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Gifted and Talented Students' Views on Engineering Design-Oriented Integrated STEM

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ABSTRACT

This research aims to present gifted and talented students' views regarding STEM (science, technology, engineering, mathematics) education and STEM disciplines in engineering design-oriented integrated STEM activities. The research was modeled as a case study, using a qualitative research design, and was conducted with seven 7th grade students, who were getting support education at Yozgat Science and Art Center. Individual interviews were conducted to reveal the views and definitions of students about STEM disciplines before STEM activities. During implementation process, ten-week STEM activities were conducted to the students. After STEM activities, individual interviews were held with students and student views on STEM disciplines and STEM education were revealed. Observation forms and STEM activity booklet as documents were used during the STEM activities to support the interview data. Data that was collected was analyzed through content analysis. In this study, it was seen that gifted and talented students STEM disciplines separately from each other and independently from real-life situation, however after STEM education, they were able to make interdisciplinary associations and associate them with other disciplines and real life. In line with the findings, it was concluded that STEM education is effective in defining STEM disciplines and in providing interest and motivation for STEM disciplines.

Keywords: integrated STEM education, gifted and talented students, STEM activities

Üstün Zekalı ve Yetenekli Öğrencilerin Mühendislik Tasarımı Odaklı Bütünleşik STEM Hakkındaki Görüşleri

ÖZ

Bu araştırmada, üstün zekâlı ve yetenekli öğrencilerin mühendislik tasarımı odaklı bütünleşik STEM etkinliklerinde STEM disiplinlerine ve STEM eğitimine yönelik görüşlerinin ortaya konulması amaçlanmıştır. Araştırma, nitel araştırma desenlerinden durum çalışması olarak modellenmiştir. Çalışmaya Yozgat Bilim ve Sanat Merkezi'nde destek eğitimi alan yedi 7. sınıf öğrencisi katılmıştır. STEM eğitimi öncesi öğrencilerin STEM disiplinlerine ilişkin görüş ve tanımlamalarını ortaya çıkarmak amacıyla bireysel görüşmeler gerçekleştirilmiştir. Çalışma kapsamında öğrencilerle on haftalık STEM etkinlikleri gerçekleştirilmiştir. STEM eğitimi sonrasında da öğrencilerle bireysel görüşmeler gerçekleştirilerek STEM disiplinlerine ve STEM eğitimine yönelik öğrenci görüşleri ortaya konulmuştur. Görüşme verilerini desteklemek için STEM etkinlikleri süresince dokümanlar (gözlem formu, STEM etkinlik kitapçığı ve fotoğraflar) kullanılmıştır. Elde edilen veriler içerik analizi yolu ile analiz edilmiştir. STEM eğitimi öncesi öğrencilerin STEM disiplinlerini birbirlerinden ayrı ve gerçek yaşamdan bağımsız olarak tanımladıkları görülürken STEM eğitimi sonrasında her disiplini birbirleriyle, farklı disiplinlerle ve gerçek yaşamla ilişkilendirerek tanımladıkları görülmektedir. Elde edilen bulgular doğrultusunda STEM eğitiminin, STEM disiplinlerini tanımlamada ve STEM disiplinlerine yönelik ilgi ve motivasyon sağlamada etkili olduğu sonucuna ulaşılmıştır.

Anahtar kelimeler: bütünleşik STEM eğitimi, üstün zekalı ve yetenekli öğrenciler, STEM etkinlikleri

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1 | INTRODUCTION

While schools generally focus on improving the academic performance of underachieving students, insufficient attention has been paid to the education of gifted and talented students, who will become effective at many jobs in the future (Thomas, 2018). Gifted and talented students require differentiated educational programs that are calibrated to their pace of development (National Mathematics Advisory Panel, 2008). Toward this purpose, the use of enriched curriculum content and materials is recommended in the education of gifted and talented students (Corrigan et al., 2013; Ericsson, 2014; Miedijensky & Tal, 2016). In most studies that have focused on gifted and talented students STEM education is recommended as it creates a learning environment that is effective in meeting the needs of these students (Andersen, 2014; Choi, 2014; Robinson et al., 2014; Schroth & Helfer, 2017; Tofel-Grehl & Callahan, 2017; Trna & Trnova, 2015; von Károlyi, 2013; Yoon & Mann, 2017). STEM education is a proper education model for gifted and talented students, which, by instilling interest and curiosity, provides them with the opportunity to develop solutions to complicated problems and make discoveries (Lee et al., 2013). Through STEM education, gifted and talented students are given the opportunity to collaborate in interdisciplinary studies and deal with difficult tasks through challenge-based learning (Song et al., 2010). By employing STEM education, which is carried out with gifted and talented students, it is now possible for creative individuals, equipped with required skills for STEM-related career fields, particularly science and mathematics, to be introduced to society (Adams et al., 2008). Accordingly, the significance of including STEM activities in the education of gifted and talented students has become evident. During the course of this study, engineering, design-oriented activities have been carried out while students' opinions on both STEM disciplines (science, technology, engineering, and mathematics) and the effectiveness of STEM education have been introduced before and after this education.

THEORETICAL FRAMEWORK

STEM is an acronym used to refer four different fields, i.e., science, technology, engineering, and mathematics, or some combination of the fields. When searched for integration in education, the concept of STEM emerges as the integration of science, technology, engineering, and mathematics disciplines. Bybee (2010) states that the aim of STEM education is to "develop in-depth understanding of STEM fields and to achieve development in technology" (p.30). It is stated that STEM education, which is an interdisciplinary integrated education, is effective for the learners to receive more qualified and rich content (Bryan et al., Mahoney, 2010; Honey et al., 2014). Integrated STEM provides learning opportunities in the connection of academic knowledge of basic sciences such as physics, chemistry, biology, and mathematics with technology and engineering applications. In this way, it is possible to use the knowledge acquired through activity beyond the memorization of mere knowledge. Integrated STEM refers to the integration of at least one STEM discipline with specific knowledge and skills of a discipline based on the interests of students (Corlu et al., 2014). While performing interdisciplinary practices, special knowledge and skills of each discipline are included (Callı, 2017). The integrated STEM education enables the use of knowledge and skills in basic sciences through activities. It is seen that although students are taught what information they need to know and what this information does, students cannot use these knowledge and skills effectively when they encounter with the applications. In this direction, it is important that students use their academic knowledge through activities.

