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The Effect of STEM Applications on the Scientific Creativity of 9th-Grade Students

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Abstract

The study aims to investigate the effect of STEM applications designed for the atomic system and periodic system unit on the scientific creativity of 9th-grade students. The exploratory sequential design, mixed research, is used in the study. The pretest-posttest quasi-experimental design has been preferred for the quantitative part of the study and the phenomenology design for the qualitative part. The study lasted 12 weeks during the first semester of the 2016-2017 academic year. The sample of the study consists of 133 ninth-grade high school students. The study uses an experimental and a control group. The Scientific Creativity Test was used as a data collection tool. Quantitative data were analyzed using the independent samples t-test through the package program SPSS 22. On the other hand, the qualitative data were analyzed using content analysis. As a result of the study, a statistically significant difference was observed to exist between the groups in terms of scientific creativity in favor of the experimental group. In addition, the participants were determined to have put forward many different and extraordinary thoughts with different perspectives. Based on these results, including activities that will improve students' scientific creativity in chemistry lessons is suggested.

Introduction

Creativity is a very old concept and cannot be easily defined because it cannot be observed directly (Lewis, 2005). Although there is no universal definition of creativity, there are some common points where different definitions come together. Considering these common points, the statements "unusual, original, cannot be evaluated with certain standards" draw attention to the concept of creativity (Boden, 1994). Creativity appears in different fields and includes different process steps (Glück et al., 2002). For example, creativity in the field of science is expressed as scientific creativity.

Torrance (1984) defined creativity as the ability individuals have to be sensitive to disruptions, changes, or incompatibilities in their environment; to identify the problems in their environment, and to produce solutions to these problems. Torrance (1984) highlighted issues related to scientific creativity such as presenting the problem situation clearly and listing different solution suggestions in the solution process. Scientific creativity can be expressed as creating new theories, organizing new experiments, and putting forward new ideas based on existing scientific knowledge (Hu & Adey, 2002; Moravcsik, 1981). Problem-solving hypothesizing, experimental design, and technical innovation are expressed as components specific to scientific creativity (Alexander, 1992; Lin et al., 2003). The steps in the process of scientific creativity are listed as recognizing the problem, ordering the solution suggestions, testing and determining the most appropriate solution, applying it, and finally accepting, rejecting, or revising it (Hu et al., 2013; Moravcsik, 1981).

To develop scientific creativity, teachers should support the use of open-ended questions. Therefore, students should be able to ask enough open-ended questions to solve a problem. Teachers should also encourage their students to use techniques such as brainstorming (Siew, et al. 2015). In addition, teachers should develop their students' critical thinking and product creation skills. In other words, to encourage creative thinking, teachers should enable their students to form hypotheses for the solution of a problem, design experiments, and enable them to follow technological developments (Lin, et al., 2003). For all these reasons, activities based on STEM education were used in this study.

Different studies are found in the literature on determining creativity (Guilford 1988; Torrance, 1990). The most widely known of these is the Torrance Tests of Creative Thinking Test (TTCT). It consists of two verbal and two modal parts, four in total. In addition, TTCT consists of the sub-dimensions of fluency, flexibility, and originality (Chen et al., 2015). Because determining creativity in a specific field such as a scientific field is not possible with TTCT, the Scientific Creativity Test for Secondary School Students (SCT) was developed by Hu and Adey (2002) to determine students' creative thinking. SCT consists of seven open-ended questions, each measuring an aspect of scientific creativity (i.e., unusual uses, problem finding, product development, scientific imagination, problem-solving, science experimentation, and product design). Each question is evaluated in terms of the sub-dimensions of fluency, flexibility, and originality (Lin, et al., 2003).

Hu and Adey (2002, p.391) created the three-dimensional Scientific Structure Creativity Model (SSCM) to explain scientific creativity (see Figure-1). The SSCM consists of three basic dimensions: process, personal feature, and product. The dimension of the process is based on imagination and thinking. Imagination is one of the most basic features found in creative individuals. In the process, individuals think about the solution to the problem using their imagination. Thinking here is not in the form of convergent thinking (suggesting the most appropriate solution according to the available information) but divergent thinking (proposing the untested, different, or outside the existing solution). The dimension of the personal feature includes the sub-dimensions of fluency, flexibility, and originality. Fluency is defined as the ability to produce many solutions to the problem situation, while flexibility is defined as the ability to produce different solutions by looking at the problem situation from different angles. Finally, originality is expressed as being able to produce unique individual solutions for the problem situation. The dimension of the product consists of four sub-dimensions: technical product, scientific knowledge, scientific fact, and scientific problem. The creative product presented as a solution to the problem situation should have a technical infrastructure, scientific knowledge, and a structure that includes scientific facts (Hu & Adey, 2002).

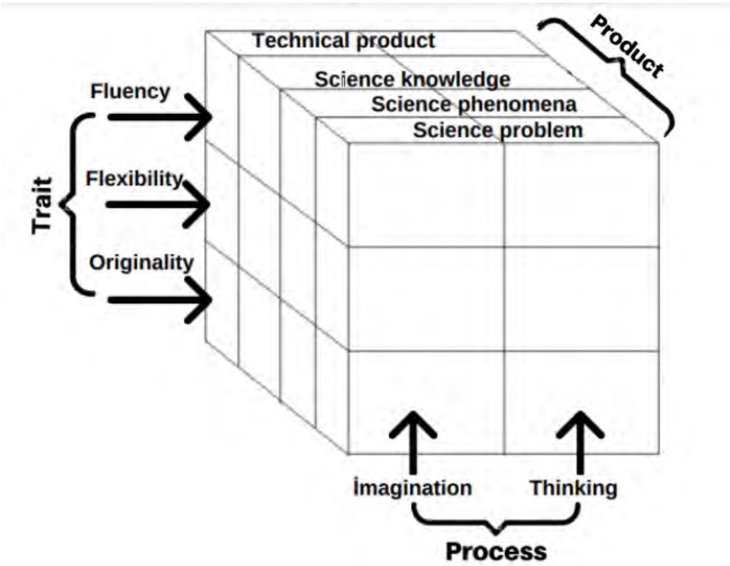

Figure 1. Scientific structure creativity model (Hu & Adey, 2002)

Scientific creativity can be expressed as a driving force in the emergence of scientific developments. Therefore, young people with creative skills are needed for countries to develop economically and progress in the fields of science and technology by increasing their competitiveness (Martins & Terblanche, 2003; Selby et al., 2005). Educational environments need to be rearranged to raise young people with scientific creativity. In other words, environmental conditions must be made suitable for developing individuals' creativity skills. Improving individuals' environmental conditions is necessary for the classroom environment. When examining the related literature, classroom environments enriched with various tools are stated to be important for developing students' creativity skills (Kang et al., 2015; Urban, 2005).

Science classes have an important role in developing scientific creativity skills. In science lessons, students learn that science begins with curiosity, that imagination has an important place in scientific studies, and that a problem can have more than one solution. In this respect, science classes support the development of scientific creativity (Hadzigeorgiou et al., 2012; Moravcsik, 1981).

As a science class, chemistry is also an important lesson that can contribute to developing scientific creativity. One of the chemistry course aims is to raise creative individuals who learn by doing, question, are solutionoriented and curious and have scientific literacy (Daud et al., 2012). Therefore, this study has adopted the idea that students' scientific creativity can be developed in chemistry.

