zande 2010). While STEM is considered as logical, analytical and useful; art is considered as intuitive, emotional and frivolous. Art creativity provides a new motivation for STEM because it develops problem-solving skills, memory, motor coordination and analytical skills (Sousa and Pilecki 2013).

If enterprises like STEM education are adopted, art must be an indispensable part of this enterprise. For this reason, art must be included in science education under the name STEAM education (Steele and Ashworth 2018). It is necessary that the theoretical background of the design process is understood well by educators to comprehend the importance of art and how to combine it with STEM by adding it as a discipline.

STEAM design process

The core of STEAM education lies in the ability of students in designing their own ideas and in understanding the tendencies of others in some learning situations. Proper education must be designed to enable them to achieve this. Planning the lessons to guide through creative design processes is an important factor in STEAM education (Park et al. 2016). Following a structure that will help students develop more creative and interdisciplinary practices as part of their STEAM experiences will guide educators (Henriksen 2017).

In STEM education, generally, engineering design is employed (Dym 1994). Although there are many engineering design steps in the literature (e.g. Brunsell 2012; Wendell et al. 2010), a design process generally consists of steps like clarifying the problem, creating a program for needs, planning the design, creating a prototype, testing the prototype, optimizing the prototype, analyzing the product, and presenting the resulting product to customers or target audience (Vossen et al. 2019). In this study, the STEAM design, which was developed by Oh et al. (2013), and which had partly similar steps, were preferred. Although the engineering design process includes similar design processes and similar dispositions with the STEAM design, the difference between them is that the design of products, buildings, computer graphics, interactive video games and other similar elements in STEAM design is based more on aesthetic concerns than in an engineering design cycle, and the designers act in a more artistic way (Bequette and Bequette 2012). STEAM education takes creativity development into consideration and guides students to explore and be aware of a number of methods. This can be carried out with open-ended problem scenarios, by providing appropriate concepts and tools, and through experiences (Herro and Quigley 2016), and in doing this, rich opportunities may be provided for creativity.

When Oh et al. (2013) created the STEAM design steps, they took into account the creative design steps of the Korea Foundation for Advancement of Science and Creativity. The creative design steps that were proposed by the Korea Foundation for Advancement of Science and Creativity (2012) consist of setting an objective, planning and designing, analysis of design, making, and testing and evaluation. These steps were specified as the characteristics of STEAM education (Oh et al. 2013). The new STEAM education steps, which were formed by using the STEM teaching steps, were given as experiencing priming water for an idea, coming up with an idea, planning, and design fusion, making or synthesizing, testing and evaluation.

In the *experiencing priming water for an idea* step, problems are identified and an idea is created for the subject as the beginning because the design process begins with a problem (Chand and Runco 1992). STEAM includes creative and imaginative problems that are placed in problem scenarios helping students to conceptualize and solve the problem, which is not seen possible, but larger and real (Herro et al. 2017). In the *coming up with an idea* step, it is ensured that students create a variety of ideas for the given problem situation and share them collaboratively. In the *planning and design fusion* step, the ideas of the students are merged and grouped together as plans (Oh et al. 2013). In the *making or synthesizing* step, it is ensured that students make products or syntheses based on science, technology, engineering, and artistic ideas (Oh et al. 2013). Design means problem-solving as well as the production and realization of new ideas (Dorst 2003). In the *testing* step, it is ensured that students are encouraged to experiment with the products they produce and to determine whether they produced the solutions (Oh et al. 2013). In the *evaluation* step, it is ensured that all groups present their products to each other, perform inter-group evaluations, and through these, the idea is improved (Oh et al. 2013). Evaluating a designer or a design solution is one of the key concepts for creativity (Dorst 2003).

The STEAM design process must support creativity (Bequette and Bequette 2012). In this process, for the purpose of developing creative knowledge, students are given a situation in which they can find new ways to explain the science phenomena, make predictions, solve problems, express or imply the unknowns. In addition, students are given the opportunity to propose changes based on their knowledge in the transfer of scientific knowledge. As an alternative to the developing new ways and methods of students for the development of creativity, they are encouraged to question and criticize with any science and knowledge discipline (Herro and Quigley 2016).