Engineering design-oriented STEM concept emerges in the use of students' academic knowledge related to mathematics and science through activities. Engineering design is defined as providing solutions to complex and semi-structured real-life problems (Callı, 2017). In engineering design, the solution of complex problems involves a systematic way that use technology with science and mathematics concepts. Since engineering design involves social and realistic problems, providing students interest and motivation is also effective to develop an in-depth understanding of science, mathematics, and technology (Morgan et al., 2013). In addition to academic knowledge, skill usage and skill development gain importance in engineering design-oriented STEM activities. Engineering design-oriented integrated STEM is introduced to us through different implementation methods involving intramural and extramural learning strategies (pull-out/pull-in strategies) in the education of gifted and talented individuals. The regular curriculum that is implemented in schools may lead to limitations in terms of improving students' high-level skills in science and mathematics (Adams et al., 2008). According to The National Research Center on Gifted and Talented (NRC/GT), the majority of the schools where education programs designed for gifted and talented students are carried out, and the teachers that work in these schools, do not comply with the required criteria in terms of the education of these students (Archambault et al., 1993). Subotnik et al. (2007) have stated that STEM education is the form of education that can be implemented in the pull-out activities for gifted and talented students. Pull-out STEM education is introduced as an education strategy that includes enrichment and differentiation strategies, intending to satisfy the needs of gifted and talented students.

Looking at the existing studies that have been conducted regarding the gifted and talented students, it has been stated that STEM education had a positive influence on students' success (Choi, 2014; Olszewski-Kubilius, 2009; Tofel-Grehl & Callahan, 2017; Trna & Trnova, 2015), skills (Andersen, 2014; Lubinski, 2010; Robinson et al., 2014; Schroth & Helfer, 2017; von Károlyi, 2013; Yoon & Mann, 2017), and career choices in STEM fields (Coleman, 2016; Jen & Moon, 2015; Steenbergen-Hu & Olszewski-Kubilius, 2017; Rinn, et al., 2008; Stoeger et al., 2017; Wegner et al., 2014). Accordingly, the significance of implementing STEM activities when designing the learning content for gifted and talented individuals became evident.

Research Question

In this study, the following research questions were proposed by carrying out engineering, design-oriented integrated pull-out STEM activities with gifted and talented individuals:

1. What are the opinions of gifted and talented students concerning STEM disciplines before and after STEM education was performed?
2. What are the opinions of gifted and talented students concerning the conducted STEM education techniques?

2 | Method

Within the course of this study, engineering, design-oriented, integrated pull-out STEM activities have been conducted with gifted and talented students, and, during the same process, the aim was to identify the specification of student opinions regarding STEM and STEM education. Toward this purpose, the study has been modeled as a case study, one of the qualitative research designs. Using a case study approach enables a researcher to closely examine specific situations (person, program, process, etc.) within specific contexts (Merriam, 2001).

Participants

The participants in the study consisted of seven 7th grade students who had been identified as gifted and talented by the Guidance and Counseling Research Center (GCRC). Students in Turkey who are diagnosed as gifted and talented by the GCRCs of district directorates of the Ministry of National Education of Turkey receive out-of-school support education at SACs. Upon getting the required permissions, 7 gifted students all of whom volunteered for the STEM course, participated in the study. In terms of protecting the privacy of participants' information, the students names were coded as S1, S2,…,S7.

The Implementation of the Process

The research was conducted in two stages: A pilot study and a main study. In the first stage, the research team carried out the pilot study in order to address the deficiencies in the data collection tools and the content of STEM education. After the pilot study process was completed, the relevant arrangements were made regarding the STEM activity content, implementation, and data collection tools. The research team conducted the main study during the fall term of the 2017-2018 academic year.

Table 1. Course Content

Activity		Implementations
STEM artifacts activities	Bridge (4 hour)	Presentation about the bridges Creating discussion environment on bridge properties Problem status as "weight-resistant bridge model" Designing bridge models Constructing and testing models
	Windmill (4-5 hour)	Discussion of air pollution renewable energy sources Reading the "Don Quixote and the Windmills" then discussion physical properties of the windmills Problem status as "You have been asked to design a windmill to reduce pollution from energy sources. Create a working windmill for this purpose" Designing windmill models Constructing and testing models
	Catapult (4 hour)	Presentation about the catapult in history Watching animated movie about catapult shooting Problem status as "ejection catapult" Designing catapult models Constructing and testing models in "The farthest throw race"
	Kite (4-5 hour)	Creating a discussion environment for what purposes kites can be used Presentation of kites from past to present Watching animated movies about flying and discussing the physical properties of the kite Problem status as "flying a kite" Designing kite models Constructing and testing models
STEM activity with LEGO Mindstorms Kits	Rubik Cube's Solver Robot (6 hour)	Creating discussion environment on developing robot technology Trying to solve Rubik's cube Problem status as "Can we make a robot that makes our job easier?" Creating a robot by following the instructions Discussing the advantages and disadvantages of developing technology
3D STEM activity	My Logo (4 hour)	Introducing 3D printer technology Introducing Tinkercad program Modeling for logos in Tinkercad Printing models from a 3D printer Evaluation of the students' products
	Fractal (3 hour)	Investigation of fractal models in nature Modeling for fractal models in Tinkercad Printing models from a 3D printer Evaluation of the students' products
	Cell Model (3 hour)	Revealing preliminary information about the cell Cell observation with microscope Modeling for cell models in Tinkercad Printing models from a 3D printer Evaluation of the students' products
	Balance Model (4 hour)	Playing interactive game about balance and investigating the working principle of scales or seesaw tools Modeling for balance models in Tinkercad Printing models from a 3D printer Evaluation of the students' products

STEM activities, a variety of manipulatives (written and oral presentations, simulations, concrete, and abstract models) and technological tools (computer, 3D printer, simulation, Tinkercad 3D Modeling Program) were used during the implementation process. Through this approach, the study aimed to maintain the effectiveness of STEM activities via an enrichment of the activity content. During the implementation of STEM activities, the students generated solutions for engineering-based problems. The implementation process regarding the STEM activities is illustrated in Figure 1.