When examining the related literature, different learning strategies are seen to have been used to develop scientific creativity in science lessons (e.g., Semmler & Pietzner, 2017). As an interdisciplinary approach, STEM education is among the strategies used to develop scientific creativity (Barry & Kanematsu, 2006; Barry et al., 2017; Henriksen, 2014; Kanematsu & Barry, 2016; Walsh et al., 2013).

STEM is the abbreviation for the disciplines of science, technology, engineering, and mathematics (Dugger, 2010, p. 2). STEM is an innovative approach in the field of education based on the integration of these four main disciplines (English, 2017; White, 2014). The philosophical foundations of STEM education are based on the constructivist approach (Kelley & Knowles, 2016). Constructivism puts the student at the center of the learning process and is an approach in which the teacher guides the process. Constructivism wants students to take an active role in the learning process and advocates the development of creativity skills (Fosnot, 2013). This philosophical approach is suitable for the nature of STEM, which is based on learning by experience (Nuangchalerm, 2018), and the nature of scientific creativity based on generating many different solutions to real-life problems (Barry & Kanematsu, 2006). In addition, because the 5E (engage, explore, explain, elaborate, evaluate) learning cycle model is a useful and frequently preferred learning model especially in science and chemistry lessons, STEM applications have been decided to be integrated into the 5E learning cycle model (Bybee & Landes, 1990).

Many studies are found in the literature on the positive effects of STEM in the field of education (Cole & Mathilde, 2008; Ostler, 2012; Van Soom & Donche, 2014). These studies stated the integration of different disciplines into courses will increase students' academic achievement, contribute to their meaningful learning, and increase their motivation toward lessons (Van Soom & Donche 2014). STEM has also been underlined to play an important role in the development of 21^{st}-century skills such as critical thinking, problem-solving, and creativity (Wang, 2012).

In addition to those mentioned above, the literature has emphasized learning environments supported by STEM education to increase scientific creativity in students (e.g., Walsh et al., 2013). Kanematsu and Barry (2016) argued that all countries wanting to get stronger should develop scientific creativity with STEM education. Barry and Kanematsu (2006) stated the field of chemistry to be important for society and many things in daily life to be related to chemistry. This is why chemistry teachers need to turn their lessons into scientific experiences and encourage scientific creativity in the laboratory. Based on all these, STEM education is used in this study to improve students' scientific creativity. As the subject, the "Atomic and the Periodic System" course has been chosen. When examining the contents of the atomic and periodic system unit, most topics are seen to be abstract and to not allow exceeding the ideas put forth (e.g., coming up with many different and original ideas about atomic models and the periodic table is not possible in a scientific framework) (Azizoğlu et al., 2015). The aim is to examine whether students' scientific creativity can be improved in a subject involving abstract concepts and limitations using STEM-based lesson activities. Conducted to reveal the effect of STEM-based lesson activities on students' scientific creativity, the study seeks answers to the questions "What is the effect of STEM applications on ninth-grade students' scientific creativity scores?" and "What are the students' thoughts about scientific creativity?"

Method

Research Model

This study uses the explanatory sequential design, a mixed research method, taking into account the classifications of Creswell and Plano Clark (2007). The study uses the pretest-posttest control group quasi-experimental design for collecting the quantitative data. The phenomenology design has been used to collect the qualitative data of the study. Phenomenology offers the researcher the opportunity to examine people's existing event experiences in depth (Van Manen, 2007). Researchers can interpret participants' views of the participants using the hermeneutic model of phenomenology (Van Manen, 2007). This study prefers hermeneutic phenomenology to interpret the effect of STEM-based applications on students' scientific creativity based on the participants' experiences.

Participants

The target population of this study is all 9th-grade students in the Kocasinan district of Kayseri Province in Turkey. The accessible population is the 9th-grade students in the Kocasinan district. To generalize the accessible population, the number of 9th-grade students in the accessible population was determined first, and at least 10% of this number was reached (Tabachnick & Fidell, 2013). Cluster sampling was preferred in the study. Cluster sampling is based on the inclusion of groups that are similar in some respects in the accessible population (Thompson, 1990). In this study, the existing classes in the accessible population were accepted as clusters. Therefore, four classes from the clusters in a school in the accessible population were included in the study.

The sample of the study consists of 133 9th-grade students studying at an Anatolian High School that the first researcher could easily access; the experimental group has 68 students and the control group has 65. Qualitative data were collected using easily accessible case sampling, a type of purposeful sampling. With this sampling, researchers prefer participants who are appropriate in terms of time and location and who also want to participate in the study voluntarily (Merriam, 2013). In the findings section, participants in the experimental group are represented by the letter "E". In this study, the researchers used the statements of the participants in the experimental group for qualitative data, as they tried to prove the effectiveness of the practices in the experimental group on scientific creativity.

Data Collection Tools

This study uses the 7-item Scientific Creativity Test for Secondary School Students (SCT) developed by Hu and Adey (2002). The researchers examined the Turkish version of the test (Atasoy et al., 2007) and adapted the test questions to the "Atomic and Periodic System" unit. The pilot application of the draft test was carried out by the first author to determine the understandability of the questions. The pilot study was applied to 69 tenth-grade high school students (48 girls and 21 boys).

The results obtained from the pilot study were presented to the opinions of three science educators, and the necessary corrections and changes were made to the test questions. For example, regarding Question 7, the students were determined to be unable it present creative ideas and to have been affected by the examples given under the questions. Accordingly, the question "Please design an atomic model that can best describe the internal structure of an atom by considering the model that appears in your mind when the atom is mentioned. Draw the picture of the model you have designed and indicate the name and function of each part" was changed completely to "Design an experimental setup for proving the conservation of mass. Describe each step of the experiment using pictures or figures. Write down the names of each implement or base substance in the setup".

In addition, the statement "How did people from ancient times treat their illnesses?" was removed from the second question and the statement "How will people treat their illnesses in the future?" was added. In addition, in the study, the Cronbach alpha reliability coefficient was calculated as .823 to determine the reliability of the scores obtained from the BYT. Therefore, researchers have determined that the scores of the participants reflect reality at the level of .823 (Pallant, 2016).

Data Collection Process

The necessary official permissions have been obtained for each stage of the study. The data were collected in the first semester of the 2016-2017 academic year. SCT was applied as a pretest (pre-SCT) at the beginning of the study and as a posttest at the end (post-SCT). Course applications were carried out by a chemistry teacher, not the researchers. The first researcher conducted teacher training on STEM activities before the pretest was applied. The practicing teacher did not have any previous knowledge about STEM education. The first researcher gave him one-week training.

The teacher was also supported with written documents related to STEM education. Throughout the application, the first researcher helped the teacher of each group. A research assistant in science education took classes as an observer to observe the teacher. Lessons were conducted in both the experimental and control groups as prescribed by the chemistry course curriculum. The treatment took eight weeks. Teacher training, pretests, treatment, project presentations, and posttests were conducted over a total of 12 weeks.

