Educational Policy Analysis and Strategic Research, V19, N1, 2024

STEM-Engineering Education with a Disadvantaged Student Group

Ganime AYDIN[1]
Çanakkale Onsekiz Mart University
Mehpare SAKA [2]
Trakya University
Jale ÇAKIROĞLU [3]
Middle East Technical University

Abstract

The aims of this research were to examine the changes in the students' perceptions of engineers, engineering as a profession, learning of engineering design processes (EDP), awareness of engineering branches, and their future career choices through Engineering Design Process activities with the 5E learning model. Sixty disadvantaged students between 4th grade to 8th grades comprised the sample group. Engineering activities were held over 8 weekend days outside of school with engineers and science educators. The study was a single group pre-test and post-test weak experimental design using qualitative data sources. Draw an Engineer Test (DAET) along with written descriptions were used as a pre-test and post-test to examine students' perceptions of engineers and engineering before and after the intervention and the career choice test (CCT) was used to compare their future career choices and awareness of engineering branches. Based on the results, their perceptions about engineering changed by using the words design, produce, invention, and production, which were included in EDP. Their career choice of being an engineer or learning engineering branches changed with the aim of improving their standard of living.

Keywords: Engineering education, STEM, Engineering Design Process, Disadvantaged students

DOI: 10.29329/epasr.2024.655.3

Submitted:27 November 2023 **Accepted:** 11 February 2024 **Published:** 31 March 2024

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[1]Associate Professor, Education Faculty, Çanakkale Onsekiz Mart University, Çanakkale, Turkey, ORCID: 0000-0001-6112-5243

Correspondence: ganime31@gmail.com

[2] Associate Professor, Education Faculty, Trakya University, Edirne, Turkey, ORCID: 0000-0001-9730-8607

Email: mehparesaka@gmail.com,

[3] Professor, Education Faculty, Middle East Technical University, Ankara, Turkey, ORCID: 0000-0002-1014-7650

Email: jaleus@metu.edu.tr

Introduction

There is a worldwide requirement for graduate students with 21st-century skills and enriched scientific knowledge because of the changing global need for innovation. Many countries added STEM education programs to formal education and informal education under the guidance of the National Science Board (2010) and the National Research Council [NRC] (2012). The next generation of science standards ([NGSS], 2013) includes the goal of science within the framework of K-12 education as "ensuring that by the end of 12^{th} grade, all students will have some appreciation of the beauty and wonder of science, possess sufficient knowledge of science and engineering to engage in public discussions on related issues, be careful consumers of scientific and technological information related to their everyday lives, be able to continue to learn about science outside school, and will have the skills to enter careers of their choice, including (but not limited to) careers in science, engineering, and technology" (p. 14). The NCR noted the sustainability of STEM education from pre-school to the end of university, but there are some restrictions on STEM applications for all students in a society, for instance, families, schools, and teachers. The social status of the family is the most important factor in the success of students and their choice of career (Bourdeu, 1990). Weininger and Lareau (2003) stated that other than the social background of students, the education system also sets up individuals in different classes. Xie, Fang, and Shauman (2015) asserted that learning science requires education, and science offers the opportunity to attain a high-status occupation with relatively high income and social prestige. They emphasized that STEM education is required for science or engineering employment and suggested which social determinants (family, individual factors like cognitive level of student, teacher, racial and ethnic differences, schools) influence the attainment of STEM education by all students. Lowrie, Downes, and Leonard (2018) explained the requirement of STEM education for disadvantaged groups, indicating the presence of barriers such as school factors, personal factors, and home factors. They also explained ways of overcoming these barriers by implementing STEM activities during holiday periods, in out-of-school programs, and requirements for STEM integration into the school curriculum. Altan and Koroglu (2019) studied STEM activities with disadvantaged students in a school program, and they found improvements in student perceptions and career awareness regarding STEM fields. In a similar vein, the participants of the present study were sixty students residing in children's houses/orphanages under the protection of the Ministry of Family and Social Services.

When we look at the evaluations of STEM applications in which the engineering design section stands out, we see in the NRC (2012) report that engineering courses applied at the K-12 level increase students' success and motivation, improve conceptual learning, higher-order thinking skills and engineering design skills (Fan & Yu, 2017) were observed. The engineering education in this study, which was related to the current science curriculum, was provided in a rich learning environment including university laboratories, a factory, an orchard, an art gallery, and two historical places in Turkey like Troy and Edirne, one of the capital cities of the Ottoman Empire. Therefore, the main aim of this study was to examine the changes in the students' perceptions of engineers, engineering as a profession, learning of engineering design processes, awareness about engineering branches, and their future career choices through engineering design process activities with the 5E learning model.

