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Abstract

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Keywords

K-12 engineering education, integrated STEM education, teaching engineering, professional development, teacher collaboration

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Expressed Willingness of STEM Teachers to Teach Engineering

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Abstract

Teaching engineering at the middle and high school levels has been a topic of discussion among scholars regarding the challenges it creates. One of the most critical challenges at the school level is identifying qualified teaching staff to lead engineering courses. The present study explored teachers' willingness to lead an engineering course and the reasons behind their willingness or unwillingness to do so. The study involved 434 participants, who were enrolled in a STEM professional development program and were diverse regarding their teaching subjects, the grade levels they taught, and the locations of their schools in Turkey. In this mixed-methods study, researchers collected data at the beginning of an online professional development program. Quantitative data were analyzed descriptively, while qualitative data were analyzed with a data-driven codebook. Almost two-thirds of the participants were keen to teach an engineering course, yet differences were observed according to the subjects they taught and their professional backgrounds. Most of the mathematics teachers, the group with the highest percentage of willingness, seemed to have a holistic approach towards engineering, with half emphasizing collaboration between teachers and engineers. The study provided further insights into how initial teacher training and continuous professional development programs can be structured based on teacher expectations and needs.

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Introduction

The scope of engineering is not limited to higher education anymore. Several influential engineering organizations support the introduction of engineering at the K-12 level (Strimel & Grubbs, 2016). Similarly, the National Research Council (2009) argues for introducing engineering at the K-12 level, so all students would be ready to face local and global problems as informed decision-makers. In addition, several scholars argue that all students need a basic understanding of how engineers work and engineering's impact on the welfare of society (English et al., 2011; Marshall & Berland, 2012). In the meantime, there is a decline in the engineering workforce globally. While the number of students pursuing an engineering degree at the higher education level is shrinking, an early introduction of engineering at the K-12 level emerges as a scheme to attract more students who would pursue a career in engineering (Becker, 2010; Johnson & Jones, 2006; Pretz, 2016). In support of this argument, Daugherty et al. (2014) claim that a positive relationship exists between student interest in science, technology, engineering, and mathematics (STEM) careers and their exposure to engineering practices during their K-12 education. Some others claim that early exposure to engineering practices may later result in a population of engineers with a more balanced representation of gender and ethnic diversity (Katehi et al., 2009; Ozogul et al., 2017). Thus, the scope of engineering is reaching the K-12 level for multiple reasons. At this point, a critical question emerges: Is our schooling ready to welcome the reach of engineering into our schools?

Engineering education becomes an essential part of K-12 curricula as more studies provide evidence for the positive impact of engineering education on student academic development in other STEM subjects (Alemdar et al., 2018; Cunningham & Carlsen, 2014; Gero, 2013; Schnittka et al., 2012; Zakharov et al., 2020). Some claim that engineering tasks can help students broaden their learning in mathematics (Diaz & King, 2007; Huang et al., 2008) or understand complex science concepts (Alemdar et al., 2018; Bybee, 2011; Cantrell et al., 2006; Lehrer & Schauble, 1998; Sengupta-Irving & Mercado, 2017). Others believe that the role of engineering in school curricula is to provide a context for teachers to teach science and mathematics (Katehi et al., 2009; National Academies of Sciences, Engineering, and Medicine [NASEM], 2020). Given that mathematics and science are predominantly taught with little relevance to the daily lives of students, several scholars believe engineering has the potential to make both mathematics and science more relevant, exciting, and engaging for students at the K-12 level (Katehi et. al., 2009; Sengupta-Irving & Mercado, 2017). In short, Moore et al. (2015) recap some of the main arguments for integrating engineering-based education into K-12 classes as supporting the development of 21st-century skills in students, increasing student achievement in mathematics and science, and cultivating student interest in STEM disciplines and careers.

Despite the optimistic stance of several educators in favor of engineering to be part of schooling, engineering is rarely integrated into the existing curricula in mathematics, science, or technology (DiFrancesca et al., 2014; English, 2017; English et al., 2011, 2017; Gutierrez et al., 2020). Thus, it is still a significant challenge for curriculum developers and teachers to integrate various engineering skills into their planning because different engineering fields require different skill sets. The following section in our inquiry aims to identify principles and features of the engineering curricula implemented at the pre-college level to determine how ready our schooling is to welcome engineering.

The Role of Engineering in School Curricula

Engineering is usually not a stand-alone subject in school curricula but integrated into other STEM disciplines, necessitating an understanding of *STEM Education* or *integrated STEM*. For example, Corlu (2012) defines *STEM Education* as a set of pedagogical approaches that enables students and teachers to utilize content, context, and methods of at least two STEM disciplines while students are working on an authentic and complex problem. In this definition, the overall purpose of STEM Education is to construct knowledge, acquire skills, and develop attitudes at the intersection of students' and teachers' interests and past experiences. According to some other researchers, the integrated STEM approach is related to "working in the context of complex phenomena or situations that require students to use knowledge and skills from multiple disciplines" (Honey et al., 2014, p. 52). In short, several scholars agree that engineering presents a context, a problem, a methodology (e.g., engineering design, project-based learning), or essential skills while teaching mathematics, science, or technology content (Bybee, 2011; Katehi et al., 2009).

