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Meeting the Challenges of STEM education in K-12 Education through Design Thinking

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Abstract

This paper explores the ways in which the design thinking (DT) approach can be utilized in addressing the challenges of STEM education in K-12 education. The study is based on an extensive literature review about STEM education and the DT approach, and exploratory research conducted to understand the challenges and needs of STEM education in Turkey. The findings from the exploratory research indicate that STEM education in Turkey has significant challenges: The teachers have difficulties in integrating diverse disciplines and technologies into their STEM activities; the training programs for teachers and the general education for students encourage a result-oriented mindset rather than a process-oriented approach; and the teachers have difficulties in following the problem-solving process based on the engineering design approach. Furthermore, collaboration among teachers for developing and implementing STEM activities needs to be addressed as an important issue in terms of scheduling. Additionally, there is a need to develop STEM activities appropriate to the educational level of students. Equipping teachers with skills and knowledge appropriate to their new roles as guides and mentors should also be considered as a significant issue concerning the implementation of STEM activities. The study concludes that the DT approach as an interdisciplinary, collaborative, and human-centered problem-solving process can support STEM education and resolve the stated challenges. This study also suggests that there is a need to develop a customized DT approach for teachers, non-designers, so that they can easily apply their expertise to STEM education.

Keywords

STEM education, design thinking, design thinking for educators, design thinking in education, design thinking in STEM education in Turkey, design thinking in K-12 education

Introduction

STEM education aims to integrate Science, Technology, Engineering, and Mathematics disciplines, and has become widespread in Turkey in the last decade. However, the local and international works of literature show a tendency towards including a wide range of disciplines in STEM education (Ministry of National Education, 2016; Carrell, Keaty & Wong, 2020). There is also a need to design and implement the STEM activities appropriate to the educational level of students (Bruce-Davis et al., 2014; Uştu, 2019). Both works of literature further highlight the need for collaboration among teachers for the implementation of STEM education (Margot & Kettler, 2019; Akgündüz et al., 2015).

Design thinking (DT) is defined as a method to identify and solve problems in a human-centered way, and it has been applied in K-12 education to address a variety of challenges (Tran, 2017). This paper explores how the DT approach can be utilized to support STEM education and resolve the challenges it presents. With this purpose, the study is based on a literature review about STEM education and the DT approach, and exploratory research that reveals the challenges and needs of STEM education in Turkey. This paper concludes by suggesting ways on how the DT approach can be used in STEM education.

STEM education

The acronym “STEM” stands for the first letters of science (S), technology (T), engineering (E), and mathematics (M), and in the literature, there are multiple definitions or perspectives on STEM education. However, common characteristics of STEM education can be found around the following: engaging students in real-world problem-solving, employing student-centered pedagogies, connecting STEM disciplines, and supporting the development of students’ 21st-century skills (Moore et al., 2014).

Although STEM may be perceived as a simple acronym, many variants of STEM approaches that tend to integrate non-STEM disciplines into STEM education have been discovered in both works of literature. For example, in international literature, some scholars bring STEM together with humanities as HDSTEM (Carrell et al., 2020), in Turkey, some scholars emphasize visual arts by integrating ‘A’ into STEM as STEAM (Okka, 2019). Moreover, the National Science Foundation (NSF, 2015) defines STEM fields broadly, including not only common STEM fields, but also psychology, social sciences, economics, and sociology. In both works of literature, the place of a wide range of disciplines including humanities or arts education in STEM education is also questioned (Carrell et al., 2020; Daugherty, 2013; Ministry of National Education, 2016). This situation raises new questions about which disciplines STEM education includes and how non-STEM disciplines can be integrated into STEM education.

Currently, there is no extended national curriculum for STEM education in Turkey. Only changes have been executed in the national curriculum of primary and secondary school science education and technology and design education for the implementation of STEM education (Turkish Science Education Curriculum, 2018; Turkish Technology and Design Education Curriculum, 2018). According to this, the technology and design education curriculum focuses on the design-based product development process, based on creativity, innovation, and user-centered design. In the adoption of STEM education in Turkey, the technology and design teachers are further proposed to be trained for being mentors to other teachers (Ministry of National Education, 2016). In the science education curriculum, students are expected to develop solutions for daily life problems related to the subject within the scope of Engineering and Entrepreneurship Practices in every unit.

There are inequalities in the education system in Turkey. For example, socio-economically disadvantaged students go to schools that are considered low in performance and quality. When the competencies of 8th-grade students in mathematics are analyzed regionally, the rate of students who are below the basic competency level is quite high throughout the country; particularly in the eastern part of Turkey (Oral & Mcgivney, 2014). In connection with these problems, Uştu (2019) emphasizes the importance of preparing STEM activities which take into account the academic and social levels and the school contexts of students as well as the specific region in Turkey where the students are located. Furthermore, in the international literature, it has been discovered that teachers modify the existing STEM units or design new ones for the level of knowledge and skills of students (Bruce-Davis et al., 2014). Considering both works of literature, there is a need to design and implement the STEM activities appropriate to the educational level of students.