Engineering, Engineering Education and Engineering Design Process

Today engineering goes beyond the theoretical knowledge of science, mathematics, design, and engineering; it includes many competencies that require working as a team, effective transferring of ideas, understanding different cultures, and understanding the impact of technology on individuals and societies; in short, it is the design of today's technology (NRC, 2014). Engineering was also defined in the Ministry of National Education (MoNE) science curriculum as follows; "engineering includes objects that meet the requirements of people and practices which are systematic and open to improvement by planning processes and design" (MoNE, 2018, p. 10). Engineering education that advances student motivation, problem-solving skills, and critical thinking abilities supports learning of mathematics and science as well as linking engineering with science (Brown and Borrego, 2013; Katehi, Pearson and Feder, 2009). In evaluations about STEM practices where engineering design is prominent, NRC (2012) reported that engineering courses applied at the K-12 level increase the students' academic achievements and motivation. In this teaching model, discussions included topics like a number of integrated disciplines, which discipline should be the main discipline connecting with others, the role of technology, and whether it is a product or tool during implementations. Moore, Glancy, Tank, Kersten, Smith and Stohlmann (2014), while describing engineering as the natural integrator of STEM teaching, emphasized that engineering should include science and mathematics for technological advances. NRC (2012) also stated that engineering is the basic mechanism for meaningful learning of science concepts in STEM applications. Therefore, the framework of STEM applications is to implement practices that will connect the concepts of science and mathematics at the center of the engineering discipline. The STEM education model based on engineering design processes (EDP) aims to educate students and produce successful individuals who think systematically, are creative, have ethical values, can solve problems with proper solutions, are scientifically literate, open to communication, and complete engineering design projects integrating different disciplines as an engineer (Guzey, Thank, Wang, Roehrig, & Moore, 2014; Mann, Mann, Strutz, Duncan, & Yoon, 2011; Rogers & Porstmore, 2004). In each stage of engineering design processes, students improve and learn what engineers work on, transfer scientific and mathematical knowledge within their solutions, generate different solutions, and gain critical skills (Lotteroperdue, Bolotin, Benyameen, and Metzger, 2015). Engineering allows students to design creative and innovative solutions as a problem-solving context linking science and mathematics knowledge (English & Hudson, 2013). In addition to this, EDP not only involves the processes to produce a product, it also requires complex decision-making and problem-solving skills (Cunningham & Lachapelle, 2014; Fan, Yu, & Lou, 2017). In addition to the effectiveness of EDP in various ways, recommendations were developed during implementation. Schnittka and Bell (2011) indicated that engineering design alone was not enough to promote a conceptual understanding of science. In their research, they investigated how an engineering design intervention that addresses alternative conceptions is more successful in helping students learn science content at a deep conceptual level. In the present study, engineering education was structured through inquiry-based learning within the 5E learning model to teach science concepts, and EDP was given in the elaboration stage of the 5E learning model. Also, when different kinds of engineering branches were examined, EDP was used to change perceptions about engineering, to understand how engineers work, and to enhance the self-efficacy of students about STEM-related careers.

Engineering as a career choice

Firstly, for young people to choose careers in the STEM fields, it is important they have academically successful experiences in science and mathematics to ensure STEM integration and the necessary competencies in these areas (Blotnicky, Franz-Odendaal, French & Joy, 2018, Heilbronner, 2009; Kelly, Dampier & Carr, 2013;). Even though very clear changes are observed in the beliefs related to competency and expectations of success among students from the primary school years to middle school years, the rate of this variation was identified to reduce from the 9th grade to the 11th grade during the high school years (Mangu, Lee, Middleton, & Nelson, 2015). The causes of this variation in self-efficacy beliefs of students were stated to include the gender variable, e.g., the belief that girls have higher competency for verbal lessons, while boys have higher mathematic competency and this being supported by academic success outcomes, along with ethnic, socioeconomic, and sociocultural differences and peer groups (Wigfield & Eccles, 2002). Timur, Timur and Çetin (2019) pointed out another factor related with gender difference that teachers play vital role in determining students' interest in subjects and they effect on students' future career due to their role model function.

During the high school years, the most important factor affecting choices in the STEM field is self-efficacy, as explained by Heilbronner (2009) and Kelly, Dampier, and Carr (2013). Another topic affecting career choices in STEM fields is the degree to which students have knowledge of engineering (Compeau 2016; Karatas, Micklos, & Bodner, 2011). Inclusion in STEM activities was stated to be another factor affecting student choice of careers in STEM areas (Franz-Odendaal, Blotnicky, French, & Joy, 2016). In the present study, when performing activities in many engineering branches with EDP, the first author explained what engineering is at the beginning of implementations.

STEM with disadvantaged students

We aim to identify disadvantaged students who face specific barriers compared to their peers. These barriers can be categorized into three groups within the light of literature (Banerjee, 2016; Fan, Yu, & Lou, 2017; Henley & Roberts, 2016). The first group includes disabilities, encompassing mental, physical, or chronic illnesses. The second group consists of sociocultural barriers, such as gender, race, ethnicity, beliefs, sexual orientation, immigration status, refugee status, residing in rural areas, and the educational level of their families. The third category of barriers can be described as socioeconomic, which is directly linked to sociocultural factors, including low family income, the quality of schools and teachers' experience, academic qualifications of teachers (master's or doctorate), school learning environments (availability of laboratories, digital tools, etc.), and peer-related factors (cognitive and cultural diversity of peers in the same schools, class size, etc.). All three categories are interconnected and impact students' academic achievements and career choices.

Considering these factors, STEM programs for students facing these barriers offer an opportunity to change their destiny. According to existing literature, these barriers have a direct influence on students' goals and their interest in career choices (Brown & Lent, 1996; McWhirter, 1997; Lent, Brown, & Hackett, 2000; Fouad & Byars-Winston, 2005). Henley and Roberts (2016) addressed various barriers that students face, including economic, geographic, social, and educational obstacles. These include a lack of family support, mentoring, and career guidance, as well as insufficient access to advanced high school courses and funds for postsecondary preparation activities. Students also lack confidence in securing local employment. STEM education for disadvantaged students contributes to social justice (Ebenezer, 2013) and reduces school dropout rates (Ball et al., 2019; Chachashvili-Bolotin et al., 2016; Flynn, 2016). Socioeconomic status, gender, ethnicity, racial minority status, and learning gaps/disabilities all influence the STEM career choices of disadvantaged students (Uluduz & Calik, 2022).

