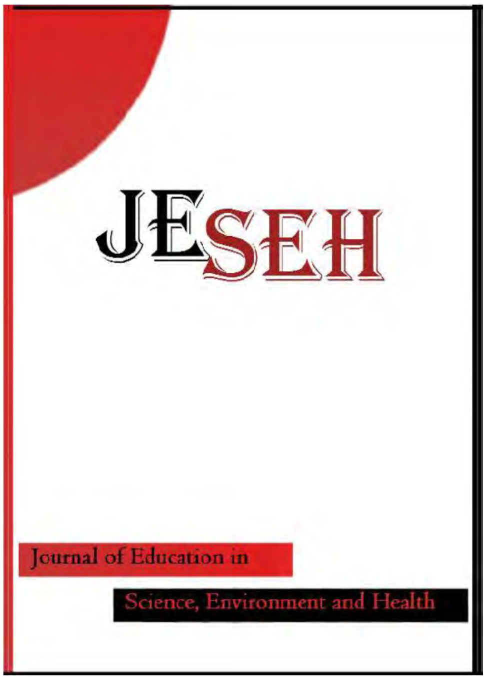

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The Effects of STEM Education on the Students' Critical Thinking Skills and STEM Perceptions

Yasemin Hacioglu[1], Filiz Gulhan[2]
[1]Giresun University
[2]Ministiry of National Education

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Yasemin Hacioglu, Filiz Gulhan

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Abstract

Critical thinking and STEM career perception are important in 21th century and STEM education is necessary to promote middle school students' critical thinking skills and STEM perception. In this research we aim to research the effects of engineering design-based STEM education on the middle school students' critical thinking skills and STEM perceptions. In this case study, STEM activities were developed according the subjects of "Reflections in Mirror" and "Absorption of Light" and prepared activity booklet. The activities implemented with 30 seventh grade middle school students in Istanbul province for five weeks (20 course hours). While student solved the design problems in the housing estate and designed "Safe and Eco-Friendly House Estate", the teacher guided students in this process. To solve the problem/ground design challenge, they did five mini designs and five researches/experiments in six teams of five students. The quantitative data were performed California Critical Thinking Disposition Inventory (CCTDI) and STEM Perception Test as pre and post-test and analysed statically. Semi-structured interviews were performed to support quantitative data and analysed descriptively. STEM education developed students' critical thinking skills and STEM perceptions positively and also it had indirect effects on their career awareness.

Introduction

The concept of knowledge economy has been the focus of educational reforms in recent years (Ralls et al., 2020). With the increasing importance of the knowledge economy, it has become important to raise individuals who will add value to this economy, but the business world is concerned about whether the generation that will contribute to the workforce will meet the goals of the countries (Walton & Johnson, 2015). The growing generation has come to the fore as individuals, who have 21st century skills, who can offer solutions to daily and global problems, can think creatively and critically, contribute to innovation. (Johnson, 2018; Modi, 2011). Accordingly, the need of countries to develop learning in line with the demands of the information society has emerged (Organization for Economic Co-operation and Development [OECD], 2015). Science, Technology, Engineering and Mathematics (STEM) disciplines are a vital component in ensuring economic prosperity (Gough 2015; Murphy et al., 2018; Office of the Chief Scientist, 2014; Turkish Industry & Business Association, 2017; The Royal Society 2014; UNESCO 2015) has been the primary goal of countries to raise STEM professional awareness in the short term and to train competent STEM experts in the long term (Ralls et. al., 2020; Smith & White, 2019). Also, researches (e.g., Bybee, 2013; Johnson et al., 2015; Partnership for 21st Century Skills [P21]) show that 21st Century Skills are essential for a STEM literate society and a wide range of careers. It is noteworthy that many countries encourage the implementation of STEM education based on the integration of disciplines (Bybee, 2010; Guzey et al.2017; Hoeg & Bencze, 2017; Smith & White, 2019) to raise generation that have 21st century skills and STEM career.

STEM education is an approach that integrate science, technology, engineering, mathematics and has especially brought innovation to science education (Bybee, 2013). STEM is also called interdisciplinary because it is the creation of a discipline based on the integration of another disciplinary knowledge into a new whole (Lantz, 2009). Therefore, STEM education is also evaluated as a bridge between the education and career (Gillies, 2015; Gomez & Albrecht, 2014). The integration of disciplines has been discussed in variety of ways (e.g., design based, problem based, project based, inquiry-science and engineering implementation) in literature in STEM education (Park et al., 2018; Guzey et al., 2020). In all implementation of STEM education should be carried out the working processes of related disciplines (scientific inquiry, computational thinking, data processing or mathematical modelling, engineering design process) (National Research Council [NRC], 2012) and should focus on integrated STEM issues, real life problems, collaborative and doing learning, student-centered applications process evaluation and twenty-first century skills (Thibaut et al., 2018). Engineering plays a unifying role in STEM education, since engineering design process requires using the knowledge and skills of other STEM disciplines (Cavlazoglu & Stuessy, 2018; National Academy of Engineering [NAE] & NRC, 2009; NRC, 21010; NRC, 2012). For this reason, combining scientific inquiry and design- especially engineering design - activities in STEM education practices facilitates STEM integration at the K-12 education (Guzey et al., 2017; Guzey et al., 2019; Johns & Mentzer, 2016; Roehrig et al., 2021). These implementations are carried out within the context of design challenges, that provide an interdisciplinary context to learn science concepts (Wendell, 2008). In fact, design problems provide an interdisciplinary context to learn science concepts (Bybee, 2010). The individuals work on the solution of an authentic design problem with an interdisciplinary nature and thus, they manage the design process (Moore et al.,2014). Most generally they will manage the engineering design process stages: identify and define problems, develop possible solution(s), select best possible solution, construct a prototype, and test and evaluate the solution(s) (Wendell et al., 2010). In this process students are exposed to design-based challenges with which they can manage design processes. They will need scientific knowledge and skills to solve the given design challenge. In this process students engage develop solution to the engineering design challenge in authentic engineering experiences and establish conceptual integration between STEM disciplines. (Roehrig, et al., 2021).