Method

Research design

A pre-test/post-test quasi-experimental design was employed in the present study with a Study and a Control Group. To explore the effect of STEAM education on students' creativity, this research included a control group. The instruction was carried out with the STEAM activities in the study group. Each activity aimed to make students acquire the learning outcomes in the curriculum. The courses that contained the same outcomes were also taught in the Control Group as recommended by the Ministry of National Education (plain narrative, questions, and answers, using science textbook activities). The two groups followed the same curriculum outcomes, but different teaching approaches were used in the groups.

Research group

This study was conducted with 7th Grade students at a Middle School in Istanbul, Turkey. The school was picked through random selection. The two 7th classes in the school were randomly assigned as the Control and Study Group. There were 37 students each in the Control and Study Group. Participants' ages ranged from 13 to 14 years. None of the participants had received STEM–STEAM education before. The gender distribution of the groups is given in Table 1.

Data collection tools

To examine the effects of STEAM education on the creative thinking of the students, the Torrance Verbal and Figural Creative Thinking Test (TTCT) was used. The test directly measures creative thinking and has two parallel forms as A and B. To avoid that the students might think that they answer the same questions, the A form was distributed to the Experimental and Control Group before the application, and the B form was distributed after the application. Thirty minutes is enough to answer the Figural test, and 45 min is enough to answer the Verbal test (Torrance 1966).

The Torrance Test of Creative Thinking was developed by Torrance (1966) and was first published in 1966. It measures verbal and figural creativity. Torrance (1966) created TTCT Figurative A–B equivalent forms as a result of 5-year research. The tests have a wide usage area ranging from preschools to university students. It has been widely used in the world since its publication. TTCT has been translated into 35 languages worldwide (Millar 2001). When the Turkish version of TTCT was prepared, Turkish linguistic equivalence, reliability, and validity studies were conducted. Aslan (2001) conducted the linguistic equivalence, reliability and validity studies for A and B forms of the test. The Cronbach Alpha Internal Consistency Coefficients for the verbal part of the TTCT were calculated as 0.64 and 0.86; and for the figural part, as 0.50 and 0.96. The total, item-remaining and item-specificity analyzes were carried out for internal validity. Significant relations were detected at $p < .01$ level for all score types of the verbal and figural parts of the TTCT.

Table 1 Gender distribution by groups

Gender	Control	Study	Total
Female	9	16	25
Male	28	21	49
Total	37	37	74

In the verbal form of the TTCT, there are 7 different tests; ask and guess, guessing causes, guessing consequences, product improvement, unusual uses, unusual questions and just suppose tests.

When scoring is done, fluency, flexibility, and originality are calculated for all tests. The sub-dimensions of the verbal test may be summarized as follows.

1. Fluency means how many different ideas a person can produce in a certain time limit.
2. Flexibility means different categories of thoughts and the change in the thoughts that a person has.
3. Originality means that the answer is rare and unusual.

In the figural part of the test, there are three tests, which are; picture construction, picture completion, and lines (in the A form)/circles (in the B form). The Scoring Criteria, which are called as "Norm-Based Scores" and "criterion-based scores" are used for scoring the figural test.

There are 5 types in the Norm-Based Score Types; fluency, originality, abstraction of titles, elaboration, and resistance to early closure. There are 13 Criterion-Based Score Types; emotional expressiveness, storytelling articulateness, movement or action, expressiveness of titles, synthesis of incomplete figures, synthesis of lines or circles, unusual visualization, internal visualization, extending or breaking boundaries, humor, richness of imagery, colorfulness of imagery, and fantasy.

The Norm-Based Score Type criteria used in scoring may be summarized as follows.

1. Fluency means how many different ideas a person can produce in a certain time limit.
2. Originality means that the answer is rare and unusual.
3. Abstractness of titles means the ability to produce different and good titles for the product. This requires the synthesis of the processes, operations, and organization.
4. Elaboration is the amount of the details needed for the clarity of the product.
5. Resistance to early closure means the ability of individuals to keep the mind open and to delay the closure enough to make the mental jump that makes original ideas possible.

The Criteria-Based Points are summarized here under the title Checklist of Creative Strengths.

1. Emotional Expressiveness means how much lines or verbal additions reflect emotional expressions.
2. Storytelling Articulateness means telling a story or providing enough details to convey an idea and establishing strong and open communication.
3. Movement or Action means an indication of the perception of the movement in the products.
4. Expressiveness of Titles means a new emotion or another synthesis about the product.
5. Synthesis of Incomplete Figures means an indication of the ability to see relations between divergent or irrelevant elements. It is a very rare situation.
6. Synthesis of Lines or Circles means the synthesis or combination of two or more circles or line sets. It is seen rarely and refers to moving away from the ordinary or known one.
7. Unusual Visualization means a visualization that is not plain, usual, and front and is not alike many responses of other individuals.