Although both works of literature highlight the need for interdisciplinary collaboration with teachers in STEM education, teachers need to allocate extra time to collaborate and prepare the materials (Margot & Kettler, 2019; Akgündüz et al., 2015; Okka, 2019). Moreover, the use of technology in STEM education is stated to be vague in international literature. Ellis et. al. (2020) point out the significance of matching the technology selection with the desired learning outcomes and considering how these are used within the context of the educational purpose. In the light of these points, analyzing students' skills, interests, and learning styles is important to choose the appropriate technology for STEM education.

Design thinking approach

The design thinking (DT) approach is not a new concept for designers and can be traced back to Herbert Simon's seminal work "The Sciences of the Artificial" which was first published in 1969 (Hassi & Laakso 2011). The DT approach has gained popularity through the efforts of the Institute of Design at Stanford (d.school), and American design firm IDEO, and particularly after Tim Brown, one of the IDEO's chairs and designers, wrote "Design thinking" in the Harvard Business Review (Brown, 2008; Tran, 2017). Currently, DT is applied in multiple contexts including education, management, engineering as an interdisciplinary, collaborative, and human-centered problem-solving process. The common purpose of applying the DT approach is to foster people's creative thinking skills and develop innovative, creative solutions to the problems by investigating the user's/stakeholder's needs (Leifer & Steinert, 2014; Lor, 2017; Chon & Sim, 2019).

Recently, DT has been applied in K-12 education, and one of the most important reasons for the use of the DT approach in the field of education is its human-centered principles and their applicability in the field of education (Diefenthaler, Moorhead, Speicher, Bear & Cerminaro, 2017). In both local and international works of literature, the focus of using DT in education has been on curriculum and instructional design, solving the challenges of education, improving students' skills, and training teachers. Considering the international literature, it has also been used in organizational development in the educational institutions, design of learning environment, and solving students' problems (Table 1). According to the literature, using the DT approach in education can provide numerous benefits to students and teachers in their learning and teaching (Tran, 2017).

Table 1. The areas using design thinking in the educational context

	International literature	**Local literature**
Curriculum and Instructional design	Tran, 2017	Şahin, 2018
Solving the challenges of education	Loescher et al., 2019	Çetin & Aydemir, 2018
Improving skills of students	Lor, 2017	Atacan, 2020
Teacher training	Diefenthaler, et. al., 2017	Çetin & Aydemir, 2018
Organizational development in the educational institution	Loescher et al., 2019	
Learning environment design	Tran, 2017	
Solving problems of students	Shadow a student, n.d.	

As an innovative and creative process, DT's approach to problem-solving can serve the purpose of STEM education that focuses on inquiry-based, creative, and hands-on learning (Reinking, &

Martin, 2018). International literature indicates that the DT approach is used to train teachers to integrate STEM education into school (Diefenthaler, et. al., 2017), and evaluated under student-centered pedagogies used in STEM education (Ellis et al., 2020). In both works of literature, it is also utilized as a problem-solving process in the STEM program, and K-12 education (Diefenthaler, et. al., 2017; Şahin, 2018; Atacan, 2020).

In the literature, there are multiple DT approaches that involve several steps, design practices, or methods. Although there are some similarities in the number and the name of the process stages, the typical DT approach has three to six stages, and they are based on human-centricity, interdisciplinarity, ideation, and experimentation (Efeoglu, Møller, Sérié & Boer, 2013). Among these approaches, Brown's DT approach as IDEO's method of working with design and innovation can be regarded as a milestone due to being forwarded as a problem-solving process that can be used by everybody, not just designers (Brown, 2008). Brown (2008) divides the DT process into three primary stages. In Brown's method (2008), while *inspiration* means researching to understand the problem and identify the insights, *ideation* means generating ideas, developing them through prototypes, and testing the possible solutions. The last stage of *implementation* means developing an action plan to put the solution into the market.

Three DT approaches are mostly used in the education context: d.school at Stanford University, HPI's (Hasso Plattner Institut), and IDEO's (Design thinking for Educators) DT approaches. The DT process, used since 2005 at the d.school at Stanford University (n.d.), consists of five stages: *empathy, define, ideate, prototype*, and *test*. The DT process, used at HPI (Hasso Plattner Institut) (HPI, n.d.) since 2008, has six stages: *understand, observe, point of view, ideate, prototype*, and *test*. The DT process, used since 2012 in IDEO (Design thinking for Educators) (2012), includes five stages (*discovery, interpretation, ideation, experimentation,* and *evolution*) and a zero-step (*define a challenge*).