Engineering design challenge is related a real-world problem and this problem is important for STEM disciplines' conceptual integration (Kelley & Knowles, 2016; Moore et al., 2014; Reynante et al., 2020; Sanders, 2009). Thus, the scientific research and inquiry process will be put to work. It includes establish a relationship between scientific inquiry and engineering design, confirmatory research inquiry and problem solving and an integral part of traditional science education (NRC, 2012). Thus, what is important in STEM education is not only to make a design or generate a product, but also to understand, realize, and get engaged in application areas of the knowledge and skills related to the discipline (Lachapelle & Cunningham, 2014; Lewis, 2005). Also, integrated STEM education requires to students to participate in twenty-first century skills (Roehrig at al., 2021) and some researches indicated that it affects positively students' knowledge and skills (Bybee, 2010; Gonzalez & Kuenzi, 2012; Meyrick, 2011). Despite these positive effects, it is clear that there is still a need to improve STEM teaching and learning from the current educational environment (Rall et al., 2020) and to understand the impact of them on student outcomes (Roehrig, et al., 2021).

One of the main reasons for the inception of STEM education is that "the young generation will acquire and use the 21st century skills" (NAE & NRC, 2009). Critical thinking, one of the important skills of the 21st century, is a skill required to keep up with the age we are living in (Schafersman, 1995) and is emphasized in science education curricula of many countries (Ministry of National Education, 2008; NAE & NRC, 2009; NRC, 2012). Critical thinking is the skills to evaluate all ideas for the solution of a real-life problem and to make a decision to solve the problem (Chaffee, 1994). For this reason, individuals become aware of and evaluate both their own and others' ideas, discuss and implicate in the critical thinking process (Chaffee, 1994; Kuhn & Dean, 2004). This process requires both problem solving and reasoning and decision making (Willingham, 2008) and is often expressed as: define the purpose of the problem, present questions and assumptions, gather data to try them, evaluate the data gathered with different points of view and draw conclusions for problem solving (Nosich, 2012) and thus it must be administered during the education process. There are concerns about how to gain or develop critical thinking skills in education (Duran & Şendağ, 2012; Hacıoğlu, 2017). For this purpose, designing learning environments that will enable students to think critically and implementing learning designs that will operate the critical thinking process (Bob, 2009; Duran & Şendağ, 2012; Ernst & Monroe, 2006; Hacıoğlu, 2017; Jonassen, 1997; Savery & Dufy, 1996) may indicate that there is still a need in education programs. In addition to emphasis put on critical thinking skills in STEM education, Hacıoğlu (2017) stated that critical thinking process and engineering design process included similar procedures. Hacıoğlu (2017) and Ure (2012) engineering design process, which executes STEM education, would make contributions to the development of students' critical thinking skills. Drew conclusions in the study carried out about engineering design process their critical thinking skills developed, and they even started to use the skills they acquired outside the classroom. It is considered that the association of critical thinking and engineering design process with these studies will make important contributions to the literature.

One of the other reasons for the STEM education is that young generation are component in STEM career fields (Bybee, 2010; NAE & NRC, 2009), because performing engineering design applications in STEM education gives students the opportunity to work as an engineer, learn the connections between science and engineering, and apply the scientific knowledge and skills they have acquired in the design problem (Guzey et al., 2019). Also, students can understand the nature of STEM disciplines, especially engineering, by carrying out the work processes of STEM professionals through the engineering design process (English et al., 2017; Fan & Yu, 2017). It is important to spend the effort required for career orientation for STEM disciplines during middle school when students plan their career goals (Almeda & Baker, 2020).

The middle school students' perceptions towards STEM fields are critically important for their future careers (Christensen & Knezek, 2017; Knezek et al., 2015). It is considered that STEM skills which students acquire at middle school level form a basis for a successful STEM career (Knezek et al., 2013). However, many middle school age students do not have positive perceptions towards STEM disciplines (Mills, 2013). Students have wrong and stereotypical judgements about the people who do STEM (Fralick et al., 2009; Gülhan & Şahin, 2018; Jung & Kim, 2014). Hence, students' perceptions towards STEM disciplines need to be developed. Despite the literature reveals that engineering education at K-12 level (Bybee, 2011; NAE & NRC, 2009; NRC, 2010; Sullivan, 2006) and STEM education (Gallant, 2011; Özkul & Özden; 2020; van Tuijl, C. & van der Molen, 2016) might have positive effects to develop students' STEM Perceptions, Engineering focused STEM implementation neglect in middle school (English, et al., 2017). Franz-Odendaal et al. (2016) in their research determined that the most important effect, which led students to STEM career, was the participation in STEM activities. Thus, it can be interpreted that the effects of STEM education on STEM perceptions are important research subject matter.

Although STEM education approach has become popular recently, the attempts to implement STEM education have been increasing both in national and international platforms. It is considered that the explanation of implementation process of the integrated STEM education which aims to develop the 21st century skills of the new raising generation is important for the individuals' career options (Bybee, 2000). The investigation of contributions of STEM education to students' critical thinking skills and career awareness will also set a good example for teachers and researchers to perform STEM education implementations. Some researchers in the field assert that it is important to increase students' awareness of learning the disciplines, but teachers who carry out STEM implementations have difficulties with their administration (Nathan et. al.,2013).