8. Internal Visualization means the ability to see the internal and dynamic functions of objects.
9. Extending or Breaking Boundaries may be extended out of lines and circles. The sense of depth is given with an upward extension.
10. Humor means comic, smiling and entertaining details in the title and products.
11. Richness of Imagery means the diversity and vitality of products felt by people.
12. Colorfulness of Imagery means that the product is exciting in terms of addressing five senses. Other identifiers may be defined as taste, unreality, ghost-like sensory appealing, being fantastic, etc.
13. Fantasy means the display of products and images, which we know from mythology.

Procedure

The study was implemented in the fall semester of the 2016–2017 Academic Year. The study was conducted for 11 weeks (4 h per week). The education lasted 9 weeks. The pre-tests and post-tests were applied in the first and last weeks. The planning was made with the aim of teaching the learning outcomes in the "Force and Energy" Unit of the 7th grade in the study. To avoid any disruption in the educational curriculum, activities were carried out in the Study and Control Groups in the weeks mentioned in the curriculum. The same teacher taught both of the groups. Before starting the study, a pilot study was conducted, and all the details of the experimental study were told to the teacher.

The distributions of the subjects applied in the Study and Control Group every week are given in Table 2.

Treatment in the study group

STEAM design-based instruction was implemented in the Study Group. Nine STEAM activities were developed according to the achievements given in the curriculum. These activities, which were developed by the researchers, were arranged in line with the 7th Grade of the Middle School Curriculum.

Table 2 Science topics distributions

Weeks	Science topics-tests
Week 1	Torrance test of creativity (figural and verbal) form A
Week 2	Gravitational force
Week 3	Mass–weight
Week 4	Pressure in solids
Week 5	Pressure in liquids
Week 6	Gas pressure
Week 7	Force–work
Week 8	Energy–work
Week 9	Energy transformation
Week 10	Frictional force
Week 11	Torrance test of creativity (figural and verbal) form B

In this study, the Context-Based STEAM Instruction Model (Moore et al. 2014) was used. In the Context-Based Instruction, while science content is the basic point, other contexts help the teacher to put the learning in place. That is, in this context-based integration, while science content is the basic point, other context helps the teacher to put the learning in place. Thus, this study adopted a science and art based approach by teaching the science topics. The technology was made use of with tablet computers. Tablet computers are among the multi-sensory tools employed in STEAM education. The add-ons like applications on the tablet computers or tactile display covers allow more sensory interaction (Taljaard 2016). The engineering field includes the design process (Charyton 2015). The mathematics field is included in the calculations of the STEAM design. STEAM is about "the idea of science and technology interpreted through engineering and art", and all these fields are based on the elements of mathematics (Kwon et al. 2011). Art, on the other hand, takes part in the activation of the imagination in freeing students to improve their creativity. In the study, the creative design processes were implemented, and creativity was present in all of these steps (Bequette and Bequette 2012). For the purpose of not limiting the creativities of the students, many materials from different colors were provided. The tools and equipment used in the STEAM design were the materials that could be purchased from all markets and stationery stores.

Worksheets were prepared previously to implement the activities in a planned manner. These worksheets were presented to the expert opinion of two faculty members and two science teachers who worked in the field of STEM and STEAM. The worksheets were finalized according to the expert opinions.

When the worksheets were developed, the steps given in Fig. 1 were followed. Figure 1 summarizes the process carried out in the STEAM group.

In this group, firstly, the worksheets were distributed to the students. The students were told to follow the instructions given in the worksheets. After the worksheets were distributed to the students, a volunteering student was asked to read the problem situation aloud to the class. The reason for this is to involve the students in the lesson effectively and to ensure that the steps are realized at the same time. A problem situation was given as a sample in Fig. 2. The nature of design includes idea generation process (Linsey et al. 2011; Osborn 1957). Students brainstormed about various possible solutions to solve the problem. The teacher only provided guidance throughout the entire STEAM design process and did not interfere with the students. S/he enabled the students to reach the solution of the problem with their own solutions.