When illustrating these three DT approaches under the Brown (2008) three-stage process (Table 2), it is discovered that all DT approaches have similar stages based on Brown's method. The main difference is based on whether having the *implementation* stage in which the iterative process of developing solution is ended. For example, only IDEO (2012) has the *implementation* stage, while others have only *inspiration* and *ideation* stages. HPI also has a DT process in which three steps (*ideate, prototype, and test*) are the same as the d.school process. Moreover, in the three DT approaches, the functions of the stages are similar despite having different names, and some of them being separated into two parts. For instance, the *empathy* in d.school and *discovery* in IDEO have nearly the same function, but, in the HPI process, the role of these stages is divided into two as *understand* and *observe* stages. The function of IDEO's *experimentation* stage is also divided into two; both in HPI and d.school processes as being a *prototype* and *test* stages. It can be concluded that DT approaches executed in the education field have similarities with each other except having changes about the names and the number of the stages. Compared to Brown's approach, having more stages makes the DT processes more tangible for people with a non-design background owing to the division of functions.

Table 2. Comparison of d.school, HPI, and IDEO design thinking approaches considering Brown's design thinking approach

<table>
<tr><th>DT Approach</th><th colspan="7">Stages of Design Thinking</th></tr>
<tr><td>Brown's (2008) DT approach</td><td colspan="3">Inspiration</td><td colspan="3">Ideation</td><td>Implementation</td></tr>
<tr><td></td><td colspan="3">Researching to understand the problem and identify the insights</td><td colspan="3">Generating ideas, developing them through prototypes, and testing possible solutions</td><td>Developing an action plan to put the solution into the market</td></tr>
<tr><td>d.school's DT approach (d.school at Stanford University, n.d.)</td><td colspan="2">Empathy</td><td>Define</td><td>Ideate</td><td>Prototype</td><td>Test</td><td></td></tr>
<tr><td></td><td colspan="2">Empathizing with the people you design to understand what is crucial for them, and how they interact with their environment</td><td>Synthesizing the collected data into needs and insights to define a problem statement</td><td>Generating multiple ideas</td><td>Turning ideas into physical forms through prototypes</td><td>Getting feedback from the users about the prototype and developing it to reach better solutions</td><td></td></tr>
<tr><td>HPI's DT approach (HPI, n.d.)</td><td>Understand</td><td>Observe</td><td>Point of View</td><td>Ideate</td><td>Prototype</td><td>Test</td><td rowspan="2"></td></tr>
<tr><td></td><td>Collecting data related to the theme/ problem through research</td><td>Developing an understanding of the problem and users by doing qualitative research</td><td>Sharing of the knowledge collected in the previous stages, combining them to identify needs and insights, and reaching a problem statement by developing a point of view</td><td>Developing ideas by brainstorming on the question generated during the POV stage, and selecting the best ideas</td><td>Building the selected idea through prototypes</td><td>Getting feedback from the users for the prototype, and revising it or the whole concept to reach better solutions</td></tr>
<tr><td>IDEO's (Design Thinking for Educators) DT approach (IDEO, 2012)</td><td colspan="2">Discovery</td><td>Interpretation</td><td>Ideation</td><td colspan="2">Experimentation</td><td>Evolution</td></tr>
<tr><td></td><td colspan="2">Creating a common understanding of the problem within the team by sharing your knowledge, reviewing constraints, defining the target group, and doing qualitative research for collecting data</td><td>Transforming the data into insights by sharing and documenting your findings, and making sense of them with identifying themes, insights, and opportunities</td><td>Generating ideas by brainstorming and selecting the promising one/ones</td><td colspan="2">Making prototypes, sharing them with other people, and getting feedback about them</td><td>Planning further steps for production and documenting the success criteria and the production process.</td></tr>
</table>

Exploratory Research

Within the scope of this study, exploratory research has been conducted to understand the challenges and needs of STEM education in Turkey. This part had two phases: conducting interviews with teachers and the school principals and participating in a workshop about STEM education as a participant-observer. In this study, considering both national and international works of literature, STEM is used as an umbrella term to refer to all disciplines.

Phase 1: Conducting interviews with teachers and school principals

To understand the state of the art of STEM education in Turkey, from 14 February 2017 to 24 March 2017, a total of 11 interviews were conducted with school principals, and teachers from several disciplines in four private schools that give STEM, STEM+A, or STEAM education (Table 3). In the selection of the institutions for the exploratory research, their varied approaches to the perception of STEM education were taken into account to get rich data and insights.