Treatment

The application process consisted of 16-course hours, two hours per week. In addition, the presentation of the project studies was made in the ninth week. In the experimental group, lessons on the atomic and periodic system were conducted using the disciplines of STEM education. While integrating STEM into the lessons, chemistry was focused on, and at least one of the other disciplines (technology, mathematics, and engineering) was included with the course integration being carried out according to the steps in the 5E learning cycle model. In the STEM activities created to develop students' creativity, the attempt was made to present learning environments with visuals and the support of digital resources. In addition, the attempt was made to support students' creativity through activities that encourage students to research and view a situation from different angles. The weekly distribution of STEM activities associated with the 5E learning cycle model, dimension of STEM, and scientific creativity is shown in Table 1.

Table 1. Distribution of STEM activities by week

Week	STEM activity	5E	Dimension of STEM	Association with Scientific Creativity
1	Black Box	Explore	Science, technology, engineering, and mathematics	Identifying numerous solution suggestions for predicting objects in the box (fluency) Model creation (originality)
2	Einstein's Big Idea	Elaborate	Science and technology	Emphasis on how scientists use their creativity in their work (fluency, flexibility, and originality)
3	Democtritus' ideas about the atom	Engage	Science and mathematics	Making inferences about how Democtritus' ideas about the atom were formed (fluency and originality)
4	Project_1 (subatomic particles)	Evaluate	Science, technology, engineering, and mathematics	Creating products using different materials (originality)
5	Atomic models (Dalton, Thomson, and Rutherford)	Explore - Explain	Science and technology	Supporting students in making original drawings that contain many ideas about the structure of the atom (fluency and originality)
6	Classification of the elements	Explore - Explain	Science, technology, and mathematics	Students are expected to make different classifications based on elements' different physical/chemical properties (fluency, flexibility, and originality)
7	4D element	Elaborate	Science and technology	Enabling students to create different compounds by combining different elements (fluency and originality)
8	Project 2 (My favorite element)	Evaluate	Science, technology, engineering, and mathematics	Asking students to choose one of the first 20 elements in the periodic table and design a model for their chosen element (fluency, flexibility, and originality)
9	Project 3 (Periodic table design)	Evaluate	Science, technology, engineering, and mathematics	Asking students to design periodic tables using different materials (fluency, flexibility, and originality)

This study is based on the Scientific Structure Creativity Model (SSCM). Activities were designed by taking into account the dimensions expressed in this model. In the control group, courses were carried out by traditional methods in line with the objectives in the chemistry curriculum. The methods, techniques, and learning tools used by the teacher in her class were used. Although the science program adopted a student-centered approach, the teacher took a more teacher-centered approach. For instance, only textbooks and smartboards were employed in the lessons. In addition, no experiments were performed in the courses. The teacher explained the lessons with lecturing and solved the sample questions in the textbook. The teacher wrote some parts on the board, then the students wrote what was on the board in their notebooks.

Power and Effect Size

The minimum number of samples required in the study was calculated as 102 using GPower 3.1.9.4 program. For this aim, the level of significance (α = .05), the calculated power (p = 0.80), and the effect size (d = 0,5) was determined at the beginning of the study (Cohen et al., 2003; Hinkle et al., 2003). In this study, the number of participants was 133 and therefore, more than the minimum number of samples. The calculated power was compared with the observed power of the study obtained by the GPower 3.1.9.4 program. Also, the effect size at the beginning of the study was compared with the effect size at the end of the study. Therefore, the generalisability of the study to the accessible population was discussed in terms of external validity. The effect size at the end of the study was calculated using the effect size calculator excel file on the cem.org site.

Data Analysis

Quantitative data analysis. Quantitative data were analyzed using the SPSS-22 package program. To decide whether parametric tests can be used or not, the normal distribution was first checked (Pallant, 2016). For this purpose, the Kolmogorov Smirnov test was used as the sample size is over 50 (Pallant, 2016). Secondly, whether the arithmetic means, mode, and median values (measures of central tendency) are close to or equal to each other was checked to test the normal distribution (George & Mallery, 2001). Thirdly, whether or not the skewness and kurtosis values were between -1 and +1 was checked (Tabachnick & Fidel, 2013). In addition, the assumptions of adequate sample and homogeneity of the variances between groups (Levene test) were met (Pallant, 2016). After the assumptions were seen to be met, the research question was answered using the independent samples t-test (Pallant, 2016). A significance level of $p > 0.05$ was taken as the basis in the statistical analysis.

Qualitative data analysis. Qualitative data was analyzed obtained from the participant expressions and drawings in the SCT using content analysis (Marshall & Rossman, 2006). Codes and categories were created for the students' responses. Taking into account the studies in the literature (e.g., Deniş Çeliker & Balım, 2012), the codes for each question were collected together. Therefore, they coded openly. At the next stage, they collected the codes under categories, taking into account the causal connections between the codes. Thus, they did axial coding (Corbin & Strauss, 1990). The categories were created taking into account the scientific creativity dimensions of Hu and Adey (2002). Therefore, themes are fluency, flexibility, and originality. Authors have reached a consensus on categories and codes. Since the scientific creativity test covers the trait dimension, the other two dimensions of creativity were ignored.

Three different sub-scores were calculated for Questions 1, 2, 3, and 4 about fluency, flexibility, and originality. While calculating the fluency sub-score, the answers given by the participants unrelated to their qualifications regarding the questions were counted. Participant expressions were categorized to calculate the flexibility sub-score. Participants received a score of 1 for each category in which their answers (codes) were included. To calculate the originality sub-score, the participant codes were scored based on the percentage of repetition. A sub-score of 2 was assigned for answers with a repetition frequency of less than 5%, of 1 for answers with a repetition frequency of 5-10%, and of 0 for answers with a repetition frequency of more than 10% (Deniş Çeliker & Balım, 2012). In Tables 2-5 below, the categories and codes for the fluency and flexibility for Questions 1-4 are listed in each respective table.

Table 2. Question 1: Categories and codes created for fluency and flexibility

Category	Codes
Modeling	Chemistry modeling
	Modeling states of matter
	Atomic structure
	Creating an atom model
Experimental	Establishing an experimental setup
Features of the ping-pong ball	Physical-chemical properties of a ping-pong ball
Used in Physics, Biology, and	Use in physics
Astronomy	Use in biology
	Use of Astronomy
Material making	Chemistry material making
Lecture	Atomic calculations
	Historical development of the atom

Table 3. Question 2: Categories and codes created for fluency and flexibility

Category	Codes
Past life	Dinosaurs
	Daily life in ancient times
Future life	Life in the future
	Technology in the future
Discovery	Past discoveries
	Future discoveries
The beginning of life	The beginning of humanity and the world
Health	Health in the past
	Health in the future
Scientists and scientific studies	Structure of the atom
	Scientists
Mysterious events	Egyptian pyramids
Past events	History of the Turks
	Ottoman period
	The beginning of Islam

Table 4. Question 3: Categories and codes created for fluency and flexibility

Category	Codes
Elemental Properties	Changing elements' location
	Examples of elements
	Changing the names of the elements
Visually impaired	Braille for the visually impaired.
	With sound and light
Functional / electronic	Electronic
	Tactile feature
	Coded
	Smart device application
	Interactive
	Usage in different places
Different criteria	Different size and dimension
	Different shapes
	Secret alphabet
	Fragrant
Instructive	Game
	Instructive
	Humorous
Visual richness	Different coloring
	Enriched with visuals

Table 5. Question 4: Categories and codes created for fluency and flexibility

Category	Codes
Earth / Planet	Changes regarding Earth and planets.
...it breaks down	The balance would be disrupted.
	The structure of matter would deteriorate.
Developments (inventions/technology)	Technology would not improve.
	Different studies and inventions could not be made.
Creatures and life	Vital activities get harder.
	Item variety decreases.
Structure of the atom	There would be no atom and subatomic particles.
	Electron-related change.
Gravity	There would be no gravitational force
	There would be no magnetic field.