Treatment in the control group

In the Control Group, the teacher started the lesson with a question on the subject. The reason for this is to motivate students to participate in the activities in the class. Lecturing method was used by the teacher. The teacher is active throughout the process. The teacher followed the 7th Grade science textbook throughout the teaching process. The activities in the textbook were carried out under the guidance of the teacher, and 7th Grade science textbook was used as the basis of the curriculum. It contains nine activities on the same topics of the STEAM group. The tools and equipment used in these activities are easily available.

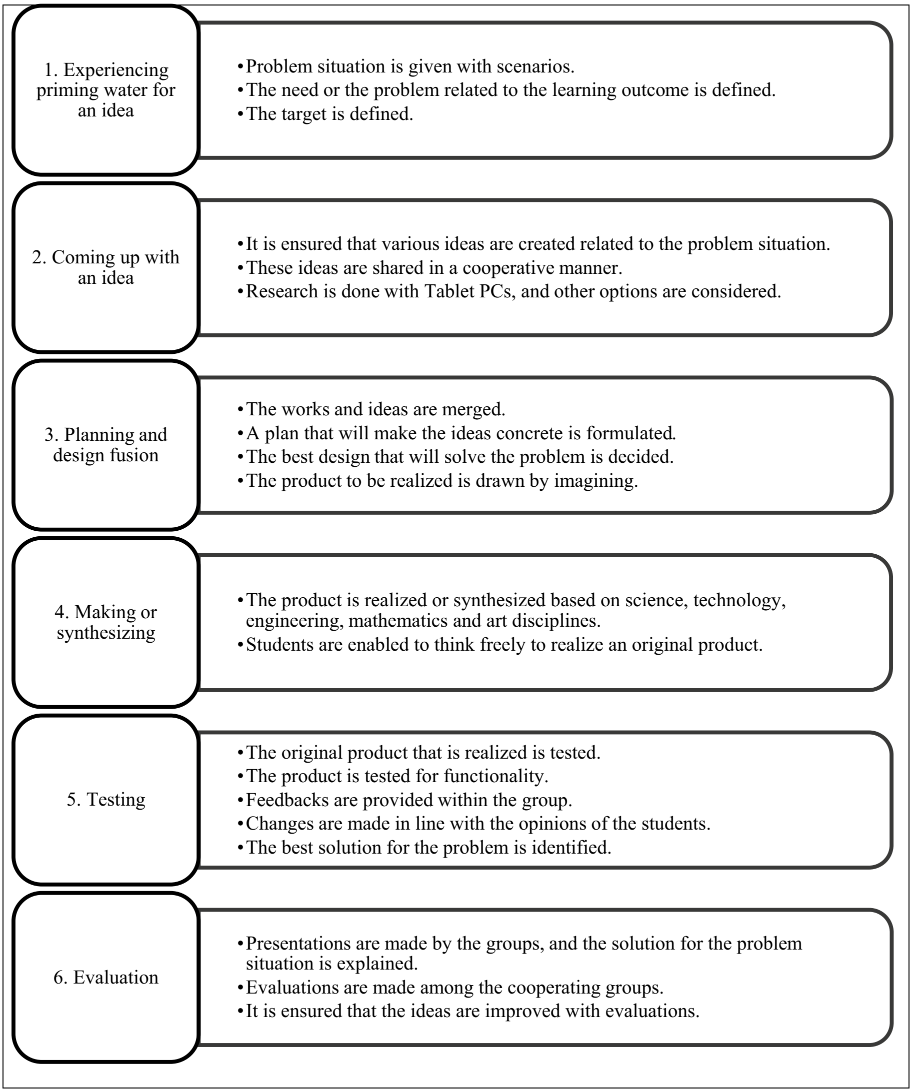

Fig. 1 STEAM design process

Data analysis

The Torrance Test of Creative Thinking scoring is made by making use of the scoring key after the rater has adequate knowledge about scoring (Torrance 1974). After the scoring, the scores may be used as raw scores or may be converted into standard scores to obtain one single creativity score. Scores are transferred into score forms that are prepared for each student individually. It is time-consuming for one participant, requiring approximately 2 h to analyze.

ROCKET MAKING TASK

YOUR TASK:
You are in a team of engineers and scientists who will be authorized in space studies to be performed in our country. You've been tasked with building the rocket that's planned to launch into space.

Things to consider in your design:
-The design should be completed in the given time.
-The cost of the design should be low.
-Your design should be different and outstanding.

What kind of information do you need to solve the give problem situation?