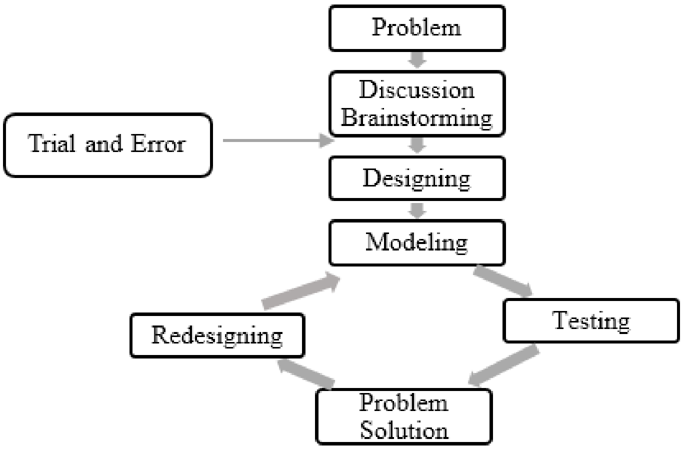


Figure 1. *Implementation Steps of STEM Activities*

STEM activities include three stages: Introduction, implementation, and evaluation. In the first stage, the problem is identified, defined, and discussed. Implementation follows and is a process that includes the designing and modeling stages. The third step involves testing the model, with solutions to the problem discussed and the product remodeled if necessary. Before STEM education, individual interviews were carried out with the students in order to identify the students' opinions on STEM disciplines, and this was followed by the engineering-oriented, three-month-long STEM activities. In this process, sample images of STEM activities performed with students are presented in figure 1. Sample images from the learning environment of this process are presented in Figure 2. After the STEM education process had also been completed, the opinions of the students regarding STEM disciplines and the implemented STEM education were revealed.

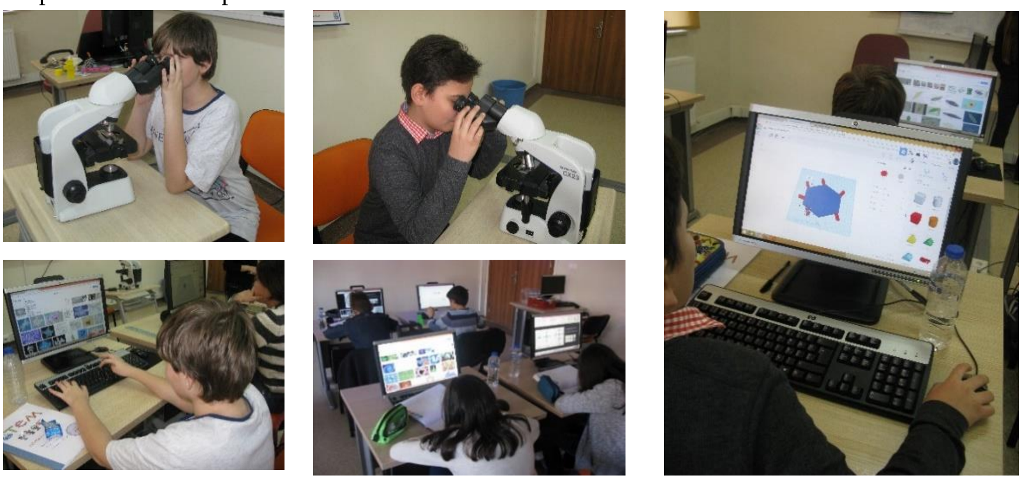


Figure 2. *The Learning Environment for The STEM Activities*

DATA COLLECTION

The study aimed to identify the opinions of the students on both STEM disciplines and implemented STEM education before and after STEM education. For this reason, the main source of data was the individual interviews. Alongside the individual interviews, the researcher observation form, STEM activity leaflet, and photographs were used as documents (observation form, STEM activity booklet, and photographs) for data support. By using a variety of data sources, data loss was prevented, while the comparison and confirmation of data were ensured.

Individual interview: The researcher conducted individual interviews with the participants both before and after STEM education. The contents of individual interviews were assessed, aiming to reveal the opinions of each participant on STEM disciplines and activities. The aim was to determine both the effectiveness of the implementation and the students' changing opinions through pre-STEM and post-STEM individual interviews. The individual interviews were one-to-one interviews between the researcher and the participant, and they were carried out in the silent atmosphere of the SAC counseling office, where the participants would feel comfortable and safe. The individual interviews lasted for 15-20 minutes. Before the interview, each participant was informed that both the contents of the interview and the participant's name would be kept confidential, and that this information would not be shared with third parties. The participants were also informed about the objective of the interviews by the researcher. During this process, the participants were not given any information about the questions, subject, or scope of the interviews. During the course of conducting the interviews, a recorder was used for the researcher to record the interviews and prevent the loss of data, while also helping to keep the interview content in written form. Looking at the results of the literature review, a draft form containing six questions was prepared by the researcher. In order to determine the suitability of the draft form regarding the personal characteristics of the gifted individuals and their levels, as well as to define its suitability to the scope of the planned objective, the researcher gained the permission of the three researchers who are experts in science and math education and the education of gifted and talented individuals to act as consultants. The experts, who volunteered to help, were given detailed information regarding the content, subject, scope, and objectives of the study, and the individual interview form was reorganized according to the written feedback of the experts. Interviews with two 6th and 7th grade students at SAC were carried out to test the suitability of the prepared form for the students. Together with these interviews, the individual interview form was also made ready for use in the pilot study. After the pilot study, the individual interview form (IF) was put into its final form, along with the pre-STEM interview form (PSIF), which contained six questions and nine sub-questions, and the post-STEM interview form (POSIF), which contained six questions and 23 sub-questions. The IF was composed of the questions that included the definition of science, technology, engineering, and mathematics as STEM components, as well as the evaluation of STEM education and the researcher. (Appendix-1)

Observation: In this study, the observation form (Appendix-2) was used to support the data obtained from the individual interviews. After the draft observation form, which included skills and sub-skills, was prepared, it was then sent to the professional educators for consultancy to determine its suitability regarding the content of the study. With this purpose, it was put into its final form by consulting the two expert researchers in mathematics and science education. During the course of the study, the non-participant observer attended the activity setting. For each student, the semi-structured observation form was used in each activity to enable the researcher to make the observation. The observation form was prepared to define the skills of the students, as well as their views and behaviors toward the studies.

Documents: The written documents in the study included the STEM activity booklet, which was prepared by the students, and the photographs of the learning environment. The STEM activity booklet (Appendix-3) included sections where the students took notes during STEM activities and designed a model, as well as parts that contain their questions before and after the activities. The STEM activity booklet was prepared as a draft, and the two educators who are experts in STEM education were consulted. As a result of this consultancy process, the activity booklet was put into its final form by context editing according to STEM activities in the study. The students' written opinions, which they put down in the booklet, helped the researcher to acquire data concerning the presentation of the targeted opinions and skills within the scope of the study. In addition, the STEM activity booklet also included a student journal, where the students could express their feelings and opinions after the activity. This inclusion of this journal aimed to identify students' opinions on STEM activities and course.