Table 3. Institutions and participants in phase 1

School	Educational Approach	Participants
School A in Samsun (kindergarten, primary school)	STEM	mathematics/science teacher, school principal
School B in İstanbul (kindergarten, primary and secondary school)	STEAM	school principal, science, Turkish and kindergarten teachers
School C in Samsun (kindergarten, primary and secondary school)	STEM	science teacher, school principal
School D in Samsun (kindergarten, primary and secondary school)	STEM+A (STEM with Arts)	visual arts, robotics, and science teachers

Methodology

In this phase, qualitative research methods were utilized, and data were collected through semi-structured interviews with teachers and school principals (Table 4). The interview questions were prepared under four main groups: teachers' understandings about STEM education, the development, and implementation of STEM activities/curriculums, and teacher training about STEM education.

Table 4. Data collection methods in phase 1

Exploratory Research / Phase 1	Data Collection Methods	Number of Interviews	Duration of Interviews	Date
Conducting interviews with teachers and school principals	Interview	11	20-45 min.	14 February - 24 March 2017

All interviews were conducted in Turkish, and seven interviews were recorded. The rest of the interviews could not be recorded because the interviewees did not give consent. These interviews were recorded by taking quick notes during the interview, and the notes taken were reviewed after each interview. In phase 1, the duration of the conversations was between 20 to 45 minutes.

To start the analysis of the data, the digital audio files of all interviews were transcribed and organized into individual folders under the name of schools. The school names were coded as "School A" or "School B" to hide their real names. Then, the data has been analyzed based on the template analysis method which is a style of thematic analysis. The core of template analysis is developing a list of codes representing themes defined in the data (King, 2004). In this research, the initial template was defined based on the interview questions as follows:

- What STEM education means for teachers
- How STEM activities/curriculums are developed
- How teachers learn STEM education
- How STEM education is implemented in Turkey

Starting with the initial template, the data were coded through a computer-assisted qualitative data analysis software, MaxQDA. During the process of coding, the revision was made on the initial template. For instance, under the main code of "What STEM education means for teachers", it was first discovered that non-STEM disciplines are included in STEM education. Later, it was understood that this integration is made either purposefully or unconsciously because some teachers realized that they included non-STEM disciplines in their activities while talking about the activities they implemented (Table 5).

Table 5. The evolution of the coding process

What STEM education means for teachers		
including non-STEM disciplines	• including non-STEM disciplines purposefully 1. "S" in STEM means all disciplines in Turkish translation 2. the engineering design process is the "Art" side of STEM education 3. the visual arts are integrated into STEM purposefully • including non-STEM disciplines unconsciously	including non-STEM disciplines either purposefully or unconsciously

After reading the text many times, the final template (Table 6) was created, and findings were illustrated by making direct quotations from participants' views.

Table 6. Four pre-established codes with refined sub-codes

What STEM education means for teachers	**How teachers learn STEM education**	**How STEM activities/curriculums are developed**	**How STEM education is implemented in Turkey**
including non-STEM disciplines either purposefully or unconsciously	getting training from the STEM research centers	having a STEM+A curriculum • collaboration: revising and developing STEM+A curriculum collaboratively with teachers of the same discipline in all schools	implementing STEM education in which discipline integration is organized around a common theme

the perceived characteristics of STEM education by teachers	collaboration: getting training/assistance from the STEM experienced teachers	collaboration: creating, revising, and developing STEM activities/projects with all teachers or STEM/STEAM experienced teachers	implementing a STEM+A curriculum
	self-education		implementing project-based STEM education under a club activity
	getting in-house education		implementing the story-based projects through books with team teaching (collaboration in teaching)
			teaching the lessons with problem-solving activities
			utilizing the engineering design process as a problem-solving process
			the challenges of implementing STEM education in Turkey

The Findings of Phase 1

What STEM education means for teachers

The findings indicate that the representation and visibility of disciplines vary in implementation. It was observed that in some cases the disciplines were “there”, but they were not integrated purposefully by the teachers. For example, the science teacher at School C claimed to implement STEM education by focusing on four STEM disciplines. Upon my question about whether he uses non-STEM disciplines in his activities, he recalled that he facilitated a discussion between medical doctors and students in one of his activities and realized that topics from Turkish literature were already integrated into the activity. He also remembered another activity in which English as a foreign language had also an active role in students’ presentations about the solar system.

For School A and B, “S” in STEM represents all branches of science. This perspective may be due to the translation of “S” or “Science” (*Bilim* and *Fen Bilimi*) into Turkish since in Turkish, it means both “all branches of sciences” including formal, natural, social, or applied sciences, and “natural sciences” including physics, or biology. According to the science teacher in School B, the engineering design process is the “Art” side of STEM education because it includes drawing and modeling activities. School B prefers to call it STEAM instead of STEM. Furthermore, in School D, the visual arts are integrated into STEM education purposefully and called STEM+A. As a result, whether it is called STEM, STEAM, or STEM+A, non-STEM disciplines are included in STEM education in these schools. This finding also verifies the related literature about the tendency to incorporate non-STEM disciplines into STEM education (NSF, 2015; Ministry of National Education, 2016).