... does not occur	Elements, compounds, and mixtures would not have been formed. Integrity/ objects would not be formed There would be no chemical reactions. There would be no electricity/electrification. Magnetism would not have formed. Machines would not be used / would not work Bonds would not be formed. There is no change of state. Nothing would happen.

Question 5 was scored as the sum of the fluency and originality sub-scores. Participants were asked to divide a square into four equal parts, and the participants' drawings were scored. According to this, a sub-score of 3 is given for each drawing with less than a 5% repetition rate, 2 points for a 5-10% repetition rate of drawings, and 1 for each drawing with a repetition rate greater than 10%. Below are the drawings encountered in the Pre-SCT in Figure 2.

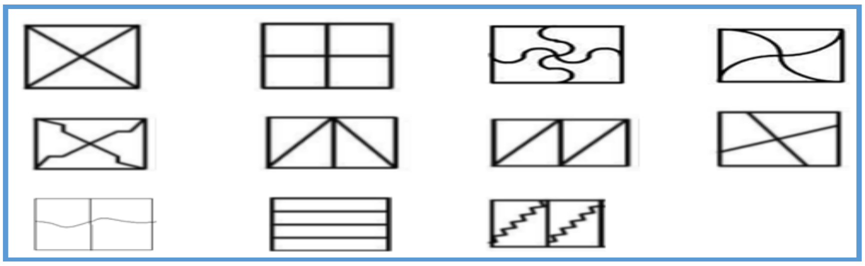

Figure 2. Pre-SCT drawings.

Question 6 asks the participants to suggest methods for comparing the reactivity of two metals. Scoring for this question was carried out in over two different sub-scores: fluency + flexibility and originality. Participants received two points for each method they suggested, and an additional two points when they made explanations about the method. The total score was expressed as the method score. Also, each method was sub-scored separately while giving points for originality. While giving scores for originality, a sub-score of 4 was given for each answer with less than a 5% repetition rate for the drawings and of 2 for a 5-10% rate of repetition. Some of the methods suggested by the participants are listed below.

- Reaction state.
- Melting /Heating.
- Ability to attract other metals.
- Resistance.
- Magnetic attractiveness.
- Electrical conductivity.
- Electron donation tendency.
- Position on the periodic table.
- Mass.
- Combustion reactions.
- Reactivity with nonmetals.
- Mixing with different substances.
- Density.
- Using parentheses.
- A neutral bar.
- Reactivity with water.
- Oxidation (Reactivity with Oxygen [O_2]).
- Luminosity.
- Measuring precise angles.
- Machinability.
- Research.
- The damage they cause when thrown to the ground.

Question 7 asks the participants to create an experimental setup showing the conservation of mass. Regarding this question, students were expected to make drawings and explanations about their drawings. For the experimental drawing setup, a fluency + flexibility sub-score was given for a maximum of 3 points for each criterion (a maximum of 15 points total). In addition, a sub-score of originality between 1 and 5 points was given based on the overall impression. Unrealistic expressions were also scored by consensus as 1 sub-score for the originality. Table 6 lists the criteria that formed for Question 7.

Table 6. Criteria for Question 7

Criteria number	Criteria name
1	Particle-sized display
2	Expressing through numbers
3	Establishing an experimental setup
4	Giving examples of elements and using compounds
5	Explanation of the process
6	Other (Unrealistic Statements)

Validity and Reliability

Regarding external validity; the sample size was chosen to reflect the accessible population and to be generalizable to the accessible population. To generalize to the accessible population, the effect size and power of the study were calculated. In addition, regarding the number of participants in the sample, it was acted by the rule of working with at least 10% of the accessible population.

Regarding internal validity; a content validity study was conducted for the data collection tools used in the study. For this purpose, the literature was reviewed and the available tests were listed and evaluated together. The current test was partially arranged according to the "Atom and Periodic System" subject contents. At this stage, the expert opinion of three science educators who are experts in their fields was sought. A pilot study was conducted to test the suitability of the items. Changes made according to the results of the pilot study are mentioned in the data collection tools section.

To prevent elements that threaten internal validity; bias was prevented in assigning the participants to the groups, the sample size was kept large considering the possibility of data loss, sufficient time was left between the pretest and the posttest to prevent the pretest effect, and the implementation was made by a teacher to prevent the researcher from affecting the practice. Reliability analysis was performed for BYT and Cronbach's alpha reliability coefficient was calculated.

Results

Quantitative Findings from the Scientific Creativity Test

Table 7. Pre-SCT and post-SCT normality test analysis results

Tests	Group	Kolmogorov-Smirnov Statistic	*df*	*p*
Pre-SCT	Experiment	.060	68	.200*
	Control	.145	65	.002
Post-SCT	Experiment	.057	68	.200*
	Control	.069	65	.200*

Table 7 shows the analysis results from the pre-SCT and post-SCT normality tests. The scores can be said to show normal distribution except for the pretest scores from the control group. An evaluation was made for normal distribution by taking into account the criteria mentioned below.

Table 8. SCT pretest-posttest descriptive statistics values

Group	n	Mean	Mode	Median	Skewness	Kurtosis	Min	Max
Pre-Experiment	68	24.220	24	24	-.061	-.689	8	40
Pre-Control	65	22.076	20	21	.705	.892	10	39
Post-Experiment	68	30.147	23	30	.351	-.296	13	55
Post-Control	65	22.646	17	23	.393	-.334	12	39

Table 8 includes the SCT pretest and posttest arithmetic means, modes, medians, skewness, and kurtosis values. When examining the pretest and posttest results separately in terms of the experimental and control groups, the arithmetic means, modes, and medians appear approximately equal to each other. Also, the skewness and kurtosis values were determined to be between +1 and -1. As a result of these values, the SCT pretest and posttest scores are considered to be normally distributed (Field, 2013).

To meet the assumption of sufficient sampling, a study was conducted with 133 participants from among the accessible population of 1,394 (at least 10% of the accessible population) (Pallant, 2016). Because the same sample is valid for the dimensions of fluency, flexibility, and originality, the assumption of sufficient sampling is met in both cases. Levene's test has been used for the other assumption of homogeneity of variances. According to the Levene test results ($t_{(131)} = 5.490$; $p = .004$), the alternative *p-value* ($p = .000$) is used due to the significant difference between the groups' variances (Pallant, 2016).

Table 9. Independent samples t-test results regarding the pre-SCT and post-SCT scores

Tests	Class	*n*	Mean	*SD*	t	*df*	*p*
Pre-SCT	Experiment	68	24.220	7.915	1.827	131	.070
	Control	65	22.076	5.440			
Post-SCT	Experiment	68	30.147	9.234	5.490	131	.000
	Control	65	22.646	6.308			

$p < 0.05$

Table 9 is analyzed separately in terms of the pretest and posttest. Accordingly, no statistically significant difference is found between the Pre-SCT scores for the experimental and control groups ($t_{(131)} = 1.827$; $p = .070$). However, a statistically significant difference is found between the Post-SCT scores of the experimental and control groups ($t_{(131)} = 5.490$; $p = .000$). The average of the scientific creativity scores for the experimental group ($M = 30.147$) on the posttest is significantly higher than the average of the control group ($M = 22.646$).