It is regarded that this research results will make contributions to the incorporation of engineering discipline along with technology and mathematics disciplines into science education and also will meet the need for the implemented educational activities expressed in the relevant literature (NRC, 2012). Moreover, it is considered that the study will make contributions to raising interdisciplinary awareness within the students about the importance of integration of engineering discipline into science education with regard to creating real-life contexts. In addition, the study results are important due to the development of students' critical thinking skills and perceptions towards STEM disciplines with regard to design based learning approach and also encouraging teachers for the actualization of design-based STEM education implementations.

The research aims at determining the effect of STEM education on the seventh grade students' critical thinking skills and STEM perceptions. In line with this purpose, the study sought answers to research question (RQ):

> RQ1.Does STEM education affect the seventh grade students' development of critical thinking skills?
> RQ2.Does STEM education affect the seventh grade students' development of STEM perceptions?

Method

In the research was used convergent parallel design mixed method. The purpose of this method is to simultaneously collect both quantitative and qualitative data, analysis them separately and compare the results (Creswell, 2014). In the quantitative part of the research, the single group pre-test & post-test experimental design and in the qualitative part of the research, case study was used. As case studies represent the analysis process, it aims at gathering detailed, systematic, and in-depth information. Triangulation was administered with the intention of supporting both qualitative and quantitative data and improving the trustworthiness of the study (Patton, 2002). In addition to this, in order to increase the trustworthiness of data analysis, two researchers analyzed and evaluated the data independently to enhance its credibility and thus member checking was done.

Participants

The participants consisted of 30 (13 girl, 17 boy) seventh grade students (12-13 years old) studying in a state middle school in Istanbul province in 2017-2018 school year. Convenience sampling was used for the selection of the population because of the convenient accessibility and proximity for the researchers between the classrooms. They have not been exposed to STEM education before.

Research process

First of all, STEM based activities in the literature were examined to develop STEM activities and the research related to the STEM education which would be implemented for the acquisitions of the subjects “Reflections in Mirror” and “Absorption of Light” for seventh grade middle school. When developing these activities, were taken into account integrated design-based approach, which depends on constructivist learning and situated learning and enables the integration of technology and engineering disciplines (Wendell, 2008). Design based approach is important to provide learning via real-world contexts and design process (Brown et al., 1989). The activity reflects the real-life problem on the house estate that have 700 detached houses with garden, one of the researchers and her family is experiencing. On this estate has occurred theft due to the security vulnerability. Due to the fact that the estate was built on an inclined area, the field of vision of the drivers is limited and accidents occur at the same place. The heating and electricity expenses of the estate have increased. The residents of the estate are experiencing problems for these reasons. This problem may be the problem of all students living in the same city. For this reason, it highly reflects the real-life context feature. Integrated STEM unit was designed adapting this problem to design challenge. This challenge is presented in a complex design problem case in the context of “Designing of Safe and Eco-Friendly House Estate”. If this design challenge is complex and big design problem and it requires all the knowledge and skills a unit, Wendell et al. (2010) suggested that STEM units should be created that include mini designs and mini researches design to overcome this challenge. In this direction, four mini designs and mini researches/ experiments have been created to enable students to acquire the knowledge and skills they need to achieve their grand design task (see Table 1), to perform the grand engineering design challenge related to “Designing of Safe and Eco-Friendly House Estate”. Then, STEM unit were built to implement the DBL process and to form the activities.

Two experts reviewed the activities. One of them reviewed the activities for their appropriateness for design-based learning and appropriateness for developing critical thinking, the other for appropriateness for design-based learning and STEM perceptions. The STEM unit was finalized by making changes in the instructions and contents of the activity, taking into account the feedback of expert. The “Reflections in the Mirror and Absorption of Light” unit STEM activities for seventh grade students presented Table 1 and described in detail below.

In accordance with the acquisitions of the “Reflections in the Mirror and Absorption of Light”, attention was paid that the context would continue throughout the unit and five activities including five design problems within the context of problem cases were developed under the theme of “A Design of a Housing Estate with Clean Energy and Safety” and students were asked to solve these problems in the housing estate called “Science Housing Estate” thinking like a scientist, an engineer, a technologist, and a mathematician. To implementation this activity, classroom was set up for STEM learning environment in that students worked collaboratively within the team and engaged for engineering design and scientific experiments. Six team work tables and one equipment table were set up in the classroom.

The process started with the challenge of “Designing of safe and eco-friendly house estate”. Within the framework of this design challenge, a problem case including a design problem was created for each activity. In each activity structured, the students attempted to achieve the design challenges by administering the engineering design process (Wendell et al., 2010) and following the instructions which would give them an opportunity for the scientific inquiry process by managing orientation, conceptualization, investigation, conclusion, and discussion phases implicitly in this process (Pedaste et al., 2015). An activity booklet containing instructions on the process was distributed to the students.

In the process, students conduct the engineering design process to perform both grand design challenges and mini design challenges. First, they discussed the problem and defined the great design task. In order to make it easier for students to understand the problem, a sketch of the house estate and photos of the areas where the problems occur are given. Mini design challenges were given to the students in order to present possible solutions. These design challenges included criteria and limitations. Students needed scientific knowledge to accomplish each design challenge. In order to reach this scientific knowledge, they conducted experiments, collected data and made conclusions by operating a guided research inquiry process. They offered solutions with the scientific results they obtained. They evaluated the proposed solutions as a group and evaluated them in the context of the criteria and limitations of the design challenges. They prototyped their best solution and tested it again in terms of criteria and limitations, discussing as a group whether they needed to improve their designs. In the last stage, students presented their designs and the process of creating this design to their classmates. By bringing together all the mini designs and mini researches results for the grand design, they continued the same processes for the grand design challenge.