DATA ANALYSIS

For the identification of student opinions on STEM education, the individual interviews, observation forms, and the documents were used. Data that was collected in these ways was analyzed through content analysis, which was supported by the photographs of the teaching environment, the observer notes provided from the observation form, and the direct quotations of the student responses in the individual interviews.

Student opinions provided from the individual interviews were grouped as pre-SC and post-SC. The voice recordings provided from the expressions and talks in the pre-SC and post-SC were converted into a written computer document. Coding was conducted in Nvivo 9. The codings related to students in the pre-STEM interviews were made in collaboration with the researcher who is an expert in mathematics education. The codings related to the other students were analyzed individually. The codes and the categories were compared and discussed. As a result of the efforts to reach a consensus regarding all the codings, the codes and the categories were created. The student opinions were categorized according to whether they were opinions on STEM activities and STEM disciplines pre-SC and post-SC.

Observation data was provided by the researcher and the non-participant observer. By coming together, the observation forms of the researcher and the non-participant observer were evaluated and coded. The created codes were classified under the STEM disciplines as themes. The documents, including the STEM activity booklet and the photographs of the learning environment, were analyzed and evaluated within the scope of STEM education. The student opinions expressed in the STEM activity booklets were individually coded by an educator who is an expert in mathematics education. The result of the interview was left to a concordance between the researcher and the expert educator regarding the analysis of the observations and the documents.

The concordance coefficient between the researcher and the expert educator was calculated using the formula of reliability formed by Miles and Huberman (1994) (Reliability = (agreement/agreement+disagreement) x 100). The same coding and classification, made by both the researcher and the expert educator, was accepted as consensus, whereas the different codings and classifications made by each were accepted as disagreements. In line with this, the concordance between the researchers was calculated to be 0.78. As values of reliability over 0.70 are accepted reliable (Miles & Huberman, 1994), the results of the research were accepted as reliable.

RESEARCH ETHICS

Hacettepe University's ethical committee were approved the data collection procedures and the study was recruited by following the ethical standards.

3 | FINDINGS

The findings were presented as two themes after analyzing the qualitative data. These themes are STEM disciplines and STEM education.

OPINIONS ON STEM DISCIPLINES

Individual interviews with the students both before and after STEM activities regarding their opinions on STEM disciplines, as well as the data obtained from these interviews, are presented below under the headings of science, technology, engineering, and mathematics.

STUDENT OPINIONS ON SCIENCE PRE-SC/POST-SC

Pre-SC, students considered the concept of science as a subject that was entirely independent of mathematics, technology, and engineering. In their explanations, the students were inclined to associate the concept of science with the physics, chemistry, and biology lessons they received in high school.

S1: To me, science is biology, chemistry, and that sort of subjects.

S3: Now, we have science classes. Later on, this will branch into three subjects like physics, chemistry, and biology.

S4: Physics, chemistry, biology. These are science.

S1, S2 and S7 of the students also defined the concept of science as the world of living beings. Besides, S5 and S6 defined of science as discovery, invention, and experimentation.

S1: More like the science telling about nature. I mean science which is about natural things.

S2: For example, studying the human body, plants, animals...

S7: Plants, nature, animals are science. Studying living beings in nature, the human body, and the organs.

S5: Science means fun science experiments, discoveries, inventions. It means to discover, to examine.

S6: Speaking of science reminds me of the laboratory. Scientists study like that. Test tubes, explosions.

In line with these opinions, it can be said that students' definitions of physical sciences were limited. It is considered a reason for this to be the fact that the links between science and other disciplines are not maintained, and that the introduction of science in education environments is mainly done in the form of academic knowledge. Looking at the students' opinions toward science post-SC, it was observed that these students still associated science with physics, chemistry, and biology in the same way as had done pre-SC.

S2: It has branches like physics, chemistry, biology...

S3: Science is divided into three branches: physics, chemistry, and biology. The human body or animal body, such structures are related to biology. For example, the laws of nature, laws like centrifugence force are related to physics. Properties of matter, what components and molecules it is made up of, these are about chemistry and the most general is science.

S5: Science, for example, is something like the whole of the subjects of balance and physics.

It is seen that a great majority of the students defined science in terms of daily life and the reflections of science in real life. The students' definitions about science are presented below.

S1: In short, everything is included in science. Even cooking.

S2: I think it's life itself.

S4: To me, science is life, everything that defines life. It may tell us about what's happening in our bodies. It can tell us about animals, reproduction. Electricity, water. I think everything is related to science.

S6: I think all of the phenomena and the reasoning in life are related to science. For example, the building blocks of everything in life are atoms, the formation of everything in the world, the balance of the world, the balance of the universe, these are all about science.

S7: Most of our lives are already science. The systems in our body, our cells, then microbes or so, things we cannot see.

Looking at the students' definitions of science, it was observed that the students' definitions included a variety of disciplines and associations with real life. At the same time, it can also be said that while making definitions of science, the students effectively expressed themselves by generalizing and justifications. The students made their definitions of STEM disciplines by using sampling. This situation was considered to be based on the fact that science was involved in the study in a STEM-based and applied form, rather than as a separate discipline. By getting students to make associations through discussions and activities, the students internalized the idea that science, far from being an independent discipline, is instead heavily linked with real life.

Student opinions on technology pre-SC/post-SC

Pre-SC, looking at the students' opinions regarding technology and technological tools, it was observed that the students visualized power-operated electrical gadgets in their minds.

S1: Smartboard, computer, tablets, and flying cars are technology.

S2: Electronic instruments for example, stopwatch, microscope, smart boards.

S3: Things that can be developed. For example, table. Invented before, then developed, made extending. They are technology tools.

S4: Electrical gadgets are technology. Mobile phone, the camera, the recorder.

S5: Things people use in our age; telephone, computer, television, new things, I think. The new things we use, I think old things cannot be technology.

S6: Technologic tools are developed in technology. Smartboard, computer, mobile phone.

S7: Cables come into my mind. Things that work with electricity. Advanced machinery is in technology, I think.