Hlosta, Herodotou, Bayer, and Fernandez (2021) conducted a study involving 1500 students, including those from Black, Asian, and Minority Ethnicity (BAME) backgrounds and students from economically deprived areas. They implemented three STEM courses and found that students in the experimental group had a 7% higher chance of passing the courses compared to the control group. Wilson, Iyengar, Pang, Warner, and Luces (2012) developed a mentoring program called S-STEM (Scholarships for Science, Technology, Engineering, and Mathematics) for college students from diverse ethnic backgrounds, leading to increased graduation rates and improved student performance (GPA). The latest report on science education in England in 2022 focused on STEM education for disadvantaged groups, specifically addressing gender and ethnicity (source: https://www.stem.org.uk).

In summary, there is limited research on STEM education for students facing barriers. Existing research has primarily focused on racial and ethnic groups, as well as women in STEM education (Xie, Fang, & Shauman, 2015). Therefore, this study is distinctive as it examines disadvantaged students between the ages of 10-15 who are under the government's protection.

The research questions that guide this study are as follows:

After participating in out-of-school engineering design process activities,

1. Is there any change in the disadvantaged students' future career choices?

2. Is there any change in the awareness of disadvantaged students about engineering branches?

3. Are there any changes in the disadvantaged students' perceptions of engineers and engineering as a profession?

4. Is there any change in the disadvantaged students' learning of engineering design processes?

Method

Research Design

This research was an as a single group pretest and post-test weak experimental design using qualitative data sources. In the single-group pretest-posttest design, while studying with only one group, the difference in success between the two tests is examined by applying a pretest before instruction and a posttest after instruction (Buyukozturk, Kılıç Çakmak, Akgun, Karadeniz, & Demirel, 2014). The qualitative data tools were used to find answers to the research questions with a descriptive, comparative, and interpretative approach. The study consisted of three stages. In the first stage, questionnaires were applied as a pre-test to the participants. In the second stage, out-of-school engineering design-based activities in the program prepared within the scope of the study were applied to students. In the last stage, writing a story and a post-test of the questionnaires were applied.

Sample group

Sixty students between 4th to 8th grades who reside in a children's house under the protection of the government were selected with the purposeful sampling method. Of the participants, 64% were boys, and 36% were girls. The purposeful sampling method was used in this study. Purposeful sampling focuses on information-rich situations providing answers which will shed light on the research questions (Patton, 2001). The demographic backgrounds of the students cannot be given in detail because of legislation. But generally, they have no family or family members cannot look after them because of poverty, refugees without family or family members are in prison or died in the war). These students had no model of an engineer in their life, and throughout the implementation, the researchers realized that boys spent their free time watching television series related to the police or football matches, while girls watched mostly programs about cooking, fashion, and romance series on TV. The students participating in the study were divided into three groups according to their age levels: 3rd and 4th grades, 5th and 6th grades, and 7^{th} and 8^{th} grades. In this classification, although the ages of the students are taken into consideration, the aim was to combine the students close to each other in terms of the education process.

Instruments

Data were collected through the following data collection tools: Career Choice Test (CCT), Draw an Engineer Test (DAET), and Story Writing.

Career Choice Test (CCT): It was used as a pre-test and post-test to see the changes in students' future career plans. The test includes questions like "Which profession would you like to have? Do you want to be an engineer? If yes, which branch of engineering do you want to work in?"

***Draw an Engineer Test (DAET)**:* It aims to determine students' knowledge and perceptions about engineering and engineers through writing and drawing (Knight & Cunningham, 2004). In the present study, it was used as a pre-test and post-test to examine students' perceptions about engineers, engineering, what engineers do, and branches of engineering by making a minor adaptation from the original form (Cunningham, Lachapelle & Lindgren-Streicher, 2005; Knight & Cunningham, 2004). The DAET comprises two main parts: drawings and questions. In the drawing part, students are expected to draw an engineer; in the questions part, they are expected to answer the following seven questions:

1. Tell us about the engineer you drew
2. Where does your engineer work?
3. In which fields do they work?
4. What is your engineer doing in your drawing?
5. What is engineering?
6. What do the engineers do?
7. Do you know any engineers? If so, would you tell us about them?

While the first four questions were related to the drawing, the last three questions were used to define the engineering knowledge of the students and to determine if they know what engineers do.

Story Writing: Students were asked to write a story with the title "If I am an engineer in the future" at the end of all implementations to understand the reasons for their choice to be an engineer in-depth. The writing is one of the most powerful communication tools humans have and is one of the keys to writing success in and out of school (Haris, 2005). In the stories, the students' answers to questions about how they define engineering, along with their dreams, what they want to work at, what was added to their social lives, and why they want to become an engineer, were sought. Along with the stories, it was tried to determine how the students defined engineering, their dreams, what they wanted to do, what they added to their social life, and why they wanted to be an engineer.

Implementations

In the study, engineering design process activities with 11 different engineering fields were implemented for a total of 15 days with a 6-hour duration. Since the students in the sample were disadvantaged students protected by the state, all the researchers and the instructors who carried out the applications received pedagogical training from pedagogical experts. This pedagogical training was carried out before the implementation. At the same time, all trainers and researchers met to plan the engineering applications before the implementation. The engineering activities applied in the study were developed together with architects, engineers, and science educators who participated in the activities.