The observed power is 0.89 and the effect size is .94. The observed power value is greater than the calculated power (0.80). Moreover, the effect size indicates that the learning strategy represents 94% of the variance in the post-test scores. In addition, the effect size was accepted as 0.5 (medium) at the beginning of the study. This value is less than the effect size value (.94) at the end of the study. Therefore, since the observed power is greater than the calculated power and the effect size at the end of the study is greater than the initial effect size, the difference in favor of the experimental group can be generalized to the accessible population and this generalisability is practically significant to provide the external validity (Cohen et al., 2003).

To apply parametric tests in terms of the dimensions of fluency, flexibility, and originality dimensions related to the Post-SCT, the assumptions were checked to see if they were met. Kurtosis and skewness values were examined for normal distribution, and these values were determined to be between +1 and -1. Therefore, the normality assumption for the scores for the sub-dimensions from the Post-SCT has been met.

Table 10. Independent samples t-test results regarding the groups in terms of the sub-dimensions

Tests	Class	*n*	Mean	*SD*	t	*df*	*p*
Post-Fluency	Experiment	68	13.441	4.433	5.439	131	.000
	Control	65	9.908	2.941			
Post-Flexibility	Experiment	68	11.132	3.515	5.104	131	.000
	Control	65	8.508	2.319			
Post-Originality	Experiment	68	9.941	4.121	3.746	131	.000
	Control	65	7.523	3.294			

$p < 0.05$

Levene's test was used for the other assumption of homogeneity of variances. However, the variances between the groups are not homogeneous in all three dimensions, significance (*p*) values in Table 10 are used to indicate the homogeneity of the variances (Pallant, 2016). When examining Table 10, a statistically significant difference was found between the groups in terms of fluency, flexibility, and originality regarding the scientific creativity scores (Fluency: $t_{(131)} = 5.439$, $p = .000$; Flexibility: $t_{(131)} = 5.104$, $p = .000$; Originality: $t_{(131)} = 3.746$, $p = .000$). Therefore, the mean scores for the fluency (13.441), flexibility (11.132), and originality (9.941) sub-scores of the experimental group in the posttest were found to be higher than the mean scores of the control group.

The observed power is 0.89 and the effect size values were calculated as .94 for fluency, .88 for flexibility, and .65 for originality. Therefore, the effect size indicates that the learning strategy represents 94% of the variance in the fluency post-test scores. The learning strategy also represents 88% of flexibility posttest scores and 65% of originality post-test scores. Therefore, since the observed power is greater than the calculated power and the effect size values at the end of the study is greater than the initial effect size, the difference in favor of the experimental group can be generalized to the accessible population and this generalisability is practically significant to provide the external validity (Cohen et al., 2003).

Qualitative Findings of the Scientific Creativity Test

This section involves tables containing the frequency values of participants' expressions and examples of expressions under the codes created for each question in SCT. A limited number of participants' statements are included in the tables, with detailed examinations being made in some cases by including participant expressions not given in the table.

Table 11. Pre-test/post-test codes and fluency scores of the experimental group participants for the 1st question

	Fluency (Frequency)	
Codes	Pre-test	Post-test
Chemistry modeling	18	33
Modeling states of matter	4	2
Atomic structure	15	45
Creating an atom model	-	30
Establishing an experimental setup	6	11
Physical-chemical properties of a ping-pong ball	9	3
Use in physics	16	7
Use in biology	-	1
Use in astronomy	31	20
Chemistry material making	1	2
Atomic calculations	-	4
Historical development of the atom	-	1
Total Fluency Score	100	159

Table 12. Pre-test/post-test flexibility and originality scores of experiment group participants for the 1st question

E5	Pre-test	Post-test
Direct quote	"Modeling of electrons, neutrons, and atoms can be done with the ping-pong ball."	"We can take advantage of the structural, that is, the physical feature of the ping pong ball. With the ping pong ball; We can model many things like atoms, protons, neutrons, electrons, elements, etc. In the laboratory, a ping pong ball is used as a tool to concretize things."
Number of categories	1	3
Categories name	Modeling	Modeling Material making Features of the ping pong ball
Flexibility score	1	3
Originality score	0	3

Question 1 is examined in terms of three sub-dimensions: fluency, flexibility, and originality. Tables 11 and Table12 shows that the post-test fluency sub-scores (159) of the participants in the experimental group were higher than the pre-test (100) because they expressed many ideas under more than one code. Looking at the expression of participant E5 from the experimental group, he presented many ideas embedded under many codes, such as "Modelling, Material making and Features of the ping pong ball". Therefore, in addition to fluency scores, post-test flexibility scores (3) are higher than pre-test (1). Finally, when the situation is examined in terms of originality sub-scores; E5 preferred the expressions that he used less frequently in the post-test instead of the expressions he used very frequently in the pre-test (*In the laboratory, a ping pong ball is used as a tool to concretize things*). This increased the originality score in the post-test.

Table 13. Pre-test/post-test codes and fluency scores of the experimental group participants for the 2nd question

	Fluency (Frequency)	
Codes	Pre-test	Post-test
Dinosaurs	1	4
Daily life in ancient times	33	23
Life in the future	15	8
Technology in the future	7	8
Past discoveries	23	23
Future discoveries	8	13
The beginning of humanity and the world	2	4
Health in the past	5	9
Health in the future	8	7
Structure of the atom	-	15
Scientists	-	31
Egyptian pyramids	5	4
History of the Turks	4	2
Ottoman period	4	2
The beginning of Islam	2	1
Total Fluency Score	117	154

Table 14. Pre-test/post-test flexibility and originality scores of experiment group participants for the 2nd question

E8	Pre-test	Post-test
Direct quote	"How did they communicate and talk in ancient times? Will there be teleportation in the future?"	"How was the atom found? What's the last thing we'll learn about Atom? In addition, I would like to go back to Mendeleev's time and ask how he imagined the location of elements that are not in the periodic table."
Number of categories	2	3
Categories name	Past life Scientists and scientific studies	Discovery Past life Scientists and scientific studies
Flexibility score	2	3
Originality score	1	3

Table 15. Pre-test/post-test codes and fluency scores of the experimental group participants for the 3rd question

	Frequency	
Codes	Pre-test	Post-test
Changing elements' location	8	13
Examples of elements	4	7
Changing the names of the elements	7	11
Braille for the visually impaired	5	13
With sound and light	11	18
Electronic	3	4
Tactile feature	-	3
Coded	-	3
Smart device application	-	1
Interactive	-	4
Usage in different places	3	1
Different size and dimension	4	12
Different shape	6	4
Secret alphabet	-	1
Fragrant	-	1
Game (puzzle, riddle)	-	5
Instructive	13	6
Humorous	-	3
Different coloring	11	9
Enriched with visuals	14	12
Total Fluency Score	89	131

Table 16. Pre-test/post-test flexibility and originality scores of experiment group participants for the 3rd question