Looking at this student's explanation regarding technology, it was observed that students made the definition by mentioning development and change instead of the limited understanding of technology that associates it only with electrical gadgets. The fact that the students made their definitions of technology by giving examples of technological devices may result from their interactions with certain technological devices either inside or outside school environments.

Post-SC looking at the students' opinions on technology was defined as the tools that meet human needs. Also, S1 and S2 defined of technology as development. The students' explanations are presented below.

S2: ...emerges because of needs.

S3: ...anything that becomes handy for people.

S5: Technology is help for all human beings, you know the thing that comes handy for people, makes life easy. Objects, products.

S6: Technology I think every kind of invented gadget that makes human life easy.

S7: Technology is something that makes our life easy. Tools, objects these develop with our needs.

S1: Technology, I mean when you develop something new from something that already exists, it becomes a technological tool.

S2: I think everything that can develop is in technology. I mean when something develops, it develops according to the needs, if it didn't develop, that wouldn't happen.

It was discovered that the students made comprehensive explanations regarding their definitions of technology as an engineering study involving the changes and developments in the activity of meeting human needs. In line with this, it was considered that STEM course was effective in students' overall, deepening justifications of their opinions regarding technology and technological tools. In STEM activities, the development and evolution of technological tools were mentioned, and discussion environments were presented under this subject. In addition to this, Robotics design, Tinkercad program, the use of a computer, the Internet, and the 3D printer were included in the activities. It is due to the students' interactions with the media and IT technologies that their literacy skills in the digital era were effective in this situation. During the interviews that were carried out post-SC, there were similar student opinions on technology as only constituting gadgets that work with electricity. With regard to this, a dialogue between S4 and the researcher (R) went as follows:

S4: To me, technology is everything that works with electricity. Things that are not electronic don't sound like technology to me. I mean they are only objects, but electrical things are electronic tools.

R: Does it have to work with electricity?

S4: We talked in our lessons, for example, we said "the Internet" or watched a video during the kite activity. People used to learn about the weather conditions by kites. As technology advanced, meteorology aircraft appeared. These are what I understand. But with the word technology, electrical tools come into my mind.

Looking at this student's views, it was observed that while he understood that technology was used in a range of activities, S4 was not able to get away from his/her perceived image of technology. It was viewed that, despite being aware himself/herself that he was mentioning the development of the Internet or technology, the student identified the term technology as working with electricity, which resulted from his/her internalization of the concept. It was observed that the opinions of the students, with the exception of S4, changed after the study.

Student opinions on engineering pre-SC/post-SC

It was observed that pre-SC, the students perceived engineering only as a career, which was a limited perception. Engineering was associated with career sub-fields, civil engineering, electrical electronics engineering, and mechatronics engineering. Examples of students' explanations about engineering are presented below.

S1: Different shapes of buildings. Decorating.

S3: Mechatronic engineering, mechanical engineering, or so.

S5: Engineers come to my mind. Person working in the factory.

S6: People working in the construction, the building comes to my mind. Workers are engineers.

S7: Like civil engineering, mechanical engineering. The fields of engineering as careers come to my mind. University comes to mind.

Looking into the students' opinions, engineering was defined as a professional field. In addition, engineering was also illustrated as constructing buildings and houses. Students were considered to have made these definitions based on their daily experiences. It can be said that the students' lack of experience in engineering in both their in-class and out-of-school education might have influenced their definitions of engineering. Other than these opinions, it was also recorded that S3 and S4 explained engineering as producing ideas and maintaining development.

S3: Investing in the future comes to my mind. I think engineering can be developed and it has a lot of fields. It can be worked on a lot. Engineers can produce plans, projects. You know it doesn't have to be concrete. For example, we make projects at SAC, too.

S4: Developing ideas that don't belong to the future is engineering. It can be experiments, we discover new substances there, too… We work in TUBITAK projects as engineers, too, after all, we produce new things.

It was observed that S3 and S4 made more comprehensive explanations on the concept of engineering. This situation was considered to result from the students' characteristics, experiences, and inclinations. The students approached their activities, plans, projects, and ideas in SAC and TUBITAK (The Scientific and Technological Research Council of Turkey) projects from the angle of engineering. Accordingly, students' experiences enabled them to make more comprehensive definitions regarding engineering. Looking at the student views post-SC, it was observed that engineering was not only defined as a career by the students, as some students defined engineering as relating to designing and design.

S1: The word engineering reminds me of architecture. Designing and putting the design into activity and things.

S2: Designing some original things and putting them into activity. For example, if we only designed by Tinkercad and didn't put it into activity and see how it works, I don't know, it wouldn't be complete. For example, if we only designed by Tinkercad and didn't put it into activity and see how it works, I don't know, it wouldn't be complete. I mean, it's much better to see how it works in real life.

S3: Engineering is designing some things by bringing branches of science together. It doesn't mean you have to be an engineer to do this. For example, we are not engineers but designed, too.

S7: When you speak of engineering, it reminds me of designer, designing.

S7 defined engineering as both innovation and designing as "development, innovation, this is what comes to my mind." Alongside these opinions, some students also expressed their views on the aspects of originality and creativity of the product produced as a result of engineering.

S2: Engineering means originality.

S4: Engineering is owning our design, originality. I mean one says it must be unique, a thought like it must belong to me.

S5: Engineering is something that happens with the help of our own imagination, something we created ourselves.

S6: Making new things, designing, imagination, originality, all of these are engineering.

Post-SC, it was observed that students defined engineering as the original model design or creating a product. In addition, expressions regarding product development, and innovation were also used in their definitions of engineering. It was observed that the students' definitions for engineering changed in this way due to the design and product development activities in STEM activities. Looking at the student opinions pre-SC, students made limited definitions of engineering, where it was defined as a career only done by engineers. It was revealed that these perceptions and thoughts changed through the engineering-oriented activities, broadening students' definitions of engineering.

STUDENT OPINIONS ON MATHEMATICS PRE-SC/POST-SC

Pre-SC, it was observed that the students defined mathematics as numbers and the four basic mathematical operations. The students' definitions of mathematics are presented below.

S1: Addition/subtraction and multiplication/division are all mathematics.

S4: Doing operations is mathematics.

S6: Doing operations with numbers, like addition/subtraction. Equations.

S7: Numbers, operations, equations...