> *In the United States, "S" in STEM is handled as "science" and it includes all branches of sciences, therefore the visual arts are also involved in this. They approach it holistically and I believe that it is the right way. While we are practicing this here, we have the same mindset. We name it "STEM". According to the training we received, and academically indeed, STEM does not include art; it includes four basic disciplines (Science, Technology, Engineering, Math). But in Turkey, so in the Turkish language, the letter "S" referring to Science in STEM has alternative meanings: "Science as all branches of sciences" and "Science as natural sciences". (Science/Mathematics teacher in School A)*
>
> *Art itself takes place in STEM, however, the school administration told us to consider "art" additionally. We primarily attempted to achieve "STEM" but then we realized it was "STEAM" what we already practiced. In other words, it was for including "art" in this process. To conclude, the ones practicing STEM state that STEM already includes "art" and engineering of this process means the field of art. Yet, our school asked for emphasizing the "art" more. (Science teacher in School B)*

Furthermore, the perceived characteristics of STEM education were defined. STEM education involves two types of interdisciplinary collaboration: the collaboration of teachers for preparing and implementing STEM activities, and the collaboration of students during the implementation of STEM activities. STEM education further includes teamwork, hands-on practice, learning by living, inquiry-based, project-based, and student-centered learning.

How teachers learned STEM education?

Teachers in Schools B and A usually receive training from teachers with STEM experience, and from the same STEM research center at University X, in which training focuses on science and mathematics disciplines, code-writing (called robotics), and a maker workshop. Teachers at School A adapt this training by integrating "Art" into STEM education to create their school curriculum. School B also invites STEM experienced teachers from other schools to get assistance from them. Therefore, collaboration among teachers has a significant place in learning how to execute STEM education. In School D, the science and visual arts teachers have no STEM education. However, a robotics teacher, who is also a computer education and instructional technology teacher, takes in-house education every year to learn the changes in the curriculum and the related knowledge about these changes. In School C, the science teacher implements STEM education through self-education or in consultation with friends who know STEM education.

How STEM activities/curriculums are developed?

Except for School D, others do not have a ready-made STEM curriculum. Therefore, teachers create and revise their STEM curriculums collaboratively with all teachers, or they sometimes get assistance from experienced teachers. For instance, in School A, teachers create their interdisciplinary STEM curriculum collaboratively. In School B, a kindergarten teacher assists other teachers in preparing STEAM activities. In School C, teachers prepare STEM activities collaboratively under the guidance of a STEM experienced science teacher. Teachers also contribute to the revision of the STEM curriculum. For instance, in School A, teachers from all disciplines share their experiences regarding the implementation of STEM education in each school term. Then, necessary changes are implemented in their STEM curriculum. Moreover, School D is one of the schools owned by an educational institution, and teachers of the same discipline in all schools belonging to this institution have regional meetings to define the problems regarding the STEM+A curriculum. Later, the feedback collected in these meetings affects the development of the existing curriculum. As a result, the significance of collaboration among teachers is discovered to create, revise, and develop the STEM activity/curriculum. This finding also confirms the literature pointing to the need for teachers' collaboration for the implementation of STEM education (Margot & Kettler, 2019; Akgündüz et al., 2015).

How STEM education is implemented in Turkey?

There are variations at schools in terms of the STEM integration to their education. Discipline integration in School A is organized around a common theme across different disciplines. For this reason, concepts are taught simultaneously in different disciplines/lessons under a common theme.

> *The students are now taking life sciences lesson, in other words, purely "science" lesson; -I am pointing out this for primary classes-, they are being taught this subject in this lesson because it is common with the one which is taught in a music lesson. To exemplify, if the subject "the family" has been taught in life sciences lesson, then a song about the family in a music lesson, a drawing about the family in a painting lesson, and a course about the number of family members in math class are being practiced. (Science/Mathematics teacher in School A)*

All schools implement project-based STEM education under a club activity that aims to enter competitions. According to the robotics teacher in School D, these competitions consist of two parts. The first part is the project part that includes defining and solving a problem by students, and the second part is called robotics and includes code writing under the given theme by using Lego sets. In School B, the story-based STEM projects are also executed with team teaching. In these projects, discipline integrations are made through books of Turkish, English, and social science lessons which have similar or parallel subjects in their contents. Teaching lessons with problem-solving activities based on STEM education is further implemented with individual teaching in science and math lessons. In kindergarten, discipline integration is organized around a common theme. School D also uses its own STEM+A curriculum in the lessons. Moreover, STEM education in School C is implemented in the teaching of science lessons with problem-solving activities.