E9	Pre-test	Post-test
Direct quote	"I used to make embossed pictures with special functions for the visually impaired."	"I used to emboss for the visually impaired. I'd do 3D. I'd write in the secret alphabet."
Number of categories	1	3
Categories name	For the visually impaired	For the visually impaired Different size and size Hidden alphabet
Flexibility score	1	3
Originality score	1	4

Table 17. Pre-test/post-test codes and fluency scores of the experimental group participants for the 4th question

	Fluency (Frequency)	
Codes	Pre-test	Post-test
Changes regarding Earth and planets	15	13
The balance would be disrupted	-	4
The structure of matter would deteriorate	2	6
Technology would not improve	-	9
Different studies and inventions could not be made	2	8
Vital activities get harder	-	13
Item variety decreases	-	1
There would be no atom and subatomic particles	2	15
Electron related change	-	11
There would be no gravitational force	6	10
There would be no magnetic field	5	7
Elements, compounds, and mixtures would not have been formed	5	5
Integrity/objects would not be formed	-	3
There would be no chemical reactions	5	5
There would be no electricity/electrification	-	5
Magnetism would not have formed	10	8
Machines would not be used / would not work	16	13
Bonds would not be formed	7	11
There is no change of state	-	1
Nothing would have happened	-	1
Total Fluency Score	75	149

Table 18. Pre-test/post-test flexibility and originality scores of experiment group participants for the 4th question

E31	Pre-test	Post-test
Direct quote	"... There would be no electricity."	"Since the earth would not have a magnetic field, weather events would not develop. There would be no deviation in the cathode rays. Electrons would be in the nucleus. Protons would revolve around electrons. There would be no Crocks experiment."
Number of categories	1	3
Categories name	... does not occur	... does not occur Earth/ Planet Structure of the atom
Flexibility score	1	3
Originality score	0	5

Table 13 and Table 14 show the post-test scores of fluency, flexibility, and originality for question 2. Participants asked more detailed questions in the post-test. For example, E8 asked a question about Mendeleev's imagination and increased the flexibility score in the post-test. Fluency scores increased in the post-test. Eight different codes were mentioned in the post-test (see Table 15). Similarly, flexibility scores of participants increased such as E9. In addition, the participants presented very detailed and unusual thoughts. Thus, their originality scores increased as well in the post-test (see Table 16). For instance, E9 made rare statements by mentioning 3D features and the secret alphabet in the post-test.

Fluency scores increased in the post-test. For example, the E31's fluency score was 1 in the pre-test and 5 in the post-test. Nine different codes regarding fluency were mentioned in the post-test (see Table 17). Similarly, flexibility scores of participants increased such as E31. The participants mostly associated the question with "atom and subatomic particles", and they used the names of scientists or the experiments they conducted while explaining their thoughts. For example, E31 put forward the extraordinary view that *"the Crocks experiment could not be done"*. This increased the originality score in the post-test.

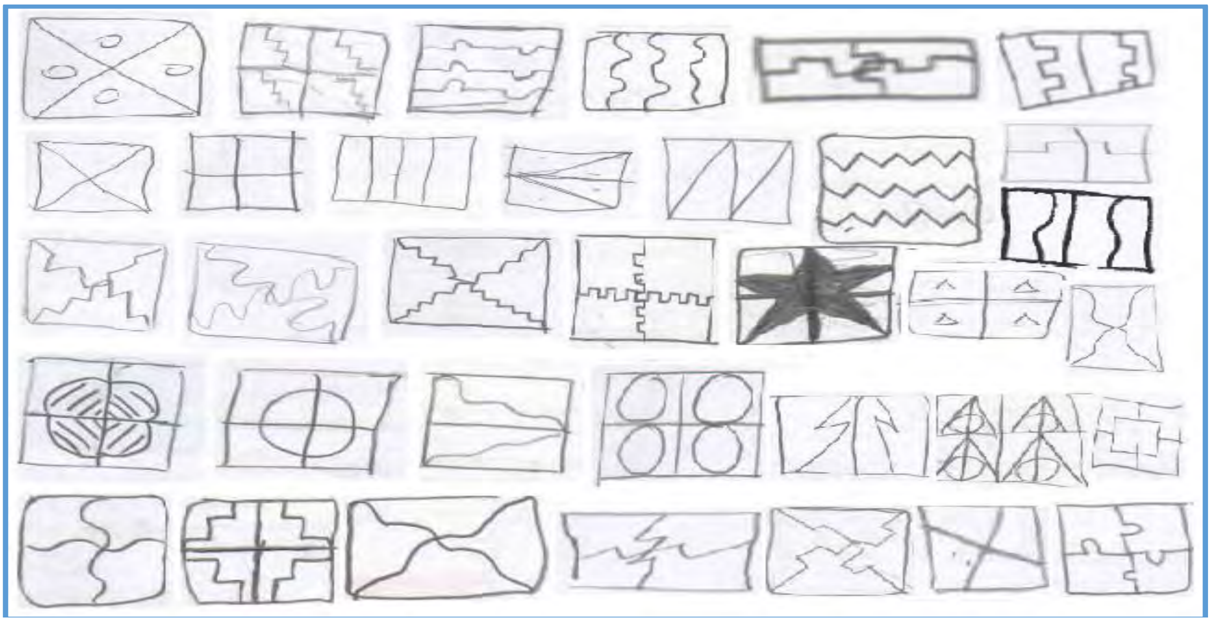

Figure 3. Posttest drawings from the experimental group related to SCT Question 5