S2 associated mathematics with geometry, depending on basic geometric forms as “speaking of mathematics, geometry comes to my mind. Geometric forms, triangles, rectangles, squares or so”. The reason for the students' perception of mathematics as a science and a lesson that includes only numbers and operations was considered to be because of the presentation of mathematics in education as only relating to theoretical academic knowledge, rather than activity. Thus, it can be said that the students failed to realize the scope of mathematics' implementation and its links with both the other disciplines and real life. Students' definitions of mathematics also included expressions that they perceived mathematics as a lesson that creates a negative attitude. S5 made the following explanation: “The lesson that I'm scared of the most and the lesson I fail comes to my mind. Because it's boring, we are always doing operations. You know I'm scared because I can't do it”. S5 statement about mathematics includes the expression "the lesson I'm scared of the most". Looking at the dialogue the student, it was seen that the content of the mathematics lessons including only numbers and operations, and therefore a lack of practical implementation, would lead the students to develop negative emotions. Apart from the attitude that considers mathematics only as a lesson, it was observed that mathematics was also associated with real life by S3 as “Life without mathematics can't be imagined. For example, we go to the grocery store, addition/subtraction is everywhere. This is the simplest example”.

Post-SC, it was observed that the students made associations about mathematics within its merit. The sample definition for this by S1 and S5 was as follows: “for example, shapes, ratio, proportion, fractions, there is everything. You know, then, rational numbers”, “A digital science. There are numbers, operations”. In addition to the students' associations of mathematics within its merit, it was seen that they also associated it with real life.

S1: Mathematics is our life itself; you know there is mathematics in everything...in making a cake, I mean there is mathematics in every part of our life.

S3: Mathematics, according to the Pythagoras theorem, everything in the universe is made up of mathematics. Everything we see in nature has a golden ratio and this is related to mathematics.

S4: Mathematics, too, is in all parts of our lives in fact. I mean letters, numbers are in every part.

S5: It's a digital science but we don't only use it in our lessons, we also use it in our daily errands a lot. Besides, we have to know mathematics to do other things.

Students such as S2, S6 and S7 included problem-solving and multiple thinking skills in their definitions of mathematics.

S2: I think it's difficult for people but it's very simple when you grasp its logic, and it has logic. In mathematics you think, you understand what you read. It helps with multiple thinking (Figure 3).

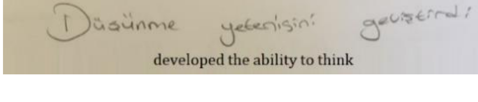


Figure 3. *S2’s Quoted Part in STEM Activity Booklet*

S6: Mathematics is logical practice to find solutions to all the problems in the world.

S7: Mathematics is the lesson that we are learning to solve the problems in our lives. I mean we are learning the problems in our lives here, for example, equations or so. We are learning many things that we see in our lives.

Post-SC, students' opinions on mathematics evolved to also include logical thinking, problem-solving, and multiple thinking, rather than just numbers and operations. The students expressed that mathematics offers the solution to problems in real life and areas of science that exists in every field of life. It can be said that STEM course was effective in terms of these changing student opinions toward mathematics. It was considered that, together with STEM course, the associative presentation of mathematics with real-life and other disciplines, as well as its applied form in the activities, changed students' opinions in this direction. Upon evaluation of the student opinions, the results in Table 3 were reached.

Table 3. Student Opinions on STEM Disciplines Pre-SC/Post-SC

Pre-SC	Post-SC
Each discipline was defined independently from each other.	STEM disciplines were defined with their interdisciplinary relations, their links with other disciplines, and real life.
Science was defined as a teaching subject at schools, and as a lesson that includes physics, chemistry, and biology.	Science, as well as including various disciplines and their sub-disciplines, was defined as real-life itself.
Mathematics was seen as the branch that includes numbers and operations.	It was mentioned that mathematics exists in all disciplines and all parts of life, and that apart from numbers, it also involves the processes of problem-solving and multiple thinking.
The relationship between science and mathematics was expressed, with mathematics consisting of the digital operations in science lessons.	Science and mathematics, being connected with most disciplines, were defined in terms of their existence in all parts of life.
Technology was exemplified by electrical and electronic tools.	Technology was defined as the development and changes that occur according to human needs.
Engineering was defined as the profession of engineers.	Engineering was described as product creation through the use individual design, originality, and innovation.

Statements of Publication Ethics

It was observed in S1, S2 and S7's opinions that the STEM activities enabled students to make interdisciplinary associations during the operation of such activities post-SC.

S1: First of all, it's all fun. We are learning to combine different fields. After that we are using these together.

S2: I think thinking boosted development, associating boosted correlation. In this way each part of the fields came together and made the whole, these make life, the universe.

S7: I saw that all of them are related to each other. We learn better when we practice it that contributed.

During the activities, STEM subject contents were presented to the students in a way that enabled them to make interdisciplinary associations. Toward this purpose, besides the science and mathematics content, technologic tools were used in the learning environment, while engineering-oriented contents were also carried out. In this process, student opinions were revealed, utilizing discussion environments, and the students were encouraged to exchange their ideas. Through this process, it was ensured that the students were able to integrate science (physics, chemistry, biology, astronomy, etc.), mathematics (geometry and arithmetic), technology (the use of technological tools, technological literacy, etc.), and engineering activities. The students' evaluations of STEM course showed that STEM activities made positive contributions to the development of their academic skills and technical abilities. Example students' statements and explanations in the STEM booklet (Figure 2) are presented below.

S3: This way by gathering all the fields of science together, I mean by doing science and mathematics together, there is no question mark left in my mind. With such activities, we were able to understand better and so become more successful in education.

S4: I've learned new information.

S5: I both enjoyed and learned a lot of things. I learned some science subjects. I improved a bit more in mathematics and technology. And besides, we discussed such subjects and so I got information.

S6: It teaches us new things, for example, we come to learn the things we don't know. Who found? Who made? Kind of new things I learned...

S4: I learned the use of a 3D printing program. My engineering improved; I think I can do more things...

S5: I liked using technological devices I can't because but here we used the computer, the 3D printer and did modeling, we used program. That's why I've got used to and I liked it a lot (Figure 4).