Fig. 2 Sample of problem situation

Following the Torrance Verbal Creative Thinking Test scoring process, the mean and standard deviations were found for each sub-dimension. The raw scores were calculated for each student in all sub-dimensions. For the total verbal creativity score, the scores of the subdimensions (fluency, flexibility, originality) were collected. After the Torrance Figural Creative Thinking Test scoring, the scores were calculated for each subdimension (fluency, originality, abstraction of titles, elaboration, and resistance to early closure). After collecting the mean scores for each subdimension, this total score was divided into five. After adding criteria-referenced points to the result, the Creativity Index was calculated.

A total of 148 forms that included the pre-tests and post-tests (figural and verbal tests) were scored by the researcher. Then, another rater scored the 20 forms. The interrater reliability coefficients between the scores given by the two raters were found as 0.95. The researcher also reevaluated these 148 forms after 6 months and found the intra-scorer reliability coefficient as 0.93. As a result of all these efforts, it was concluded that the intra-rater reliability and inter-rater reliability were achieved.

For the purpose of scoring and using the TTCT for scientific purposes, one of the researchers received special training from the person who adapted the test into Turkish. The implementation and scoring of the test were carried out by this researcher. The SPSS package program was used in the analysis of TTCT.

Results

The findings that were obtained as a result of the Torrance Figural and Verbal Creative Thinking Tests, which were applied to compare the figural and verbal creativity of the Study and Control Groups, were evaluated separately.

Results from torrance verbal creativity test

The Study and Control Group were set up and a Single Factor Analysis of Covariance (ANCOVA) model of statistics was chosen for the split-plot design encompassing the pre- and post-experiment measurements. The results obtained from the application of the Torrance Verbal Test as a pre-test are given in Table 3.

Table 3 Descriptive statistics for the torrance verbal test scores on the pre-test, by groups

Group	Dimension	n	M	SD
Control group	Fluency	37	49.21	8.45
	Flexibility	37	50.24	10.47
	Originality	37	47.91	7.69
	Total	37	48.81	8.8
Study group	Fluency	37	50.79	11.41
	Flexibility	37	49.76	9.65
	Originality	37	52.09	11.6
	Total	37	51.19	11.06

M mean, *SD* standard deviation

In the Table 3, it is seen that the standard deviations are high since they receive a wide variety of answers from the students. On descriptive statistics for the Torrance verbal pre-test for dimension of flexibility, the M value for the control group is greater than the value for the study group. In a Single Factor Analysis of Covariance (ANCOVA), while determining the effectiveness of the experimental method, if the pre-test scores of both groups (study and control) are not equal to each other, pre-test scores are controlled as a covariate. Since the mean scores of the groups on the pre-test are different, to determine whether the difference between the students' pre-test mean scores was significant, the Independent Sample *T* Test was used. It was seen that the difference between the pre-test scores of the groups was significant, the ANCOVA statistics was applied.

The one-way ANCOVA statistical method was selected for the split-plot design measurements before and after the experiment in the two different treatment groups. ANCOVA is used to test the main and interaction effects of the factors while controlling for the effects of the covariate(s). ANCOVA has four assumptions: Normality, equality of variances, homogeneity of slopes, and dependency of scores on the dependent variable (Büyüköztürk 2011).

In the covariance analysis performed, the post-test scores on the torrance verbal creativity test were the dependent variable, the pre-test scores the control variable and the particular treatment (group) was used as an independent variable. All of ANCOVA's assumptions were tested. Since all of ANCOVA's assumptions were proved, the ANCOVA was used to test whether the groups' post-test scores, adjusted according to the pre-test scores, showed any significant differences. The analysis results are shown in Table 4.

According to the ANCOVA results, there was significant difference between the total verbal scores, and all of the dimensions in the post-test scores of the groups adjusted according to the fluency pre-test scores [$F_{(1,71)} = 32.002$, $p < .05$], flexibility pre-test scores [$F_{(1,71)} = 27.057$, $p < .05$], originality pre-test scores [$F_{(1,71)} = 62.658$, $p < .05$], total-verbal pre-test scores [$F_{(1,71)} = 55.299$, $p < .05$]. It was thus seen that there was an association between the verbal creativity of the students and the teaching approach that had been applied.

The average post-test average scores of the study group were higher at a significant level than the post-test scores at fluency (M = 55.28), flexibility (M = 54.67), originality (M = 56.19), and total post-test score (M = 55.80) compared to the control group fluency (M = 44.72), flexibility (M = 45.33), originality (M = 43.81) and total post-test score (M = 44.20).