> *We are going forward with story-based projects instead of lessons in secondary school. The subject in the social science lesson of secondary classes was "Anatolian Civilizations". The sites of Anatolian civilizations and their historical genealogy were taught with their mathematical aspects, then the "Technology" discipline continued with researching in a computer lesson. Also, the students realized the engineering process by trying to build up their prehistoric cottage in the drawing and painting studio. They wrote and performed a theatre play for art and literature. In this play, they were inspired by ancient civilizations and they designed costumes and so the art as a discipline was exhibited with the story of the play. (School Principal in School B)*

Moreover, it was discovered that the engineering design process as a problem-solving process is mostly utilized in STEM activities. According to teachers, it includes problem definition, researching, designing, evaluating, and testing a product, and iterating the entire process until reaching a final product.

Teachers further indicated some challenges for implementing STEM education. First of all, due to the existence of national exams and curricula, teachers have to allocate extra time to collaborate in planning and implementing STEM education, particularly for the use of technological tools in STEM projects. Additionally, the changing role of teachers from implementer to guide has been considered as a significant issue to be addressed for the implementation of STEM education with younger students. Having less educated teachers about STEM education is further stated as one of the problems of implementing STEM education. During the interviews, the differences in technology perception in STEM education were also discovered. For example, for some, incorporating technology into STEM education involves using an online program to make a quiz, create a research journal, or research for a project, while for others, it involves using scissors when building a model. Furthermore, the Turkish and Social Sciences teachers consider STEM education difficult since they cannot figure out how to create activities or projects, and how to integrate technology in STEM education. This finding also confirms the relevant literature on the uncertainty of technology use in STEM education (Ellis et al., 2020).

Phase 2: Participating in a workshop about STEM education as a participant-observer

The second phase of the exploratory research involved attending a two-day STEM workshop as a participant-observer on March 04-05, 2017 to gain insight into the teacher training delivered at the STEM research center. The workshop was organized and facilitated by a research assistant at Y University STEM research center in Ankara to teach science teachers STEM education and the engineering design process as a problem-solving process. There were also mathematics and primary school teachers in the workshop. The workshop participants were approximately 40 teachers who work in primary or secondary schools in Turkey. On the first day of the workshop, there were also four engineers from diverse disciplines to introduce engineering. In this two-day workshop, I aimed to observe how STEM education is taught, how the activities are implemented on teachers, the reactions of teachers and difficulties that teachers faced during the workshop, and the implementation of the STEM activities. Although I participated in the workshop as a participant-observer, I had the chance to have interviews with two teachers who participated in the workshop during the breaks.

On the morning of the first day, engineering and STEM education were presented by the facilitator. Later, a facilitator-led discussion took place among four engineers and teachers on engineering and its place in education. In the afternoon, the first STEM activity to design a weightlifting mechanism based on the working principle of a wind turbine was implemented by the facilitator to teachers. After the presentation of the results of the first activity given by teachers, the first day of the workshop ended. On the second day, a presentation including the engineering design process as a problem-solving process was given. During the presentation, there was a discussion between the teachers and the facilitator about the implementation and challenges of STEM education. Later, the second activity was implemented on teachers to design a space vehicle that would carry both astronauts and weight while descending from the ramp. The workshop ended after the results of the second activity were presented by the teachers.

Methodology

In this phase, data were collected through participant observation, discussions of teachers among themselves and with engineers, and interviews of two teachers (Table 7). The interview questions of phase 1 were asked in teachers' interviews in phase 2.

Table 7. Data collection methods in phase 2

Exploratory Research / Phase 2	**Data Collection Methods**	**Number of Interviews**	**Duration of Interviews**	**Date**
Participating in a workshop about STEM education as a participant-observer	Interview, Discussion, Observation	2 (mathematics and primary school teachers)	15 min. for each person	04, 05 March 2017

Interviews with mathematics and primary school teachers were conducted in Turkish, and they could not be recorded because interviewees did not give consent. These 15-minute interviews were recorded by taking quick notes during the interview, and the notes taken were reviewed after each interview. Moreover, discussions of teachers among themselves and with engineers during the STEM workshop have been recorded. To start the analysis of the data, the digital files of observations, discussions, and interviews were organized into individual folders. The collected data were analyzed to generate the final template (Table 8) according to the template analysis method by using the previous initial template and following the same data analysis procedure in phase 1.

Table 8. Four pre-established codes with refined sub-codes

What STEM education means for teachers	**How teachers learn STEM education**	**How STEM activities/curriculums are developed**	**How STEM education is implemented in Turkey**
including non-STEM disciplines	implementing the ready-made STEM activities on teachers to teach STEM education	implementing the ready-made STEM activities instead of creating and implementing their own	the challenges of implementing STEM education in Turkey
the significance of engineering in STEM education	providing teachers with STEM education without considering the differences in education level in primary and secondary schools		
the perceived characteristics of STEM education by teachers			

The Findings of Phase 2

What STEM education means for teachers

Considering the findings, the perceived characteristics of STEM education were defined to understand teachers' perceptions about STEM education. Accordingly, STEM education involves teamwork, inquiry-based learning, and two types of interdisciplinary collaboration: the collaboration of teachers for the implementation of STEM education, and the collaboration of students during the implementation of STEM activities. The findings also indicate that non-STEM disciplines are included in STEM education by teachers.