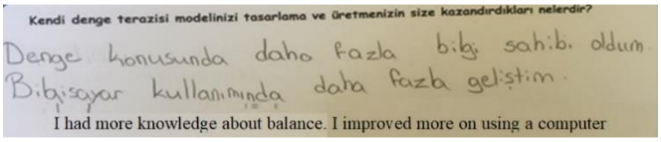
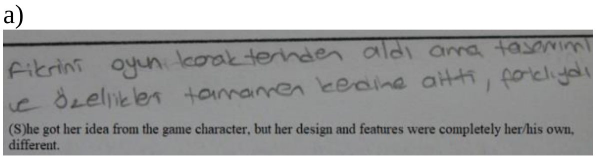


Figure 4. *S5's Note in STEM Activity Booklet*

In STEM activities, discussion environments on various subjects were created, with the students encouraged to express their opinions. In this way, the students were allowed to exchange their opinions and thoughts. At the same time, the students were also able to make use of their academic knowledge while creating products. It was observed that the students mentioned the improvement in their academic knowledge and skills during the STEM education process. STEM activities included robot designs with Lego sets, 3D modeling with Tinkercad, the use of 3D printers and computers, searching the Internet, and similar activities. In this way, the students' technical skills (engineering skills, the use of IT technologies) clearly improved, while they also gained experience in the use of new programs and tools. This was particularly noticeable in the case of a student who had difficulty in using the technology who mentioned that she had made progress in that subject. It was perceived that STEM activities supported the students' creativity and originality in their work, such as S2's explanations: "like this, designing something all over again and having its own originality. They take care of everybody individually for example in other group environments maybe they don't show this much care and materials are not enough but at the moment you can use as much as you want. This way I can do the thing I want in my mind". Similarly, it was observed that the creativity of the students was supported in the observation notes of the studies they carried out in the STEM process. Sample observation notes are presented in the Figure 5.

a)



b)

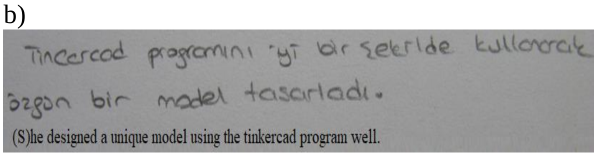
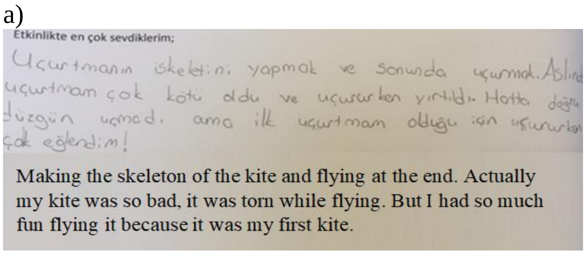


Figure 5. *The Observer's Note About a) S1 and b) S4*

Besides, S5 and S7's written expressions, who have opinions that the STEM activities process is fun, are given in Figure 6.

a)



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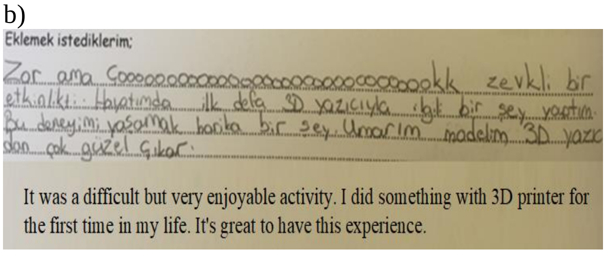

Figure 6. *a) S5 and b) S7's Note in STEM Activity Booklet*

In STEM activities, the students were planned their studies according to their wishes and were created their desired products. In this way, the students mentioned that they were effective in creating their original models, which revealed their creativity. The students thought that their engineering skills improved by modeling and performing their studies themselves. The students found the STEM activities to be interesting and motivating.

S3: School is boring but if these are put into activity, school becomes fun. Because it becomes fun, the number of successful students reaches the ceiling. Most students, although they're clever, do nothing because lessons are boring.

S4: In the subjects that don't interest me, I put my head on the desk instantly. There have been times I did this during the lesson. I mean when I get bored, I feel suffocated, and I put my head down. But four fields together attracted my attention.

S6: It was more understandable and more fun compared to the normal curriculum.

S5: At the beginning, I was scared I even asked you. "can I do it by drawing?" but later I liked it a lot. I saw I could do it. I wish we continued more.

S7: I couldn't do much for example I couldn't use a computer, or I didn't know a 3D software but now when I learn these like this, I always feel like doing it.

It was observed that the students found STEM activities interesting and fun. Students who got bored with the standard curriculum and teaching programs, and did not want to listen, were observed to find STEM activities interesting, generating eagerness in students to attend these activities. This situation is considered to be the result of interdisciplinary associations. It was noticed that STEM activities created interest and motivation in students, as these activities do not merely include academic knowledge and are instead implementation oriented. The students have positive opinions toward STEM careers, as the following opinions and written explanations in Figure 7 were demonstrate.

S4: I like doing activities and doing them myself. I was proud of myself when I saw what I could make. I show what I made to my friends saying "Look at what I've made."

S1: When we grow up in the future, we can focus on such designs more. We are learning to use the fields together and you know this will become handy when we grow up.

R: Would you like to work in such fields in the future?

S1: Yes, for example, the things we have learned here will contribute to me in those times. I will need to use technological tools for example, these can be more difficult things but now I've learned the easier form of it.

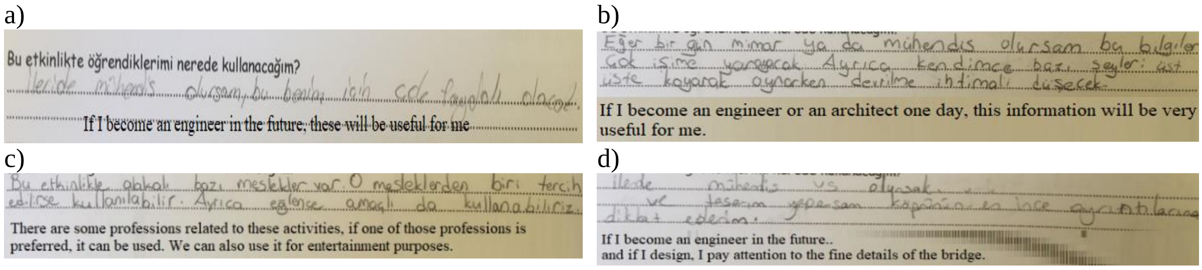

Figure 7. a) S3, b) S5, c) S6 and d) S7's Note in STEM Activity Booklet

Based on the individual student interviews and their opinions in the STEM activity booklet, it was observed that the students would benefit from their experiences in STEM activities in their future careers. Looking at the students' statements, such as "if I become an engineer in the future..., if I prefer a career, related with these fields...; if one day I become an architect or an engineer...." it was regarded that their thoughts about choosing a career in STEM-related fields had developed in their minds.