Table 4 ANCOVA results for post-test verbal creativity scores adjusted according to pre-test verbal creativity by group

Source of variance	Sum of squares	*df*	Mean square	F	*p*	η_p^2
Fluency						
Fluency pre-test	1223.181	1	1223.181	21.650	.000	.243
Group	1808.008	1	1808.008	32.002	.000	.311
Error	4011.324	71	56.498			
Corrected total	7300.000	73				
Flexibility						
Flexibility pre-test	1265.138	1	1265.138	20.321	.000	.223
Group	1684.519	1	1684.519	27.057	.000	.276
Error	4420.328	71	62.258			
Corrected total	7300.000	73				
Originality						
Originality pre-test	2523.671	1	2523.671	92.130	.000	.565
Group	1716.367	1	1716.367	62.658	.000	.469
Error	1944.876	71	27.393			
Corrected total	7300.000	73				
Total-verbal						
Total-verbal pre-test	2364.015	1	2364.015	68.501	.000	.491
Group	1908.410	1	1908.410	55.299	.000	.438
Error	2450.251	71	34.511			
Corrected total	7300.000	73				

The Partial Eta Square (η_p^2) value was examined to determine the effect size (in other words, how effective it was) in this significant difference between the verbal creativity points of the Study and Control Group with the education method that was applied. This value ranges from 0 to 1, and 0.01 is considered as low, 0.06 is considered as the medium, and 0.14 is considered as a very large effect (Büyüköztürk 2011). The partial eta-squared value found in this study for fluency ($\eta_p^2 = .311$), for flexibility ($\eta_p^2 = .276$), for originality ($\eta_p^2 = .469$) and for total ($\eta_p^2 = .438$) indicates that the teaching approach used had a significant effect on the mean TTCT-verbal all dimensions scores of the Study and Control Group.

Results from torrance figural creativity test

It was decided that the Single Factor Analysis of Covariance (ANCOVA) model of statistics would be used to compare the creativity of the Study and Control Group. The results obtained from the application of the Torrance Figural Test as a pre-test are given in Table 5.

In the Table 3 on descriptive statistics for the Torrance figural pre-test for dimensions of originality, abstractness of title, elaboration and resistance to premature closure the M value for the control group is greater than the value for the study group. Since the mean scores of the groups on the pre-test were different, to determine whether the difference between the students' pre-test mean scores was significant, the Independent Samples T-Test was used. The ANCOVA statistics was applied since it was seen that the difference between the pre-test scores of the groups was significant. The test was carried out after the assumptions of ANCOVA were tested.

Table 5 Descriptive statistics for the Torrance Figural Test scores on the pre-test, by groups

Group	Dimension	n	M	SD
Control group	Fluency	37	51.05	9.44
	Originality	37	51.32	9.44
	Abstractness of title	37	51.77	12.31
	Elaboration	37	50.04	10.29
	Resistance to premature closure	37	50.81	11.77
	Creativity index	37	51.78	8.99
Study group	Fluency	37	51.32	10.54
	Originality	37	48.68	10.49
	Abstractness of title	37	48.23	6.70
	Elaboration	37	49.96	9.84
	Resistance to premature Closure	37	49.19	7.93
	Creativity index	37	52.33	6.97

M mean, *SD* standard deviation

In Table 6, According to the ANCOVA results, there was a significant difference between the total figural scores and all of the dimensions of the post-test scores of the groups adjusted according to the fluency pre-test scores [$F_{(1,71)} = 48.980$, $p < .05$], originality pre-test scores [$F_{(1,71)} = 23.223$, $p < .05$], abstractness of title pre-test scores [$F_{(1,71)} = 445.563$, $p < .05$], elaboration pre-test scores [$F_{(1,71)} = 50.643$, $p < .05$], resistance to premature closure pre-test scores [$F_{(1,71)} = 7.146$, $p < .05$], creativity index pre-test scores [$F_{(1,71)} = 122.539$, $p < .05$]. It was thus seen that there was an association between the figural creativity of the students and the teaching approach that had been applied.