The 5E learning model was chosen to teach the science concepts to students participating in the study. The model consists of engage, explore, explain, elaborate, and evaluation stages (Bybee & Landes, 1990). The engineering design process activities were applied in the elaborate stage of the 5E learning model. Even though the engineering design model has many variations, they all have similar processes. In this study, eight steps of the engineering design cycle were used: 1) Ask (define the problem), 2) Research the problem, 3) Imagine (developing possible solutions), 4) Plan (selecting promising solution), 5) Create (building a prototype), 6) Test (testing and evaluating prototype), 7) Improve (re-design if needed), 8) Present (sharing design with the whole group). One of the activity plans is given in the appendix, and a detailed description of all activities can be found elsewhere (https://moaa.comu.edu.tr/, 2022). Table 1 gives a listing of each engineering design process activity, along with topics taught in the implementation.

Table 1. Topics and engineering design process activities included in the implementation.

	Engineering type	**Name of Activity**	**Topics**
Week 1	Civil engineering	Tower construction	EDP, the center of gravity, collaborative work
	Aerospace Engineering	Telescope construction	EDP, refraction by reflection, lenses
Week 2	Software engineering	Robber kidnapping robot	EDP, coding
Week 3	Biomedical Engineering	Producing natural creme	EDP, controlled experiment, dependent independent variable, natural materials
	Chemical Engineering	Producing natural spoon	EDP, chemical change, viscosity, properties of natural materials, controlled experiment, dependent independent variables,
Week 4	Electrical engineering	Vacuum cleaner	EDP, elements of electrical circuits, building electrical circuits, current, potential difference, short circuit, electric motor, energy transfer
	Electrical engineering	Toy car	EDP, elements of electrical circuits, building electrical circuits, current, potential difference, short circuit, electric motor, energy transfer
Week 5	Agricultural Engineering	Fruit Tree Grafting	EDP, DNA, gene transfer
Week 6	Architecture	Insulated houses	EDP. insulation
Week 7	Textile engineering	Fabric production	EDP, production steps from cotton to fabric
	Environmental engineering	Garbage separator	EDP, mixtures, methods of separation of mixtures
	Environmental engineering	Recycled goods	EDP, recycling
Week 8	Mechanical Engineering	Discoverer engineers at work Engineers Committee (Drama)	EDP, engineers work with other disciplines

While designing the activities, attention was paid to ensuring that the materials to be used were cheap and could be found in every region of the country. The study group continued their formal education during the implementations that were carried out on weekends and Saturdays for a total of 15 days with a 6-hour duration. Architecture, agricultural engineering, and mechanical engineering activities were carried out in one day. Also, activities were held in different learning environments for instance, the orchard (agricultural engineering, factory (mechanical engineering), garden, laboratory, classroom, beach, and the art gallery of Selimiye mosque, which was built by a world-famous architect Mimar Sinan.

Data Analysis

The code system developed by Weber, Duncan, Dyehouse, Strobel, and Diefes-Dux (2011) was used for the analysis of the DAET. This coding system consists of type, skin color, gender, location, inferences about the work done, and objects sections. In the present study, the skin color part was not used in the test, but the coding for the branch of the engineer was added. The reason for this change is to determine whether the activities are chosen from different engineering branches and whether there are differences in the perceptions of students towards these different engineering branches. In addition, the open-ended questions in the DAET test were coded by the researchers using open coding, and then the pre- and post-test percentages were compared. The drawings of students before and after implementations were coded, and results were obtained and compared with descriptive analysis by the researchers. In addition, student CCT pre- and post-test answers were compared by the researchers for percentage and frequency. The students' stories were analyzed by four science educators, apart from the researchers. In addition, taking the characteristics of the sample group into account, story analyses were carried out by a specialist in Guidance and Psychological Counseling (GPC). First, all stories were individually coded by each researcher and the GPC specialist, and the codes were collected in specific categories. Then, the researchers and GPC specialists met to compare the codes and categories. When a consensus was reached by reviewing different codes and categories, the analyses were finalized. In qualitative research, especially, the researcher's specific value judgments and expectations from the research are an important factor affecting the process and the result of the study, as well as the research validity (Maxwell, 2013). In this research, attempts were made to ensure both validity and reliability by different field experts managing the process during the activities and including different researchers in the analysis of data. The use of standardized categories is another factor that increases reliability in qualitative research (Silverman, 2015). In this study, both the use of standardized categories used previously for the DAET scale, and the analysis being conducted by different researchers are the factors that increase reliability. In addition to this, attempts were made to ensure reliability by activities being performed in out-of-class environments and applying the measurement tools at certain intervals and during free time. The data obtained from the data collection tools were organized in an integrated way and presented in the following findings section.

Results

In this section, the analysis of the data collected during the study is presented.

Findings of Career Choice Test (CCT)

Table 2 and Table 3 display the comparison of students' choice of engineering as a future career plan in pre- and post CCT.