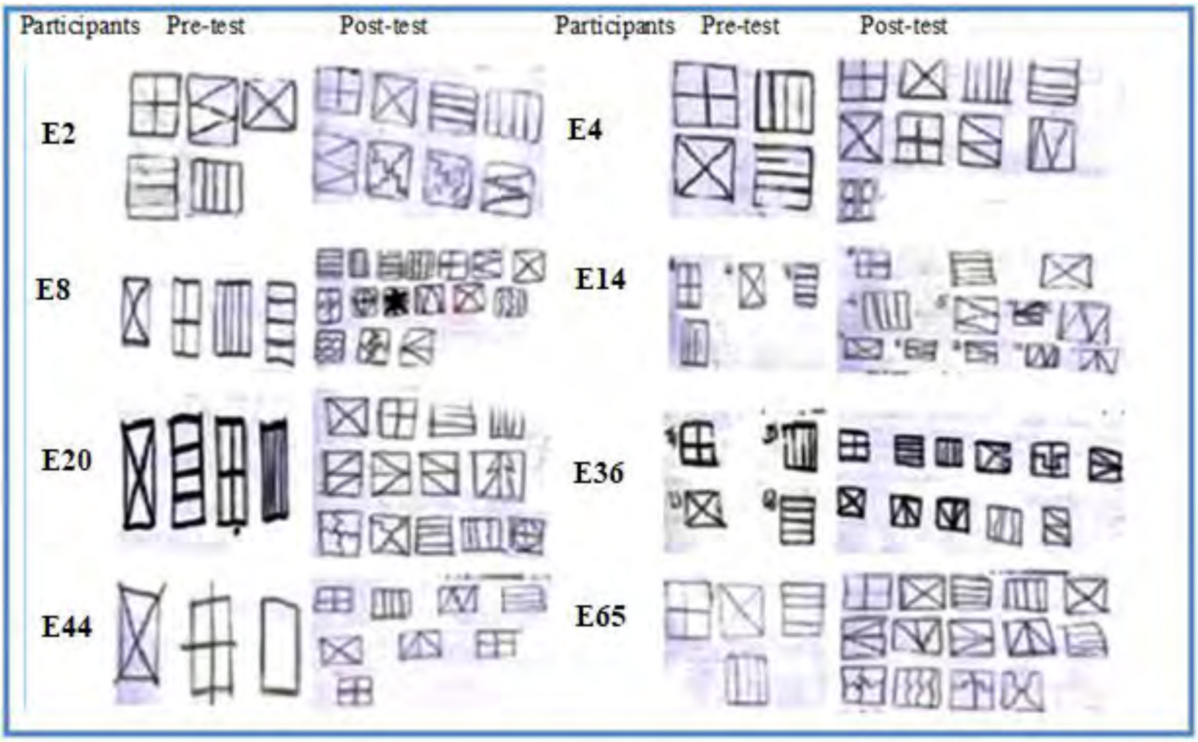

Figure 4. Comparison of SCT experimental group's pretest and posttest drawings

Question 5 of the SCT asks participants to divide a square into four equal parts to test their problem-solving skills. The participants in the experimental group suggested 36 different methods for a division operation. They offer many different drawing suggestions (see Figure 3). From this point of view, participants suggested multiple (fluency) and uniquely different (originality) drawings. Experimental group participants increased the number of suggested methods (fluency) in the posttest drawings and produced more original drawings.

Table 19. Pre-test/post-test codes and frequency scores of the experimental group participants for the 6th question

	Frequency	
Methods suggest	Pretest	Posttest
Reactive states	8	Melting/heating
Melting/heating	7	2
Can be attracted by a magnet	16	12
Don't look at electrical conductivity	21	17
Electron donation tendency	-	7
Its place on the periodic table	2	25
Mass	-	2
Reactivity with acids	-	8
Reactivity with water	-	4
Luminosity	7	2
Machinability	6	4
Physical state	-	1
Reaction rate	-	14
According to the product at the end of the reaction	-	2
Compounding	-	3
Durability	4	-
Other	4	2
Total	75	115

Table 20. Pre-test/post-test method (fluency + flexibility) and originality scores of experiment group participants for the 6th question

E38	Pretest	Posttest
Direct quote	“I'll try to shoot it with a magnet. Whichever one holds it well is good. I'd electrocuted.”	“I would experiment with the magnet. The metallic character increases as you go down the periodic table. I would put them both in a liquid where the metal would react and look at their reaction times. It reacts more quickly and is more active.”
Number of methods suggested	1	3
Methods suggested	Being able to be pulled by a magnet.	Being able to be pulled by a magnet. The place of the element on the periodic table. The state of reacting or not.
Method score	4	8
Originality score	0	6

For Question 6, the qualitative findings of the experimental group are presented in Tables 19 and 20. These tables show the pretest/posttest comparisons of the experimental group in terms of the dimensions of scientific creativity. While evaluating 6 questions, the statements of the participants were evaluated in terms of method score and originality sub-score. Unlike the pretest, it is seen that the participants conduct experiments to test metals for reactivity. In addition, in the posttest, different from the pretest, the participants presented different statements under codes such as "according to the final product of the reaction, reaction rate, and compound formation". When the statement of E38 is examined, it is seen that the participant suggested many methods. This situation caused the participant's method score in the pretest (4) to increase in the posttest (8). In addition, since the expressions such as *"looking at the reaction rate"* among the suggested methods are rare, the originality score of the participant also increased in the posttest (6).

In the post-test for this question, it was observed that some participants drew detailed figures regarding the method suggestions. The drawings were accepted as explaining the proposed method and this caused their method scores to increase. Quotations of the experimental group participants' methods of comparing metals are shown in Figure 5 below.

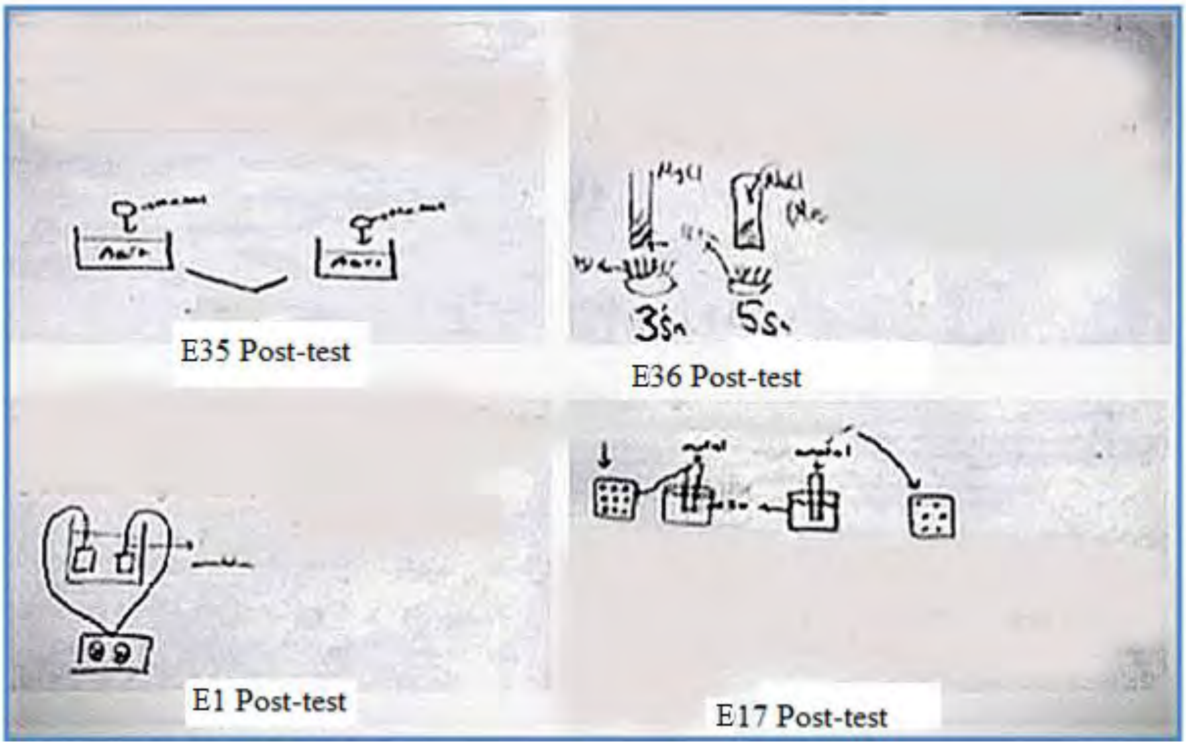

Figure 5. Drawings from some of the experimental group participants for Question 6

According to Figure 5 when looking at the experimental group participants' expressions, they were observed to make use of the properties of metals, explain the method they defend with detailed expressions and support their thoughts with drawings to compare the reactivity's of metals. This situation supports the increase in their method score compared to the control group.