Throughout the process, the teacher guides the students by asking their questions: "What are your suggestions for solving the problem? What did you do to achieve this? What did you find as a result of your research? How did you apply the research results to your solution suggestions? How did these results serve your problem? How did you decide the best solution? Does your protocol need improvement? Why is that? What kind of change should you make? How would you describe the design process?".

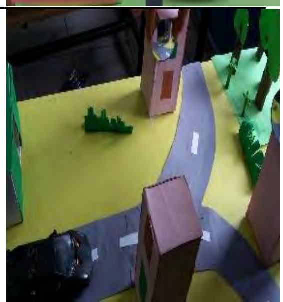
Table 1. Reflections in the mirror and absorption of light unit STEM activities for seventh grade students

Grand Design Challenge: Designing of Safe and Eco-Friendly House Estate

The grand design challenge is related a problem of house estates' residents and it need to redesign a house estate to answer the problem of the residents. House estate residents want to turn it into a clean energy and safe house estate. Students are expected to design a safe and Eco-Friendly House Estate, that will answer these problems:

- Since the theft has occurred due to vulnerability on this house estate, there is a need for a design that allows security guards to spy on more areas of the house estate.
- Due to the fact that the house estate was built on a slope, the field of vision of the drivers is limited and accidents occur in the same place. A design that will increase the field of vision of the drivers on slopes and intersections is required.
- The heating and electricity expenses of the house estate have increased. Designs that will save money on insulation and heating are required, where they can benefit more from renewable energy sources, the sun and wind.

Then, the mini design challenges and researches are performed to solve this complex problem, as follows.

Mini design challenges	Mini researches	Activity summary	Examples of student designs
1. Reciprocal mirror system design for safety: Observe the areas outside the housing estate	*Flat mirrors:* What are the characteristics of the flat mirrors? How does the image in the flat mirrors occur?	The students explore characteristics of flat mirror and image on flat mirrors. Then they design a prototype with flat mirrors system to observe the areas outside of the house estate. The students explore characteristics of flat mirror and image on flat mirrors. Then they design a prototype with flat mirrors system to observe the areas outside of the house estate. They place the flat mirror system they create in the relevant areas on the house estate model and test.	
2. Safety traffic mirrors design for safe house estate: Prevent the insecure entrance gates and accidents.	*Convex mirrors:* What are the characteristics of convex mirrors? How does the image in the convex mirrors occur?	The students explore characteristics of convex mirrors and image on convex mirrors. Then they design a prototype with convex mirrors to increase visibility in the entrance gates and ways of a house estate. The students explore characteristics of convex mirrors and image on convex mirrors. Then they design a prototype with convex mirrors to increase the field of visibility in the entrance gates and ways of a house estate. They place the convex mirrors in the relevant areas on the house estate model and test.	
3. Solar heated water tank design and positioning for eco-friendly house estate: Heat up water by using solar energy.	*Concave mirrors:* What are the characteristics of the concave mirrors? How does the image in the concave mirrors occur?	The students explore characteristics of concave mirrors and image on concave mirrors. Then they design a prototype with concave mirrors, that heat up water by gather sunlight into an area and ensures saving on heating, and placed it house estate model and test.	
4. House painting colors design eco-friendly house estate: Absorption of sunlight, heat isolation.	*Absorption of light:* How do different colors absorb light?	The students explore the relationship between the absorption of light and its colours. Then they design a prototype to absorb sun's heat energy by painting the houses and test to ensure saving on heating	
5. Colour wheel design for eco-friendly house estate: Let our colour wheel be our wind energy.	*Colour spectrum:* How do white colour occur from other colours?	The students explore how do white colours occur from other colours. Then they design a colour wheels as indicator of the amount of wind energy. They place and test these designs in places where wind energy will be used.	
Students apply their students to the grand design challenge through mini design and research. They design and explain their safe and eco-friendly house estate design.			

In the process and at the last stage, after completing each design task, students were provided to make presentations to other friends, ask questions or answer questions, and exchange views with the aim of developing critical thinking skills, as well as supporting the development of verbal communication skills. In order to improve their written communication skills at the end of the activities, they were asked to promote their designs with posters and product catalogs in order to contribute to their entrepreneurial skills and to reflect the science concepts they gained. After the designs were completed, they were asked to evaluate their solution proposals objectively in the context of criteria and limitations, and to develop critical thoughts about what they would change if they did it again. They wrote on their individual worksheets, critically and objectively, the strengths and weaknesses of their designs and the dimensions that need improvement. They scored and evaluated their designs with the help of the analytical rubric according to the design criteria (clarity of view, cost, durability, aesthetics, effective use of time).

In the seventh grade class where the activities were implemented, one of the researchers was assigned as a teacher and guided students during the implementation process of the activities. Before the implementation of activities, CCTDI and STEM Perception Test, providing the quantitative data of the research, were administered as a pre-test to the students in one class hour. Then, because students did not have any experiences about STEM education were distributed activity booklets to students and explained engineering design process and information related to their responsibilities and how the lesson would be executed. The implementation of the activities lasted 5 weeks/20 courses hours.