Table 2. Findings of students' pre-CCT

Choice of Engineering (Pre-test)	**f**	**%**	**Branch of engineering**	**f**	**%**
I want to be an engineer.	17	24.63	Civil engineering	9	53%
			Computer engineering	8	47%
I don't want to be an engineer	30	43.47	**Choice of career**	**f**	**%**
			Police	8	15%
			Soccer	7	13%
			Mechanic	5	10%
			Cook	3	6%
			Doctor	2	4%
			Hairdresser	2	4%
			Singer	2	4%
			Veteran	1	2%
I don't know	15	31.88			

Table 3. Findings of students' post-CCT

Choice of Engineering (Post-test)	**f**	**%**	**Branch of engineering**	**f**	**%**
			Civil E.	4	17%
I want to be an engineer	23	46.9	Computer E.	4	17%
			Electronic E.	4	17%
			Software E.	4	17%
			Textile E.	1	4%
			Space E.	1	4.%
			Mechanic E. engineer	1	4%
			Mechatronics	1	4%
			Chemistry E.	2	9%
			Architecture	1	4%
			Career choice	**f**	**%**
I don't want to be an engineer	26	43.1	Doctor	3	11.53
			Police	2	7.69
			Soldier	2	7.69
			Preschool teacher	2	7.69
			Cook	2	7.69
			Soccer	2	7.69
			I don't know	13	42.30
I don't know	-	-			

Before the implementation, 25% of the students stated that they wanted to be an engineer by indicating a preference for civil (53%) and computer engineering (47%). However, of the students, 43.47% did not want to be an engineer, and 32% of them did not specify any career choice for the future. At the end of implementations, the ratios of whether they wanted (47%) or did not want to be an engineer (43%) were close to each other. However, other than civil and computer engineering, other engineering branches such as electrical, software, chemistry engineering were added as branches chosen.

Findings of Draw an Engineer Test (DAET)

In this section, an analysis of students' drawings before and after the implementation was given.

Table 4. Species and other attributes of engineers in DAET pre-test and post-test drawings

	pre-test		**post-test**	
Species	**f**	**%**	**f**	**%**
Human	34	72%	45	83%
No person	12	26%	5	9%
Non-human	1	2%	4	7%
Other attributes	**f**	**%**	**f**	**%**
Laborer's clothing	17	74%	15	52%
Glasses/goggles	2	9%	7	24%
Smart, hard worker, tidy	2	9%	5	17%

While 72% of pre-test drawings included humans, this increased to 83% at the end of the implementation. Protective equipment like laborer's clothing, helmet, and goggles was seen in their post-test drawings (Table 4).

When examining students' gender, it was seen that male students did not draw any female engineers in their pre-test drawings, but after the implementation, they drew female engineers. The number of female engineers (13%) in the drawings of female students increased in post-test drawings (28%) (Table 5).

Table 5. Comparison of student gender and engineer gender on DAET

	Gender of students							
	Pre-test				**Post-test**			
	Male		**Female**		**Male**		**Female**	
Gender of engineer	**f**	**%**	**f**	**%**	**f**	**%**	**f**	**%**
Male	19	40%	9	19%	8	15%	6	11%
Female	0	0%	6	13%	2	4%	15	28%
Unknown	10	21%	3	6%	19	35%	4	7%

Regarding the type of engineers in students' drawings, they mostly drew civil (35%) and computer engineering (24%) before the implementation. After the implementation, even though civil (25%) and computer engineering (18%) were the most preferred engineering branches, the ratio decreased in their final drawings. Furthermore, while the percentage of software (12%) and chemical

(8%) engineering preferences increased, space and biomedical engineering were added, which were not mentioned before the implementation (Table 6).

Table 6. Comparison of engineering branches in pre-test DAET and post-test DAET results

	pre-test		post-test	
Type of engineering	**f**	**%**	**f**	**%**
Civil engineering	16	35%	13	25%
Computer engineering	11	24%	9	18%
Software engineering	2	4%	6	12%
Chemical engineering	1	2%	4	8%
Aerospace engineering	0	0%	4	8%
Mechanical engineering	5	11%	3	6%
Electrical- engineering	2	4%	3	6%
Environmental engineering	1	2%	3	6%
Aircraft engineering	3	7%	3	6%
Biomedical engineering	0	0%	1	2%
Agricultural engineering	2	4%	1	2%
Architecture	2	4%	1	2%
Nanotechnology Engineering	1	2%	0	0%

When the workplaces of engineers were examined in the drawings, it was found that they drew outdoor (55%) and indoor (33%) spaces as workplaces of engineers before the implementation. However, they used unidentified spaces (35%) in addition to indoor and outdoor spaces after the implementation (Table 7).

Table 7. Comparison of locations in pre-test DAET and post-test DAET results

	pre-test		post-test	
Locations	**f**	**%**	**f**	**%**
Inside	14	33%	21	39%
Undefined	5	12%	19	35%
Outside	23	55%	12	22%
Space	1	2%	1	2%
Underground	0	0%	1	2%

Regarding objects that they drew in their drawings, there are computers (14%), furniture (e.g., table, chair) (14%), bridges or construction materials (14%), and flying vehicles (7%) in their drawings before the implementation. But after the implementation, computers (15%), furniture (12%), and bridge or building materials (11%), as well as project drafts (e.g., blueprints) (9%), and robots (8%) were used in many drawings. In addition to these objects, laboratory equipment (e.g., beaker, flask, baguette), technological objects such as TV or radio, waste materials, and objects like rockets were included in their final drawings (Table 8).