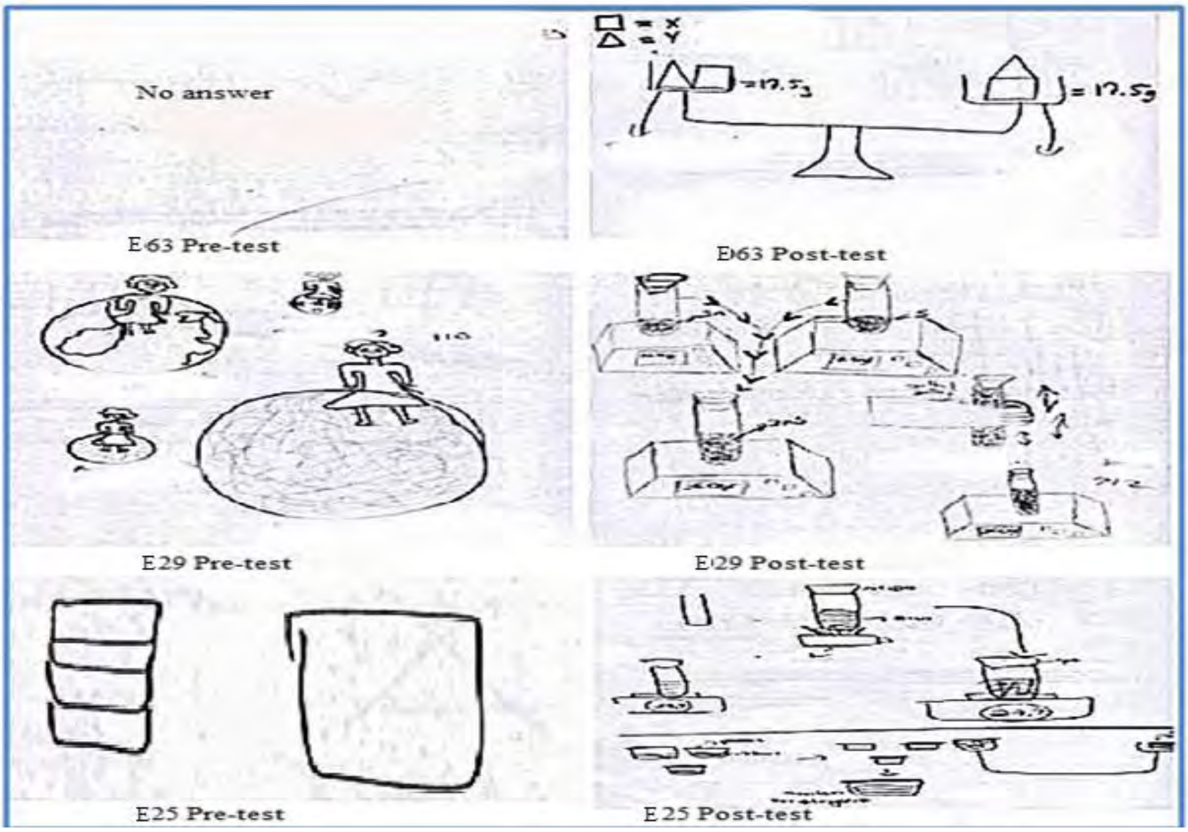

Figure 6. Question 7: pretest and posttest drawings from the experimental group participants.

When examining the sample drawings in Figure 6, all participants in the pretest are seen to have generally made drawings relating the conservation of mass to making measurements on the earth and the moon. However, when examining Figure 7 in terms of the experimental group participants' drawings in the posttest, they were found to have tried to show the conservation of mass using different experimental setups; they were observed to have symbolized elements and compounds at the micro-level and taken into account gas releases that may occur as a result of the reaction. When examining the experimental setups from the experimental group participants in Figure 7, the method / experimental setup scores are seen to be high due to meeting the previously determined criteria (criteria: *Particle-sized display, expressing through numbers, establishing an experimental setup, and Giving examples of elements and using compounds*).

Discussion and Conclusions

The research shows that STEM-based learning activities have a significant effect on the scientific creativity skills of the experimental group. A significant difference is found between the groups in terms of scientific creativity scores in favor of the experimental group. When examining the relevant studies in the literature, many studies are seen on attempts to develop participants' scientific creativity (e.g. Özkök, 2005; Siew, et al., 2015; Walsh, Anders, & Hancock, 2013). Among these studies, Özkök (2005) stated the use of technology and the interdisciplinary approach to increase students' scientific creativity. This situation supports the results from this study, which uses technology and attempts to present an interdisciplinary perspective. However, when examining the studies in the literature, studies are seen to have been conducted on the effect of STEM education on scientific creativity (Barry & Kanematsu, 2006, 2007; Henriksen, 2014; Kanematsu & Barry, 2016; Walsh, Anders, & Hancock, 2013). When considering the results from Walsh, Anders, and Hancock's (2013) study, they stated creativity to be able to be developed through education and the environment factor to be important in developing creativity. In addition, they emphasized that creative learning environments developed about STEM will increase students' creativity. This study has attempted to present students with STEM-based activities developed as well as rich and creative learning environments to improve students' creativity. In this way, the students thought differently and used their imaginations. Similarly, the results from Henriksen's (2014) study, which associated STEM and creativity, stated STEM disciplines to be related to creativity, and the creativity of successful people in these fields to also be high. The results from the current study support the results from Henriksen's (2014) study.

In conclusion, to sum up, in this study, students sought many different solutions to the problems they encountered in their daily lives to improve their scientific creativity. In addition, rich learning environments were created with STEM-based activities and students could easily express their thoughts and imaginations. In addition, students were allowed to demonstrate their productivity. In other words, STEM-based activities led students to generate many ideas (fluency), to look at the same problem situation from different perspectives (flexibility), and to produce original solutions (originality).

This study has shown students' scientific creativity to have improved in the sub-dimensions of fluency, flexibility, and originality. In the literature, Barry and Kanematsu's (2007) study on scientific creativity and STEM stated that students' creativity would improve through STEM activities. This study involved many STEM activities (e.g., STEM activities that enable students to design with different materials enabled them to develop their creativity skills). Through these activities, students were able to generate a large number of ideas (fluency) and design products by revealing different perspectives (flexibility and originality). The participants' posttest statements given in the findings section also support all three sub-dimensions being developed.

According to Hu and Adey (2002), fields such as science, mathematics, engineering, and technology require the use of imagination by their nature and provide rich thinking opportunities, enable the development of scientific creativity, and form creative products. According to Hu and Adey (2002), scientific creativity is defined as the thinking skill that enables original ideas to be produced with an interdisciplinary perspective. Based on the scientific creativity model developed by Hu and Adey (2002), this study developed students' scientific creativity using STEM-based activities, an approach that uses different disciplines such as science, mathematics, engineering, and technology together. In this way, the STEM approach has been suggested as a way for students to generate original ideas.

Recommendations

In this study, students' scientific creativity skills were developed for fluency, flexibility, and originality using STEM activities. For this reason, STEM activities that enable students to generate ideas, view events from different angles and make original designs should be planned, and such activities should be frequently included in chemistry lessons. In addition, STEM activities should be supported with open-ended questions.

Limited STEM activities are found to have been developed due to the subject being studied. Again, due to the nature of a subject's contents, activities for design creation (e.g., periodic table design) are not in the form of a design from scratch but are limited to different additions. Therefore, creating STEM activities for different subjects that allow students to design from scratch is recommended.

Scientific Ethics Declaration

We, the authors, declare that the scientific ethical and legal responsibility of this article published in the JESEH journal belongs to the authors.

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