> *STEM includes all branches; not only science or math, they do not stand separately. It involves collaborative work. I think that STEM means improving scientific processes and STEM education can also be used in Turkish lessons. (Primary school teacher)*

Furthermore, the importance of engineering in STEM education was discovered. According to the findings, engineering means creativity, working in teams, offering multiple solutions to a problem, and learning from failure. It was also stated that an engineer should know about inquiry-based problem-solving, interdisciplinary collaboration, and have social skills that include developing empathy for others. Moreover, the common steps of engineering design processes were defined from the findings; problem definition, designing, evaluating, and testing a product, and iterating the entire process.

How STEM activities/curriculum are developed / How teachers learn STEM education

It was discovered that in the teaching of STEM education to teachers, the differences in education levels in primary and secondary schools are not considered. Furthermore, instead of teaching teachers how to create and implement a STEM activity that meets the students' needs, it was observed that teachers are only taught how to implement ready-made activities in STEM education. However, as previously stated, each piece of literature highlights the need to design and implement the STEM activities appropriate to the educational level of students (Bruce-Davis et al., 2014; Uştu, 2019).

How STEM education is implemented in Turkey

Teachers indicated some challenges for implementing STEM education. One of them is to have training programs for teachers that encourage a result-oriented mindset rather than a process-oriented approach. The educational system which cares about the national exams instead of developing students' creativity has also been considered as a significant issue to be addressed for the implementation of STEM education since this issue can lead students to have a result-oriented mindset. Additionally, teachers have difficulties in following the engineering design problem-solving process.

> ***Teacher 1:*** *... But I might have missed it while making the presentation. (**Teacher 2:** There was not any problem, was there?) Yes, nobody mentioned a problem. Everyone is directly solution-oriented. I had priorly videotaped the presentation and I found an opportunity to watch it. During the presentation, nobody told that he/she had a problem, or he/she found a solution to a problem. No one paid attention to this. There was a material to use and it was certain what would be produced from*

> *that material and what we had to do with it. When everyone was concentrated on this situation, the problem which was probably the most important part was skipped.*
>
> ***Teacher 2:*** *It is backbreaking to be involved in the engineering design process step by step and practice it. (Discussion among teachers)*

The challenges originating from the needs and basic skills of the younger students were also discussed for the implementation of STEM education. For instance, according to the needs of younger students, teachers reduce the stages of the engineering design process and change the problem definition stage. Considering these findings, getting familiar with students, and defining their needs and skills are found to be important in the STEM activity design and implementation.

> *I want to talk back as a teacher working with younger children and consumed with this work. I think that we miss out on the basic skills of children. I only want to ask this: Who can sew or fix his/her ripped button? Today, the children in 2nd or 3rd grade are hardly able to dress themselves. So, it is a little hard for them to design and think over discovering a problem since they do not even know the working principle of a simple machine. Thus, I believe that one should consider the designs and skills which are already existing for the younger groups for the implementation of STEM education. These scientific skills are the ones which we mostly skip, and which try to find solutions to such problems: How to fold a dress, how to organize a closet, or how to write in a notebook, etc. (Discussion among teachers)*

Identifying needs is also considered significant in the problem definition stage of STEM activity by teachers. Furthermore, the differences in technology perception in STEM education were discovered in the STEM workshop. Teachers also emphasize the importance of the purpose of use rather than using technology as a tool for technology integration into STEM education. This finding also confirms the relevant literature on matching the technology selection with the desired learning outcomes (Ellis et. al., 2020).

Summary of the Results and Discussion

The findings obtained from the literature review and exploratory research revealed that there are different perspectives on discipline integration, use of technology, and which disciplines STEM education includes. According to the findings of the exploratory research, the perceived characteristics of STEM education and the characteristics and mindsets of engineering were identified. When they are compared with the DT approach (Table 9), the STEM and DT approach have shared characteristics, and both include interdisciplinary collaboration, teamwork, inquiry-based learning, human-centeredness (student-centered learning), and hands-on practice. Furthermore, five characteristics and one mindset are common between Engineering and DT approach, these are interdisciplinary collaboration, teamwork, inquiry-based learning, human-centeredness (empathy), learning from failure, and creativity.