Table 8. Comparison of objects in pre-test DAET and post-test DAET results

Objects	pre-test f	pre-test %	post-test f	post-test %
Computers	6	14%	10	15%
Furniture-table, chair etc.	6	14%	8	12%
Construction-bridges, edifices etc.	6	14%	7	11%
Blueprints	0	0%	6	9%
Robots	0	0%	5	8%
Flying vehicles	3	7%	4	6%
Building tools-hammer etc.	2	5%	3	5%
Pass vehicles	2	5%	3	5%
Chemistry-beaker etc.	0	0%	3	5%
Technology-tv, radio etc.	0	0%	3	5%
Environment/waste materials	0	0%	3	5%
Construction vehicles	1	2%	2	3%
Space/space objects	1	2%	2	3%
Other machines (clothes, washing machine)	1	2%	2	3%
Rockets/aircrafts	0	0%	2	3%
Writing objects-pencil, paper etc.	1	2%	1	2%
Other plants	0	0%	1	2%
Other people	0	0%	0	0%
Studied plants	2	5%	0	0%
Studied animals	1	2%	0	0%
Others	0	0%	0	0%
Non-human	1	2%	0	0%
Body parts	0	0%	0	0%
Measurement tools-ruler etc.	1	2%	0	0%

Regarding engineering activities, at the beginning of the implementation, students defined the engineering design process (EDP) as design, invention, and production (42%) and handmade, repair, and building construction (33%). Later, they defined EDP by using words such as design, invention, and production, handmade, repairing and building activities, experiments, testing, and knowledge production (26%), in addition to explaining and teaching (11%) and observation (4%) (Table 9).

Table 9. Comparison of engineer activities in pre-test DAET and post-test DAET results

Activities	pre-test f	pre-test %	post-test f	post-test %
Designing/inventing/creating products	10	42%	8	30%
Making/fixing/working on buildings by hand	8	33%	7	26%
Experimenting/testing/creating knowledge	4	17%	7	26%
Explaining/teaching	0	0%	3	11%
Doing research/projects	1	4%	1	4%
Observing	0	0%	1	4%
No action	1	4%	0	0%

Students answered questions about their perceptions of what engineering is in pre-test DAET by using the following words: expert (21%), researcher (14%), facilitating life (14%), and earning money (14%). Their words were diversified to include producer (15%), construction (13%), earning money (11%), explorer (9%), product developer (9%), contributing to science and humanity (9%), and integration of science and mathematics (9%) on the post-test (Table 10).

Table 10. Comparison of answers of students 'What is engineering?' in pre-test DAET and post-test DAET results

	Pre-test		**Post- test**	
	f	**%**	**f**	**%**
Professional	6	21%	4	9%
Researcher	4	14%	1	2%
Making life easier	4	14%	1	2%
Money earned in a job	4	14%	5	11%
Discover	3	10%	4	9%
Product	3	10%	7	15%
Making designs	2	7%	2	4%
Construction of buildings	2	7%	6	13%
Knowledgeable	1	3%	-	-
Product developer	-	-	4	9%
Being successful	-	-	1	2%
Responsible	-	-	2	4%
Hard worker	-	-	2	4%
Contribution to science and life	-	-	4	9%
Integration of science and mathematics	-	-	4	9%

When asked what engineers do, before the implementation, students claimed that engineers mostly construct buildings (24% and produce things such as robots, cars, or electronic vehicles (30%). In addition, they stated that they are people who do research (11%), repair (8%), and make designs (8%). After the implementation, the students stated that engineers are people who produce mostly cars, robots, electronic vehicles, or everything (46%). In addition, some of the students stated that engineers construct buildings (10%) and make designs (10%). Some students also mentioned that the work done by engineers is based on their branch after the implementation (13%). The students added the following expressions "experimenting," "working for the environment," and "contributing to science" as a new working area of engineers (Table 11).

Table 11. Comparison of answers of the students to 'What do engineers do?' in pre-test DAET and post-test DAET

	Pre -test		Post- test	
	f	%	f	%
Constructing buildings	9	24%	4	10%
Researching	4	11%	-	-
Discovering	2	5%	2	5%
Repairing	3	8%	-	-
Making designs	3	8%	4	10%
Producing beneficial tools for humanity	1	3%	1	3%
Depends on branch	2	5%	5	13%
Don't know	3	8%	-	-
Producing robots-electronic tools-computer-car- everything	11	30%	19	46%
Doing experiments	-	-	1	3%
Working for the environment	-	-	1	3%
Contributing to science	-	-	3	8%

Table 12. Analysis of students' stories entitled 'If I am an Engineer.'

EDP use in stories	
Design	*- I made a pencil holder I designed myself from an empty jar to put on my desk.* *- I will design a robot and it will be able to play football and everything with children.* *- The robot I invented will collect garbage more quickly.* *- They made different designs, a robot to cut cabbage, a robot to care for people…*
Imagination	*To prove to future generations that nothing is impossible, I would make a transporter machine so people can go to places that are difficult to get to in a few seconds.* *... they thought one day will I be able to make what they draw real and really be a very good architect...* *... I would do a lot of projects, and I would work to implement these projects...*
Cooperation-Discussion	*...they asked about the characteristics of an engineer, and they replied we exchanged ideas and said I'm someone like that...*
Production	*...I would like to invent a device to collect all the garbage in the environment...* *...they would build a house...*
Student reasons for being an engineer	
Acceptance	*...the houses they made sold all around the world, and they were a very famous electronic engineer.* *...they wrote their name in history with the works they constructed...*
Earning money	*...with the money I earn when I'm an engineer, I would save my friends from this swamp.* *...In the house bought with the money they earned from mining engineering, they lived together happily with their friends from the children's house. I would earn money by selling the robot I made. ....*
Help those around them by increasing living standards.	*...I would work for years so people wouldn't be homeless.* *... and ... siblings became civil engineers and built a house where they could live with their family, and they lived very happily in this house.* *...the woman was thrown out of the house because she didn't have money and was crying, I would settle her in one of the houses I built myself.* *...I would be a civil engineer building smart houses for my family to live in...* *The robot I made to help Vesile aunt, who is old and can't walk from our summer home, I will find a solution for people with physical, vision, and*

	hearing disabilities to live more comfortably; I will make a robot that plays football with children. Alex is a robot cleaning up the kitchen, and people won't lose time in traffic with the flying skateboard I produce; people will very easily reach every place with my software program for transporter technologies.