The students were encouraged for the process of implementation to work in groups and have in-group and intergroup communication. Heterogeneous groups were attempted to be created according to the achievement and gender during the formation of collaborative groups. Students' science course report grades in the first term were used as a basis for the achievement criteria. They were encouraged to work in groups (six groups/ each five students) and have in-group and intergroup communication. After they completed each mini design challenge and researches, they presented their design prototype to their peers, asked questions or answered the questions and exchange ideas with the intention of mainly developing critical thinking skills and also supporting oral communication skills. They were asked to evaluate the suggestions for the possible solutions objectively within the context of criteria and limitations and to develop opinions critically about what they would change if they could do it again.

Data Collection and Analysis

In this study, quantitative data via California Critical Thinking Disposition Inventory (CCTDI) and STEM Perception Test and qualitative data via semi-structured interviews were collected. The quantitative data were analysed statistical via SPSS-17, qualitative data also descriptively.

The California Critical Thinking Disposition Inventory (CCTDI), was used in the study to determine the effect of STEM education on students' critical thinking skills, developed by Facione & Facione (1992), revised by Facione et al. (1997) (as cited in Kökdemir, 2003). This test adapted to Turkish by Kökdemir (2003). The inventory rated on 6-point Likert type consists of 75 items and 7 sub-scales of truth-seeking, open-mindedness, analyticity, systematicity, self-confidence, and inquisitiveness. The scale's Cronbach Alpha reliability coefficient is 0.86 (Kökdemir, 2003).

STEM Perception Test, was used to determine the effect of STEM education on students' perceptions towards STEM disciplines, developed by Knezek & Christensen (1998) for STEM derived from Zaichkowsky (1985)'s questionnaire for information technologies (as cited in Knezek et al., 2013) adapted by Gülhan & Şahin (2016) to Turkish. Test consists five sub-scales: science, technology, engineering, mathematics, and career, uses 7-point (from negative [1] to positive [7]) scale like in semantics scale and test's Cronbach Alpha reliability coefficient is 0,891. The students were asked to evaluate five semantic adjective pairs for each of the five sub-scales. It was accepted that when the STEM perception score was high, the student's STEM perception was positive, so comparisons were made between the sub-scales and the total STEM Perception scores.

We statistical analysis package methods (Statistical Package for Social Sciences 17 (SPSS-17) were used for the analysis of the data obtained from CCTDI and STEM Perception Test. Shapiro Wilk test, Skewness, Kurtosis, results and Stem-and-Leaf Plot, Q-Q Plot graphs was used to test the normal distribution of the data. The dependent t-test was administered for the normally distributed data of CCTDI and CCTDI's all subscales, Wilcoxon signed rank test was used for the data of that are not normally distributed data of STEM Perception Test's subscales. p significance level was accepted 0,05 in order to reveal the significant differences of the results. Pre and post comparison of the data obtained from the CCTDI and STEM Perception Test were conducted.

Semi-structured interviews (according to Given, 2008), were carried out with the students after the implementations with the intention of supporting the data obtained from the CCTDI and STEM Perception Test to determine the effect of STEM education on students' critical thinking skills and perceptions towards STEM disciplines. Interview questions were developed by the researchers and were evaluated by two experts in the line the purpose of the study, the content of the activities and the age range of the participants. Consisted of the following questions: "What is your opinion about the process and contributions of the process?" and "Did the activities carried out throughout the process have an effect on your opinions/ideas about science, technology, engineering, and mathematics? For example, did they change your opinions about your career options?". The interview included two parts of questions: "Interview Questions about Critical Thinking" and "Interview Questions about STEM Perceptions" and throughout the interviews, the questions in Table 2 were asked to the students to elaborate their opinions when necessary. Semi-structured interviews were carried out with 6 students (3 female, 3 male), at least one student from each student group where implementations were carried out by one of the researchers and each interview lasted 7 minutes on average. The students chosen for the interviews were selected via maximum variation sampling (or sometimes called maximum diversity sampling) considering their achievements and genders.

Table 2. Semi-structured interview questions

Sub-scales		Interview questions related to the sub-scales
Critical thinking skill	Truth-seeking	How did you achieve solution way with the planning made with your friends?
		How did you choose the best solution offer for the problem solution?
	Open-mindedness	While presenting solution offers, have you only considered your own opinions or have you considered your peers' opinions?
		Are you open to the ideas of other people in daily life? Was it valid for these activities?
	Analyticity	How did you deal with the problems encountered?
	Systematicity	What did you pay attention while implementing your plan and creating your design?
		While actualizing your design, did you act either based on knowledge or intuitions?
	Self-confidence	Did you confide in yourself during the operations in the process?
	Inquisitiveness	Did your inquisitiveness about the knowledge related to the problem solution increase?
		Did you need information while solving the problem? Was there anything you were curious about?
STEM perceptions	Science	What did the activities make you think about science? Did your opinions about science change? Can you describe science in a few words?
	Mathematics	What did the activities make you think about mathematics? Did your opinions about mathematics change? Can you describe mathematics in a few words?
	Engineering	What did the activities make you think about engineering? Did your opinions about engineering change? Can you describe engineering in a few words?
	Technology	What did the activities make you think about technology? Did your opinions about technology change? Can you describe technology in a few words?
	STEM career	What did the activities make you think about STEM career? Did your opinions about STEM career? Can you describe STEM career in a few words?

Descriptive analysis technique, one of the qualitative data analysis methods, was used for the analysis of qualitative data obtained from the interview questions. In descriptive analysis, the data were read and organized under the pre-determined themes (sub-categories of critical thinking and STEM disciplines), the data were defined by supporting them with direct quotes and interpretations and comparisons were made on the results obtained.