Table 9. The comparison of the characteristics and mindsets among STEM education, Engineering, and DT approach (Red color refers to the common characteristics/mindset)

Characteristics of STEM education	**Characteristics and mindsets of Engineering**	**Characteristics and mindsets of DT approach**
interdisciplinary collaboration	interdisciplinary collaboration	interdisciplinary collaboration (Efeoglu et al., 2013)
teamwork	teamwork	teamwork (Efeoglu et al., 2013)
inquiry-based learning	inquiry-based learning (problem-solving)	inquiry-based learning (McGlynn & Kelly, 2019)
hands-on practice	offer multiple solutions to a problem	hands-on practice (Hassi&Laakso, 2011)
student-centered learning	human-centeredness (empathy)	human-centeredness (Hassi&Laakso, 2011)
project-based learning	creativity	creativity (McGlynn & Kelly, 2019)
learning by living	learn from failure	learn from failure (IDEO, 2012)

According to exploratory research, non-STEM disciplines are included in STEM education. However, teachers receive most of their STEM training within a framework that includes only four STEM disciplines, and in the STEM workshop, teachers are not taught how to create and implement the STEM activities. Since most of the teachers do not have the STEM curriculum, they have to create their activities/curricula based on this training. Therefore, teachers ought to learn how to prepare and implement STEM activities on their own, involving both STEM and non-STEM disciplines. The significance of getting familiar with students, their needs, skills, technology literacy, and educational levels are further discovered in the STEM activity design and implementation. The DT approach is described as the integration point of business, design, engineering, and social sciences (Leifer & Steinert, 2014). In that circumstance, as an interdisciplinary and human-centered process, the DT can enable the integration of diverse disciplines into STEM education and assist teachers in developing and implementing STEM activities considering the students' needs and education levels.

The exploratory research indicates that collaboration among teachers has a significant place in creating, revising, and developing STEM activities, learning STEM education, and implementing STEM projects with team teaching. Teachers also have to allocate extra time to collaboration due to the workload of the education system. The DT approach encourages dealing with multiple disciplines to develop innovative ideas (Grácio & Rijo, 2017), and fosters a collaborative culture for teachers (Diefenthaler, et. al., 2017). According to this, as an interdisciplinary, collaborative, and reflective process (Catterall, 2013), the DT can facilitate the collaboration of teachers from diverse disciplines. As it provides a step-by-step process for collaboration, teachers can use their time more effectively.

The exploratory research demonstrates that the engineering design process as a problem-solving process is mostly utilized in STEM education. However, teachers have difficulties in following the engineering design process. They further state the significance of identifying needs in the problem definition stage of the STEM activity. As an iterative process, DT's way of approach to problem-solving is similar to the engineering design process but has particular mindsets that other problem-solving approaches do not have (Diefenthaler, et. al., 2017). For instance, one of its mindsets: embracing ambiguity, provides teachers and students with a context-based problem-solving process by embracing holistic thinking (Loescher et al., 2019). Moreover, another mindset, developing empathy for people is significant when identifying the needs in the problem definition process. There has been also an inclination of implementing the DT approach in the project-based STEM activities in K-12 schools to teach multidisciplinary collaboration, creativity, prototyping mindset, and innovation by emphasizing its iterative process (Lor, 2017). Consequently, like the engineering design process, DT can take the role of facilitator and binder in STEM education to enhance creativity, skills, and STEM learning of students because of having distinctive mindsets and similar characteristics with STEM education.

The challenges of integrating technology into STEM education, including the differences in teachers' perception of technology, are also discovered in the exploratory research. According to Norton and Hathaway (2015), a teacher with a design-based teacher education can integrate technology into activities because he understands the functioning of tools (2D or 3D programs), their usage and purpose, and suitability for students. Similarly, through the problem-solving process of the DT approach, teachers can easily incorporate technology (online research tools, prototyping tools) into STEM activities at appropriate stages to achieve a specific learning goal.

The exploratory research reveals some challenges for STEM education, such as the changing role of teachers from implementer to guide in STEM education, and the training programs for teachers and the general education for students which encourage a result-oriented mindset rather than a process-oriented approach. Moreover, in Turkey, the technology and design teachers whose course structure is similar to Industrial Design education are proposed to be a mentor for other teachers in the adoption process of STEM education. According to this, integrating a DT approach as a user-centered and creative problem-solving process into STEM activity design and implementation can ease the transition from result-oriented general education to STEM education both for teachers and students. While the DT approach helps teachers to create a productive and expressive learning environment (IDEO, 2012), it can also support teachers, particularly technology and design teachers, by equipping them with skills and knowledge appropriate to their new roles as guides and mentors.

The study concludes that the DT approach can support STEM education and resolve its challenges with its creative problem-solving process (Catterall, 2013). However, DT mostly focuses on recommended techniques and tools that should be applied in certain stages by imitating the designer's way of doing for non-designers (Laursen & Haase, 2019). According to the authors, if a non-designer applies suggested tools and techniques of the 'DT' approach for certain situations without making situated actions, he will probably use his methodological approach based on his expertise because of knowing one methodological approach. In that circumstance, this study suggests that there is a need to develop a customized DT approach for STEM education.

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