The post-test average scores of the study group were higher at a significant level than the post-test scores at fluency (M = 54.99), originality (M = 54.22), abstractness of title (M = 55.80), elaboration (M = 56.38), resistance to premature closure (M = 52.91), and creativity index (M = 64.97) post-test scores compared with the Control Group fluency (M = 45.01), originality (M = 45.78), abstractness of title (M = 44.20), enrichment (M = 43.62), resistance to premature closure (M = 47.09) and creativity index (M = 52.91).

The partial eta square (η_p^2) value was examined to determine the effect size in this significant difference between the verbal creativity scores of the teaching and control groups. The partial eta-squared value found in this study for fluency ($\eta_p^2 = .408$), for originality ($\eta_p^2 = .246$), for abstractness of title ($\eta_p^2 = .391$), for elaboration ($\eta_p^2 = .416$), for resistance to premature closure ($\eta_p^2 = .091$) and for creativity index ($\eta_p^2 = .533$) indicate that the teaching approach used had a significant effect on the mean TTCT-figural dimensions scores of the Study and Control Group.

Discussion and conclusion

As a result of the present study, a significant difference was determined in favor of the Study Group in both figural and verbal forms of the Torrance Test of Creative Thinking. The partial eta-squared value found in this research indicates that the teaching approach used had a significant effect in all dimensions of TTCT-Verbal and TTCT-Figural scores of the study and control groups. The big effect size in all sub-dimensions of creative thinking shows that the applied teaching approach improves all dimensions of creativity.

Table 6 ANCOVA results for post-test figural creativity scores adjusted according to pre-test figural creativity by group

Source of variance	Sum of squares	*df*	Mean square	F	*p*	η_p^2
Fluency						
Fluency pre-test	2173.537	1	2173.537	46.969	.000	.398
Group	2266.604	1	2266.604	48.980	.000	.408
Error	3285.571	71	46.276			
Corrected total	7300.000	73				
Originality						
Originality pre-test	1035.728	1	1035.728	14.862	.000	.173
Group	1618.358	1	1618.358	23.223	.000	.246
Error	4947.820	71	69.688			
Corrected total	7300.000	73				
Abstractness of title						
Abstractness of title pre-test	454.398	1	454.398	7.404	.008	.094
Group	2796.281	1	2796.281	445.563	.000	.391
Error	4357.354	71				
Corrected total	7300.000	73				
Elaboration						
Elaboration pre-test	55.863	1	55.863	.938	.336	.013
Group	3017.337	1	3017.337	50.643	.000	.416
Error	4230.192	71	59.580			
Corrected total	7300.000	73				
Resistance to Premature closure						
Resistance to Premature closure pre-test	91.140	1	91.140	.983	.325	.014
Group	662.454	1	662.454	7.146	.009	.091
Error	6581.717	71	92.700			
Corrected total	7300.000	73				
Creativity index						
Creativity index pre-test	2003.274	1	2003.274	115.165	.000	.619
Group	2131.548	1	2131.548	122.539	.000	.533
Error	1235.030	71	17.395			
Corrected total	5516.576	73				

People working in human sciences face difficulties because they include complex processes like interpreting human behaviors and determining the perceptions of humans (Berg and Lune 2001). Investigating a structure like creativity also requires a comprehensive research process. Scott et al. (2004) conducted a detailed meta-analysis on creativity education including 70 studies conducted on a wide variety of different approaches. After the detailed investigations, they stated that creativity is a teachable element. In this study, too, STEAM education approach increased both the figural and verbal creativity scores of the students. Although the Torrance Test of Verbal Creative Thinking and the Torrance Test of Figural Creative Thinking represents different creative thinking abilities, Kim (2017) found in the study he conducted that these two tests were related at a significant level. The significant relation between the TTCT Figural and TTCT Verbal general scores may show that both versions measure a single creativity factor (Clapham 2004).

Similar results with this study were reported by Oh et al. (2013). The researchers used the Mathematics-Based Scratch Programming Language to improve the mathematical interests of the students in Korea to investigate the effects of STEAM education on the creativity of students. With the STEAM education program, it was intended to ensure that students develop their own designs, find creative solutions with technology, and develop their skills in problem-solving in the twenty-first century. As a result of the study, it was found that STEAM education had a positive effect on the figural creativity of students together with other effective features. Kim et al. (2014) found that STEAM education had a positive effect on the creativity of sixth-grade students.

Creativity may be expressed as the visualization and manipulation of images, being more open to experience, and evaluation of ideas (Hawlader and Poo 1989). With respect to the findings of the present study, it may be interpreted that the creativity of the students improved because students were set free during STEAM activities in the learning environment. In addition, the art component added to STEM education might have had a positive effect on the creativity of students.