Taking Hacıoğlu (2017) as reference for the evaluation of the responses given to the interview questions related to the critical thinking, they were analysed descriptively within the framework of critical thinking sub-scales in Table 3. Considering interview questions related to the perceptions about STEM disciplines, first of all, all the data were documented, and common codes were achieved. The expressions stated by the students in their responses to the questions related to the disciplines of science, mathematics, engineering, and technology were evaluated under the titles specified and results were obtained. Examples from the student responses to the interview questions about the subject were cited for the presentation of the results.

Table 3. Sub-scales of critical thinking disposition and evaluation of it considering its characteristics, and elements of descriptive analysis

Category	Sub-Category	Explanation
Sub-scales of critical thinking dispositions	Truth-seeking	Considering alternatives Tendency to search for truth Considering different opinions Asking questions
	Open-mindedness	Being open-minded and tolerant to different approaches Sensibility towards your own mistakes Giving importance to the ideas of others while making decision
	Analyticity	Paying attention to the possible problems/ conditions that will cause trouble Tendency towards reasoning with difficult problems and using objective evidence
	Systematicity	Research based on knowledge, planning, and detail Tendency to use a decision-making strategy based on knowledge and following a specific procedure
	Self-confidence	Confiding in your self-reasoning processes
	Inquisitiveness	Desire to get –learn unconditional information

The research process was attempted to be explained in detail for the reliability of the qualitative data analysis and the data were analysed and compared independently by the two researchers. The analysis process continued until consensus was reached between the intercoder (researchers).

Results

The results obtained as a result of the research were examined under two subheadings considering the research questions.

The Results Related to the Effects of STEM Education on Students' Critical Thinking Skills

The results, obtained from CCTDI and is related to the effect of STEM education on the seventh grade students' critical thinking skills, were presented the results obtained from CCTDI. CCTDI was implemented before and after the implementations to determine the effect of STEM education on the seventh grade students' critical thinking dispositions. Dependent samples t-test was administered to compare the students' pre-test and post-test scores related to the CCTDI and the results were presented in Table 4.

Table 4. The results for the comparison CCTDI pre-test post-test measurements of the students' scores

Scale-Subscale	N	X	SS	Sd	t	p
CCTDI Pre-test	30	208,37	235,145	29	-2,571	016*
CCTDI Post-test	30	235,14	311,765			
Truth-seeking	30	25,80	4,902	29	-2,684	,012*
	30	28,90	5,815			
Open mindedness	30	49,20	8,117	29	-3,005	,005*
	30	54,67	9,834			
Analyticity	30	44,97	8,451	29	-1,615	,117
	30	47,53	7,820			
Systematicity	30	23,83	5,173	29	-2,034	,051
	30	25,77	4,297			
Self-confidence	30	26,10	5,320	29	-,543	,591
	30	26,80	5,229			
Inquisitiveness	30	38,47	6,932	29	-,291	,773
	30	38,93	6,767			

$p<.05$

When Table 4 is examined, it is regarded that there is a significant difference between the seventh grade students' CCTDI Pre-test and Post-test scores in favour of post-test (t(30)=-2,571; p<.05). As is regarded with the differences between the pre-test and post-test scores, as a result of the t-test, there is a significant difference in favour of post-test. This result can be interpreted that the effect of STEM education on students' critical thinking skills on the limitedness of the uncontrolled variables (being familiar with the questions, experiences and etc.,) is at medium level (.2<Cohen d=0.47<.8). However, it draws attention that students' both pre-test and pots-test scores are low.

When the scores which students got from the pre-test and post-test sub-scales of CCTDI was examined, it was determined that there was a significant difference between the seventh grade students' pre-test and post-test results in terms of the sub-scales of truth-seeking and open-mindedness in critical thinking disposition test in favour of post –test results but there was not a significant difference regarding the sub-scales of analyticity, systematicity, self-confidence, and inquisitiveness. The interpretation of this result is that on the limitedness of the uncontrolled variables (being familiar with the questions, experiences and etc.,), the STEM education has an effect on the seventh grade students' critical thinking dispositions regarding the sub-scales of truth-seeking and open-mindedness but it does not have any effects on the sub-scales of analyticity, systematicity, self-confidence, and inquisitiveness.

When all results obtained from the CCTDI are evaluated, they can be interpreted that the STEM education has made contributions to the development of the seventh grade students' critical thinking dispositions. While this development has positive effects on the development of truth-seeking and open-mindedness sub-scales of critical thinking dispositions, it does not have any effects on the development of sub-scales of analyticity, systematicity, self-confidence, and inquisitiveness.

The results, obtained from interviews indicate that all the students expressed their opinions about the process supported the data obtained from the CCTDI and explained the process by putting emphasis on the truth-seeking and open-mindedness sub-scales of critical thinking. Then, students mentioned systematicity, analyticity, inquisitiveness, and self-confidence sub-scales, respectively. Only S4 expressed his opinion by emphasising the development in all of the sub-scales of the critical thinking while making an explanation. Exemplary quotations related to sub-scales of critical thinking disposition presented in Table 5. When these results were compared to mean scores of quantitative data obtained with the CCTDI, they showed parallelism with them.