4 | DISCUSSION & CONCLUSION

In this study, it was seen that gifted and talented students STEM disciplines separately from each other and independently from real-life situation, however after STEM education, they were able to make interdisciplinary associations and associate them with other disciplines and real life.

It was concluded that STEM education and activities enhanced and changed the definition of STEM disciplines. The students' improved opinions on STEM disciplines were in accordance with STEM definitions in literature. In line with this, the students' limited and deficient understanding of STEM disciplines was deemed to have been improved through STEM activities, and this helped them to make correct definitions. According to the students' opinions, they had the opportunity to carry out their studies from an interdisciplinary perspective. It was recorded that while the students previous evaluated each discipline independently, following STEM education, they realized that all of the disciplines were interrelated. This result shows a similarity to the other STEM-oriented, association-based studies (Lou et al., 2011).

Prior to their STEM education, the students defined engineering as purely a profession that related to the people who did such work. By contrast, after STEM course, they developed a different understanding of engineering as a process that includes originality in designing and creating a product. It was considered that engineering-oriented and technology-based activities, such as 3D modeling, the use of 3D printers, and robotics, were effective in these positive changes in students' opinions (Sen et al., 2020). This result parallels the findings of other studies in the existing literature (Ayar, 2015; Blanchard et al., 2015; Eguchi, 2016; Kandlhofer & Steinbauer, 2016). Similarly, Blanchard et al. (2015) has stated that some students do not comprehend STEM fields, particularly engineering. Blanchard et al. (2015) recorded that the students' understanding of engineering, and their opinions regarding its place in the society, could be changed by solving real-life problems in an engineering-oriented and technology-based study. Alongside a two-week-summer school program, an engineering-oriented study with the students was conducted by Elam et al. (2012). This study concluded that the students' perceptions of engineering changed and that they developed a positive attitude. It was observed that the results of this study corresponded with the result of the other studies in the literature, with the students' academic knowledge and skills deemed influential in the product creation process regarding STEM activities.

The students' opinions also highlighted that the academic knowledge of science and mathematics were elicited better as a result of the process. Accordingly, it was concluded that academic knowledge and skills were improved through the STEM activities, and that this acquisition of academic knowledge was effective in STEM activities. This result was supported by other studies that have demonstrated the interaction between STEM education and academic knowledge. For example, the study by Cotabish et al. (2013), which aimed to determine the effect of STEM education on academic knowledge and skills, found that STEM education was effective in the enhancement of the content of science and mathematics. Similarly, Zuga (2004) and Brophy et al. (2008) have both stated that without the content knowledge of mathematics and science, cognitive processes would not be effective, showing that academic knowledge is significant in engineering-oriented activities. In line with this finding, it was concluded that content knowledge and activities ought to be internalized within one another.

In terms of the students' opinions on STEM activities, it was clear that they gained new experiences and acquired new skills. It was also concluded that the students who got bored in the ordinary teaching environment, as they are gifted and talented, became interested in the content of STEM activities, where they could be active themselves. Similarly, Stith (2017) has stated that by implementing STEM-oriented activities with gifted and talented students in school education, students are provided with the opportunities to conduct scientific research independently and, eventually, to work in their fields of interest professionally. It was concluded that the students that participated in STEM activities believed that they could make use of the experiences they gained during such activities in the future. Similarly, Brown and Lent (2013) have stated that students' interest and curiosity toward STEM activities are effective in generating goals relating to career fields that include such activities. Buxton (2001) mentions that an interest in science and mathematics would be effective in career preferences, including in these fields. With this aim, many studies (Dabney et al., 2012; Welch & Huffman, 2011) have stated in their studies that STEM activities would increase the students' interest in STEM disciplines and affect their career trends positively. The inclusion of interdisciplinary studies in STEM course was considered to be effective in improving the students' academic knowledge and skills. It was maintained that the applied use of the students' academic knowledge, particularly their science and mathematics knowledge, provided them with the opportunity to learn more effectively. Furthermore, by employing STEM course, the students' academic and technical skills were enhanced. Rehmat (2015) states that participating students' use of the contents of the STEM disciplines through practical application developed a positive attitude. When insufficiently motivated, gifted and talented students did not attend the activities or enjoy the course environment and were indifferent to the activities.

The importance of gifted and talented students' interest and motivation was defined by Chapman (2011), who stated that such students are only interested in tasks that are beyond their abilities and start to activity them, enabling them to focus on and continue what they are working on. It was concluded that as a result of both the attendance and the enthusiasm of the participating students in the study, STEM activities were effective in attracting their attention and motivation. The result that STEM activities provide fun teaching content was furthermore supported by student opinions. This result presents parallelism with similar studies in the existing literature (Blanchard et al., 2015; Rehmat, 2015). These studies all mention that students were pleased to take part in STEM activities, and thus attended STEM activities.

In line with the outcomes obtained from the present study, the following suggestions might be made for future studies:

1. It was observed that STEM education has restored the motivation of the students that feel bored and lose interest due to the curriculum-bound activities and activities in this study. Accordingly, it is considered that curriculums and schedules can include application-based STEM education activities instead of presentation-based information transfer.
2. Owing to STEM education, the gifted and talented students that regarded each discipline as independent from each other and as a teaching subject at schools, then realized the fact that the disciplines are interrelated and connected with real life. STEM education maintains the associability of each discipline through the integration of students' academic knowledge with the scopes of application.
3. It was observed that the negative attitudes and fears of the gifted and talented female students were eliminated by their gain of experience in technology and the use of technology tools. It was considered that the engineering and innovation skills were effective in the placement of girls in the 21st-century career fields. It was reasoned that STEM education that includes information and communication technologies would enable girls to gain experience, improve positive attitude and STEM education will be effective in their career placement.

STATEMENTS OF PUBLICATION ETHICS

Hacettepe University Ethics Committee issued an ethics committee approval certificate with the decision no 815 on 13 April 2018 (35853172/433-1669).

RESEARCHERS' CONTRIBUTION RATE

Authors	Literature review	Method	Data Collection	Data Analysis	Results	Conclusion
Ceylan ŞEN	☒	☒	☒	☒	☒	☒
Zeynep Sonay AY	☒	☐	☐	☐	☒	☐

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CONFLICT OF INTEREST

No potential conflict of interest was reported by the authors.

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