Three basic factors were identified in choosing engineering as a career in the students' stories and CCT. These are helping people (disabled, elderly, poor, orphaned), meeting the needs of students about things they lack in life or miss (home, car, money), and gaining acceptance and reputation. For this reason, it was identified that the engineering branches they were interested in (software, computer, civil, electronic, environment) were associated with these 3 factors.

Discussion, Conclusion and Recommendations

The findings of the study are discussed with the literature under sub-titles below to examine the changes in the students' perceptions of engineers, engineering as a profession, learning of engineering design processes, awareness about engineering branches, and their future career choices through engineering design process activities with the 5E learning model for disadvantaged students.

Choosing engineering as a career and learning of engineering branches

Based on the results of CCT, students who wanted to be an engineer before the implementations chose just two engineering branches that are the most popular engineering types in our country: civil engineering and computer engineering. The reasons for these results can be explained by the observations of researchers before the project and through conversations with students during their break times between activities. In our country, the richest engineers are generally civil engineers, and computer engineers can easily find jobs. There is also much news in the media about these two kinds of engineering, as similarly stated by Knight and Cunningham (2004). It can be concluded that the student's choice of civil and computer engineering was related to economic gains. Students who did not want to be an engineer chose jobs like police, soccer player, cook, and mechanics at high rates. These students live in a house similar to one where a family can live, with access to TV, computers, and well-designed furniture. In each house, five students live together with their guardian, and students generally call them brother or sister in this house. Guardians are mostly high school graduates. Also, apart from three students who were orphans, most had poor or divorced families or family members in prison. Based on both post-test DAET and CCT, the students added new engineering branches such as biomedical and aerospace engineering to their choices, and the proportion selecting software, chemical, environmental, and electrical-electronic engineering branches increased. This indicates that the engineer design process activities based on different kinds of engineering helped the students learn about engineering branches. The proportion of students who did not want to be an engineer did not decline sharply, but instead of choosing police soccer player, or cook, they chose "I don't know" more often. Against the student's family background as mentioned earlier (Bourdeu, 1990, Weininger & Lareau, 2003) to eliminate barriers to STEM in schools (Lowrie, Downes & Leonard, 2018), performing STEM activities out of school contributes to career choices related to science and mathematics for disadvantaged students (Altan & Koroglu, 2019; Baran, Bilici, Mesutoglu & Ocak, 2016; Baran, Bilici, Mesutoglu & Ocak, 2019; Mohr-Schroeder et al., 2014; Shahali et al., 2015; Tseng, Chang, Lou, & Chen, 2013). In other cases, they have no role model in their social life for being an engineer or no one with a similar background to them who has succeeded in becoming an engineer (Bandura, 2001; Schunk and Usher, 2019) to motivate them and help them achieve these tasks. To minimize role model factors in a positive way, most of the activities such as chemistry, agriculture, biomedical, architecture, electric, and mechanical engineering activities were done under the guidance of engineers. Therefore, any kind of role model motivates students' efficacy for STEM activities (Gladstone & Cimpian, 2021). Again, the reason for choosing "I don't know" can be explained by Bandura's social cognitive theory stating students prefer tasks which involve previous successful experiences (Bandura, 1997; Klassen & Usher, 2010; Schunk & Usher, 2019). In the sample group of students with low marks in science and mathematics courses and no experience of STEM, they did not have enough self-efficacy to choose engineering as a career even though they eliminated soccer players police, or mechanics from their career choices. The expectations and values of students may affect their career choice to be an engineer in the future (Wigfield & Eccles, 2002). Their stories, which were written at the end of the implementation, contain their reasons for becoming an engineer. These reasons were very emotional and engrossing with three reasons for their choice of helping people (disabled, old, poor, orphan), meeting the needs of students for things they lack or miss in their lives (house, car, money), and wanting to be accepted and respected by society. It is a thought-provoking result that the students considered spending the money they will earn from the engineering profession to live with their friends or to increase their living standards. Their statements are very meaningful in that they see that the engineering profession will enable them to raise their living standards not only for themselves but also for the people around them. This was a vital outcome of STEM activities for students with different demographic and achievement backgrounds. Moreover, students who did not want to be an engineer at the beginning of the implementation did not know what an engineer is, what engineers do, or how engineers work (Compeau, 2016; Karatas, Micklos, & Bodner, 2011).

Changes in the students' perceptions of engineers and engineering as a profession