Table 5. Exemplary quotations related to sub-scales of critical thinking disposition

Sub-scales	Exemplary quotations
Truth-seeking	S6: As time went by, we wondered more about the best solution of the problem and we began to explore more and also we tried to decide whether or not the materials we used were good.
Open mindedness	S1: We shared opinions with each other to find solutions to the problem. If I acted considering only my own opinions, I would not be successful, that's why I really paid attention to others' opinions, too…
Analyticity	S4: At first, I did not put forward an idea. We were beginning with 80% imagination. But during the process we achieved the success with our designs by thinking upon how we should do and doing research.
Systematicity	S2: We evaluated everyone's opinion, combined our opinions, and generated a way for solution and implemented it. Considering the different opinions, we decided which one to use for the problem solutions and chose the best one.
Self-confidence	S5: We chose one of the practical and functional solution offers. Here, my opinions were generally chosen as the best solution. Normally, I would like them to be my opinions. I thought that mine were the best. In this study, although my opinion was chosen as the best solution, I told my peers to discuss their opinions, too.
Inquisitiveness	S3: While doing research, when we encountered something that we didn't know, we felt the need to explore them.

The Results Related to the Effect of STEM Education on Students' STEM Perceptions

The results, obtained from STEM Perception Test and is related the effect of STEM education on the seventh grade students' STEM perceptions, were presented in Table 6 and Table 7.

Table 6. The results for the comparison of students' STEM perception pre-test post-test measurements

STEM perception	N	X	SS	Sd	df	t	p	Cohen d
Pre-test	30	4,83	1,19	0,97	29	-2,22	,034	0,406
Post-test	30	5,22	0,99					

Table 7. The results related to the sub-scales of STEM perception test via wilcoxin signed rank test

Sub-scales	Pre-Post test scores	N	Mean rank	Rank total	z	p
Science	Negative ranks	10	16,00	160,00	-,698	,485
	Positive ranks	17	12,82	218,00		
	Zero differences	3				
Mathematics	Negative ranks	12	11,96	143,50	-1,356	,175
	Positive ranks	16	16,41	262,50		
	Zero differences	2				
Engineering	Negative ranks	10	12,05	120,50	-1,882	,060
	Positive ranks	18	15,86	285,50		
	Zero differences	2				
Technology	Negative ranks	10	10,30	103, 00	-2,069	,039
	Positive ranks	17	16,18	275,00		
	Zero differences	3				
Career	Negative ranks	12	14,75	177,00	-,038	,970
	Positive ranks	14	12,43	174,00		
	Zero differences	4				

When Table 6 and 7 was examined, it was determined that there was a significant difference between the pre-test and post-test measurements of the scores belonging to the technology sub-scale of the seventh grade students' STEM perceptions ($z=-2{,}069$; $p<.05$). Based on this result, it can be interpreted that STEM education caused a development with students' perceptions of technology and general STEM perceptions.

Table 8. Exemplary quotations related to STEM discipline and career perceptions

STEM perceptions	Exemplary quotations
Science	S6: I thought that science was only human body. In fact, I witnessed the development of technology, what we benefited from and what we produced." At the beginning, science seemed to be complex but as I get engaged in it, I am more curious and excited.
Technology	S4: For example, we benefited from technology to test heat insulation and used a thermal camera. I saw that it had an effect on facilitating everyday life. Moreover, we realized that heat insulation could be done not only with materials but also with colors.
Engineering	S1: The activities made me think that engineering is a difficult job. In the past I thought that engineers could make drawings, in fact I learned that they did a lot of things. I realized that engineering plays an important role in our lives. I even decided to become an engineer.
	S5: When I did not succeed in our designs, I lost my interest in engineering. However, people construct houses for other people, they make drawings and thus I respect them. But I don't like it.
Mathematics	S3: In mathematics, the teachers told us to draw an angle and calculate it and we did it. But, we did need them with our designs. We calculated the angle and by adjusting the angle via measuring the length and the angle, we placed the mirrors. By using mathematics, we revealed that it was fine and useful.
Interdisciplinary relation	S2: I understood that it was necessary and effective to use science and mathematics together. For example, engineers use mathematics and measure the size and make different, fun, and useful designs with them.
	S6: I can't work in one of these fields. I think that these are professions for talented and patient people.

The results, obtained from interviews and is related to the effect of STEM education on the seventh grade students' STEM perceptions, all students expressed their opinions about their perceptions towards science, technology, engineering, and mathematics. They determined that the STEM activities changed their perceptions towards science and technology's relationship with everyday life. S2 and S3 determined that he could have a career in the field of science, these opinions demonstrate that STEM education effected on their career awareness. All students mentioned their opinion associated with engineering design process and other STEM fields. In addition to this, S4 determined that as she had little interest in engineering and she did not want to be an engineer, she finalized her decision not to choose engineering as a career during the process and thus she mentioned career awareness. Exemplary quotations related to STEM perceptions presented in Table 8. When these results were compared to mean scores of quantitative data obtained from the "STEM Perception Test", they showed parallelism with them.

Discussion and Conclusion

The discussion, conclusion and suggestions of the study were presented under two headings considering the research questions.

Effects of STEM Education on Students' Critical Thinking Skills

As a result of the research, STEM education affects positively critical thinking skills, especially critical thinking's sub-scales "truth-seeking and open-mindedness", of the seventh graders. In other words, students' critical thinking dispositions enhanced thanks to the STEM activities implemented in the study. The study of Ure (2012) examined the effect of engineering design process on the critical thinking skills of the fifth grade high school students supports our study's results. Ure (2012) who discussed critical thinking sub-scales as organization, asking questions, planning the future, improvement, seeking opportunities, effective communication, and analytical thinking of problems revealed that students showed improvement in different critical thinking domains. Similarly, in the other researches are asserted that STEM education could be used to develop students' critical thinking skills (Duran & Şendağ, 2012; Robinson, 2016; Mater et al., 2020; Retnowati et al., 2020). The implementation period of this study is shorter than from period of implementation of the studies in the literature. This seen as a limitation, but it is not a limitation according to Garrett (2009)'s study in that stated that no significant connection between the performance time in developing critical thinking and critical thinking skills.