Presenting a problem situation to students via scenarios may be interpreted as that it developed their creativity because it stimulated their imagination. The authentic tasks that are defined about real life and the lives of students support the creativity of students (Richardson and Mishra 2018). Creative design offers opportunities to students to experience the whole self-directed process, from transforming the learning into practice and finally into a product (Park et al. 2016).

Learning environment is essential for supporting creativity. Researchers have found that a setting in which ideas are cared for and errors are seen as a necessary part of learning processes together with the desire to learn, co-create and cooperate supported creativity (Chan and Yuen 2014). In this study, the student-centered teaching throughout the design process in STEAM education may have contributed to the creativity of the students. Student-centered activities support creativity by feeding internal motivation and interest (Robinson and Kakela 2006).

Studies have shown that task-related context affects the creativity of students (e.g. Madjar and Shalley 2008; Shalley 1995). In this study, students were given the task of solving a problem situation. This situation might have contributed to the creativity of the students. Students who learn through traditional techniques are mostly auditory or visual learners, and often learn the way how teachers teach (Dunn and Dunn 2005). Creative techniques, on the other hand, often emphasize the active role of the recipient, increasing his/her self-confidence, and creating different ideas (Fard et al. 2014). The STEAM approach might have had a positive effect on the development of the creativity of students because it made students become enthusiastic and supported individual self-efficacy (Runco et al. 2017).

This study also contributes to the literature because it explains the STEAM design process and its framework in a detailed manner. Torrance (1969) considered creativity generally as a process of perceiving a problem, searching possible solutions, forming the hypothesis, testing, evaluating and communicating the results to others. In addition to this, he also stated that the process did not foresee any new relations between original ideas, different viewpoints, detachment from stereotypes, and reunification of ideas. This definition, in which Torrance (1969) summarized the process of creation, is similar to the STEAM design process steps. For this reason, it may be argued that the contribution of the STEAM design process to the creativity of students is an expected result.

In the light of the findings that have been discussed so far, it may be considered that some activities are more appropriate to encourage creativity in science education. These activities are providing opportunities for creative/different ideas and leading aesthetic experiences (Hadzigeorgiou et al. 2012). Based on the findings of this study, it is considered that STEAM education is an effective approach for improving the creativity of students. STEAM, which first appeared as STEM, has become a focal point in many developed countries (Taljaard 2016). More studies are needed to investigate the outcomes and the nature of both STEM and STEAM education.

In this study, the STEAM activities were carried out with simple materials that could easily be found. It is believed that if teachers have adequate awareness of STEAM education, they can implement STEAM activities in classroom environment easily. Each educator must be able to carry out the activities that will increase the creativity of students in his/her class.

This study was carried out with seventh-grade students in a middle school. Future studies may be conducted with other science subjects in another class or education level. Studies must be carried out especially by adding the art field to STEM education.

Teachers have a great deal of responsibility in our present day as knowledge is constantly increasing. In organizing the educational environment, teachers must show students how to access information instead of presenting information to them. It may be advised to educators to focus more on STEAM fields, to include STEAM activities during lessons, and to follow the developments in this area closely.

In the educational environment, students must be set free as much as possible when they are converting their ideas into design, and the teacher should be in the position of a guide. The creativity of students must not be limited. Students must be supported to learn by doing and experiencing. Developing the creativity of students is critical for the future of countries. Based on the findings of the present study, it is possible to argue that educators can encourage the development of the creativity of students by using STEAM activities.

Limitations of the study

The study was limited to the group of students who studied at a middle school in Turkey. The number of students in the school that was selected for the study was low. To comprehend the subject of the study better, more studies are needed with middle school students and with larger sample size at different school levels. For this reason, the results of the present study cannot be generalized to students from other age groups. About the organization of the present study, the results may not be generalized to students of various countries for different contexts. There is a need for further experimental studies with larger sample sizes. Another limitation of the study was the assumption that the students who participated in the present study had never participated in STEAM activity before. Finally, a quasi-experimental pattern was used because of practical conditions. The random assignment of the classes ensured that possible effects about class were accounted for.

Acknowledgements We would like to thank Prof. Dr. Ayse Esra Aslan, who has the legal right to use the test in Turkey and the validity and reliability study, for training in scoring Torrance Tests.

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