According to Knight and Cunningham (2004), engineering is understood to include train operators and people building houses and making car engines. Images of engineers were generally male, working with hammers, wrenches, cars, trains, and computers, and wearing hard hats. In the present study, we used an adapted form of the same DAET to measure the changes in the perceptions of students. According to Efron (1969), perception is a person's primary form of cognitive contact with the world around them, so the image of engineers changed from non-human to human, and protective equipment like helmets and goggles were seen in their post-test drawings. They wrote that engineers build apartments, repair cars, produce computers, and design projects in their explanations about what engineers do in the pre-test. The statement that 'engineers can produce everything' had the highest rate in their answers for both post-test DAET and stories, different from the study by Cunningham et al. (2014). Also, both male and female students changed the gender of engineers from male to female and changed the workplace from outside to inside and undefined places. However, the students noted that the work and workplaces of engineers changed depending on the branch of engineering. During the implementation, different locations like a laboratory, factory, garden, mosque, etc. were used. This may also affect the students' determination of the workplaces of engineers. While students drew computers, furniture (e.g., table, chair), bridges or construction materials, and flying vehicles in their pre-test drawings, they added project drafts, robotics, and laboratory equipment (e.g., beaker, flask, baguette), technological objects like TV or radio, waste materials and rockets in their final drawings. The different kinds of engineering activities improved or changed their engineering perceptions related to the tools used. Furthermore, they called engineers as experts and researchers and used words like facilitating life and earning money. During the post-test, their words diversified to include producer, construction, earning money, explorer, product developer, contributing to science and humanity, and integration of science and mathematics. The sentences related to the integration of science and mathematics are vital because the students had a limited conception of science and mathematics. This minimal realization proved our 5E learning model for the designed activities worked in practice (Schnittka & Bell, 2011). In the other research, the 5E integrated STEM-based activities increase the students' attitudes related with science while decreasing their science anxiety (Bozkurt, Altinoz, & Acikyildiz, 2023)

In sum, the perceptions of students can be changed by many EDP activities which involve students being active learners, and their perceptions can be improved easily with out-of-school activities without any formal assessment rather than in school (Bell et al., 2009; Simsek, 2011; Zaff & Redd, 2001).

Learning of engineering design processes

The results in this section were synthesized from engineering activities and what engineers do in pre-DAET and post-DAET tests and from the stories. While words relating to building and production were expressed in pre-test, research, making design, experimenting, and contributing to science were included in the post-test as engineer activities. They identified EDP by using words like design, invention, production, repair, and building construction in pre-tests, but they converted to words like design, invention, production, handmade, repairing, building activities, experiments, testing, knowledge production, and observation on the post-test. Depending on their words, we can conclude that students learned the stages of EDP concerning what engineering is and how engineers work (Compeau, 2016; Karatas, Micklos, & Bodner, 2011, Lotteroperdue et al., 2015). In their stories, statements like 'I made a pencil holder I designed myself', '… to help aunt Vesile who can't walk to…' and 'with the flying skateboard, I produce' were included in the design, production, and problem definition stages. Therefore, the activities improved students' problem-solving skills for real-life problems and designing creative and innovative solutions to their real-life problems such as "... producing robot which plays with children, flying skateboard (English, Hudson, & Dawes, 2013).

The engineering education activities with the 5E learning model related to the science curriculum completed outside of school with engineers and science educators affected the desired goals of the research. But the most effective result is that students discover their abilities and experience what they can achieve. When the students experienced these activities, improvements in their self-beliefs about being an engineer were observed. These are vital outcomes of STEM activities for disadvantaged groups to ensure they feel hopeful about their future. It was believed that STEM would reduce inequality in education, but the sustainability of STEM education with the disadvantaged group is another vital point for longitudinal outcomes. At the beginning of the study, working with this sample group was very difficult because they had limited experiences in laboratory, factory, or garden, and out-of-school learning and had negative attitudes to science and mathematics. Therefore, the recommendations for future research were given below.

- Students in Türkiye should experience activities outside of school from the early years in well-designed activities.
- The face-to-face interviews with students during the implementation will be used for future research to obtain results about EDP in detail.
- Designing activities with engineers and architects is very effective for creativity and for innovative laboratory experiments. However, not all the engineers were as competent in teaching lessons as teachers with pedagogical experience in this age group.
- Engineers may be introduced at the beginning of activities as role models.

Policy Implications

The study is produced from the project in which STEM applications with 5E learning model were applied to sixty students who are under the protection of the government (orphans) to see their perceptions of engineers, engineering as a profession, learning of engineering design processes (EDP), awareness of engineering branches, and their future career choices. At the beginning of implementations, student's carrier choice was restricted by their models around us, characters in series on TV, and their academic success specially in science and mathematics lectures were very low. The other problem they had limited self-confidence and self-efficacy to do activities related with engineering design processes. During the implementation period day to day, they realized their skills and as they successfully completed activities, their career choices, self-perceptions, and academic achievements were nurtured by a positive influence. Therefore, the study is important to see the effects of STEM education on disadvantaged students offering them pathways to future opportunities and contributing to the pursuit of social justice. The study is an experimental study consisting of our experiences that students discovered their abilities and experienced what they can achieve and feel hopeful about their future. Therefore, it is necessary for education policymakers to prioritize STEM education for disadvantaged students by fostering collaboration between education faculty. This collaboration could involve science teacher candidates implementing STEM activities under the guidance of advisors during social responsibility projects, particularly during out-of-school periods.

Conflict of Interest

There is no conflict between authors.

Funding Details

This research was produced by the "Step by Step to be an Engineer" project founded by Scientific and Technological Research Council of Türkiye (TUBITAK) Project no: 118B462 and 119B932 and produced by the permission of it.

Ethical Statement

The study reported in this paper has obtained ethical approval from the Survey and Behavioral Research Ethics Committee. The Higher Education Institute (YOK) Scientific Research and Ethics Regulation were followed. In this article, the rules of scientific research and publication ethics specified in the field.

Credit Author Statement

Ganime Aydın; Designing and writing of project, determining, and controlling implementations of STEM activities, communication with Government Office, university, factory etc. for permissions and planning and controlling budget, writing of literature and discussion conclusion.

Mehpare Saka: Designing the research method, collecting and analysis of data, design of STEM activities and implementations of them on students.

Jale Cakıroglu: Conceptualization of ideas, formulation of the overarching research goals and aims and decision of reach measurement tools, analysis of data, review and editing of article.

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