In line the results of the study revealed that students constantly sought truth to find the best solution offer during the process and while doing this, they constantly considered their group members' opinions and they frequently emphasized the sub-scales of truth-seeking and open-mindedness of critical thinking skills and engineering design process. This result is also related to the fact that the process of result a solution to a problem in the real-life context positively affects the development of students' critical thinking skills (Appamaraka et al., 2009; Duran & Şendağ, 2012; Ernst & Monroe, 2006; Hove, 2011; Jonassen, 1997; Savery & Dufy, 1996). When examined, these results can be explained with the fact that critical thinking process and engineering design process involve similar steps (Hacıoğlu, 2017; NAE & NRC, 2009, NAE, 2010). Moreover, they may be explained with the requirement that engineers must use critical thinking skills (Reed, 2010). During the engineering design process, while individuals attempt to deal with the problems, they manage critical thinking process implicitly and thus students' critical thinking skills develop (Carroll, 2014; Kwek, 2011; Robinson, 2016; Ure, 2012). It is considered that the management of the intertwined processes of engineering design and scientific inquiry in the study promotes this result (Hacıoğlu, 2017) and there are also research results which reveal that the inquiry-based activities develop students' critical thinking skills (Bybee, 2000). In addition to this, similarly, there are studies which suggest that seminars, workshops, conferences, and competitions organized and designed with the theme of science for STEM education which focuses on interdisciplinary learning and teaching develop students' critical thinking skills (Blake & Liou-Mark, 2015). Although it does not assess critical thinking skills directly, with regard to the teacher views about STEM education, teachers and prospective teachers determine that STEM education will make contribution to students' critical thinking skills (Hacıoğlu, 2017; Hacıoğlu et al., 2016, 2017). These results seem to support the study results directly.

Effect of STEM Education on Students' STEM Perceptions

As a result of the research, STEM education affects positively on the seventh grade students' STEM perceptions and particularly on their perceptions towards the STEM disciplines' relation with real life changed. There are also other experimental studies suggesting that STEM education had positive effects on STEM perceptions (Brown et al., 2016; Gülhan & Şahin, 2016; Knezek et al., 2013; Lachapelle & Cunningham, 2007; Martinez-Ortiz, 2008; Nite et al., 2014; Sarı et al., 2018; Whitehead, 2010; Zeid et al., 2014). It was found in the study that among the STEM sub-scales, a significant development was observed only with the technology sub-scale. In the literature, there are studies that reveal that K-12 engineering education has positive effects on the perception of technology (Lachapelle & Cunningham, 2007; Martinez-Ortiz, 2008). It is considered that the content of the activities is effective with the result. As a result of the interviews, it was found that some students perceived technology as electronic gadgets like computer before the activities; however, thanks to the activities, they determined that even mirrors were a product of technology. Remembering only computers when talking about technology causes semantic restriction (or narrowing) (Cunningham et al., 2005; Lantz, 2009; White, 2014; Winegar, 2000). Hence, the results demonstrating that STEM education developed perception of technology exhibit a positive effect regarding the perception of technology.

The interviews revealed that the process made contributions to students' career awareness. As a matter fact, researches indicate that STEM education improve students' STEM career awareness and increase their tendency to choose professions in STEM fields for the future (i.e. Beier et. al, 2019; Çevik, 2018; Özkul & Özden, 2020). However, while some students opined that they would choose engineering, some students determined that they would not choose engineering profession. One student remarked that because STEM fields were difficult, he would not choose career in these fields. This result can be interpreted that the students raised awareness about the importance of engineering, but they have still some perceptions that these fields are difficult. In fact, it can be considered that this situation is a gain because STEM education does not make claim that everyone will be a STEM worker and it is obvious that this is not realistic (Gülhan & Şahin, 2016). After evaluating themselves as a result of STEM education, students decide whether or not they are suitable for the field and this is a positive result because it will prevent them from making wrong career choices in the future.

Limitations and Implications

Carrying out the study within the context of science course is a limitation because the activities were developed according to the engineering design-based STEM education and the learning outcomes of science course and the learning outcomes of mathematics and technology courses were involved in the planning as a skill. If such activities are implemented in the mathematics, technology courses and similar courses in the schools having flexible curriculum, a fully integrated STEM education can be implemented.

Recommendations

It was concluded in the research that STEM education had positive effects on the seventh grade students' critical thinking skills and STEM perceptions. When the results of the study were evaluated, the following suggestions were made for the teachers and researchers:
1-) In order to develop critical thinking, one of the four basic skills (4C) of STEM education, students must be allowed to evaluate the relevant subject area, designs they make, and their own opinions and as well as their group members' opinions at each stage of the process with an inquisitive perspective during the STEM activities.
2-) To increase the number of individuals working in the STEM fields, which is the ultimate goal of the economic dimension of STEM education, it is required that students' perceptions of STEM fields must be correct. Thus, the implicit or explicit messages given during the STEM applications or by the teachers are of vital importance.

Scientific Ethics Declaration

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

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Author Information

Yasemin Hacıoğlu
Giresun University
Giresun University- Faculty of Education-Turkey
ORCID iD: http://orcid.org/0000-0002-1184-4204

Filiz Gülhan
Ministry of National Education-Turkey
İstanbul National Education Directorate-Turkey
Contact e-mail: *filizglhn@hotmail.com*
ORCID iD: http://orcid.org/0000-0002-7915-6299