One example of an engineering-integrated curriculum in the USA is the Next Generation Science Standards (NGSS, 2012) which presents science and engineering practices in tandem. The NGSS offers engineering as a real-world context for teaching science while encouraging students to develop skills and interests within science (NASEM, 2020). Several states in the USA have incorporated NGSS into their curricula (Hsu et al., 2011). The engineering practices within the NGSS require a skillful combination of inquiry and rigorous engineering/science knowledge, unlike some STEM projects that are popular among teachers with debatable connections to existing curricula or engineering (DeJarnette, 2012; English et al., 2017; Sneider & Ravel, 2021).

In Australia, engineering is an integral part of senior secondary-level education despite the limited number of references in the written curricula to *engineering* or *engineers* compared to technology and design (Salzman & Ohland, 2013). In England and Wales, plans exist to remodel the *design and technology* course, a core subject for both elementary and secondary levels, with explicit emphasis on engineering under a new STEM program (Benson, 2009). Likewise, in Ireland, the recent *Junior Cycle Framework* offers elective courses for technology subjects at the middle school level. Engineering is one of the courses under this framework with graphics, applied technology, and wood technology, while engineering maintains its distinct status as an option for senior cycle/high school students (National Council for Curriculum and Assessment, 2018).

Science educators and curriculum planners are the most enthusiastic in Turkey about adopting engineering for the elementary and middle school curriculum (Marulcu & Sungur, 2012). In the national science coursework, engineering practices are introduced as *product development tasks* that appear at the end of each unit, and students present their products at end-of-year exhibitions (Ministry of National Education [MoNE], 2018). In addition, the new seventh- and eighth-grade national curricula include technology and design coursework that focuses on engineering and the engineering design process. Similarly, the information technologies and software coursework includes programming, software, and problem-solving from an engineering perspective. In the high school curriculum, (i) biology coursework offers an introduction to genetic engineering and biotechnology concepts and applications; (ii) physics coursework describes the relationship between physics and engineering; and (iii) chemistry coursework introduces chemical engineering and metallurgical engineering. In contrast to the popularity of engineering in science education in Turkey, a quick exploration of the mathematics coursework shows no direct reference to engineering or engineers at elementary or middle school levels (see MoNE, 2018).

Engineering and Pre-College-Level Teachers

It is a generally accepted view that teachers must have a good command of their subject matter, in both the knowledge of its content and pedagogical content. Likewise, teachers need to feel comfortable teaching engineering to support student development in corresponding knowledge and skills (Hsu et al., 2011; Wang et al., 2011). However, despite the growing interest in integrating engineering into educational settings, teachers express their reluctance to carry out engineering tasks due to a lack of familiarity with and knowledge of engineering and teaching engineering (Gutierrez et al., 2020; Hammack & Ivey, 2017). Teachers' reluctance can result from the current disciplinary structure of pre-service and in-service teacher education practices (Cunningham & Carlsen, 2014; Douglas et al., 2004), in contrast to integrated teaching programs (Corlu, 2012). For example, a study with a group of middle school mathematics, science, and computer teachers concludes that teachers' content and pedagogical content knowledge in engineering vary widely, suggesting that there is a need for comprehensive professional development (PD) programs (Hynes, 2012).

The influential organization NASEM (2020) introduces the notion of *teachers of engineering* to refer to those who are proficient "at adopting and designing engineering curriculum in their classrooms" (Brophy et al., 2008, p. 383). These teachers of engineering are expected to be proficient in both content and pedagogical knowledge of engineering (Brophy et al., 2008). They are also expected to have a holistic engineering vision beyond an individualistic understanding of STEM disciplines (NGSS, 2012; Teslow et al., 2016). In addition to the knowledge dimension of effective teaching practices in engineering, teachers' weak engineering self-efficacy beliefs, lack of resources, and insufficient time for planning are among several other challenges identified in studies (Barger et al., 2006; Williams et al., 2016). To this end, teacher educators develop workshops and PD programs that emphasize the crucial role teachers play in the integration of engineering practices into classrooms (Hsu et al., 2011; Lachapelle & Cunningham, 2014; Mesutoglu & Baran, 2020; Smith et al., 2021). The target audience of these PD programs usually comprises computer education, instructional technology, science, or mathematics teachers (Hynes et al., 2017; Katehi et al., 2009).

Some scholars identify two theoretical frameworks to understand and further develop teachers' vision toward engineering education (Hammack et al., 2020). One is the STEM integration framework (Moore et al., 2014) which focuses on mathematics and science learning in more meaningful real-life contexts through technology and engineering practices. This framework presents a more holistic vision, similar to NGSS (2012). The second deals with the nature of engineering (Pleasants & Olson, 2019) with a particular focus on the engineering discipline in general, the methods engineers use, the way they approach human problems, its impact on society, and its relationship to other disciplines. In fact, engineering is not a typical subject area, and "no widely accepted vision of the nature of K-12 engineering education" exists (Katehi et al., 2009, p. 155). Therefore, it is expected that pre-service and in-service teachers at the primary and secondary levels lack a firm understanding of engineering practices or rigorous engineering knowledge (Ames, 2014; Marulcu & Sungur, 2012). Similarly, in-service teachers view themselves as lacking the necessary engineering background to delve into the teaching of engineering (Hammack & Ivey, 2017), although they believe that the inclusion of engineering practices into STEM education serves the benefit of the students (Hacıoğlu et al., 2016; Hsu et al., 2011). Nevertheless, some teachers admit certain presuppositions regarding engineering teaching because very few of their students would be willing to pursue careers as engineers in the future (Douglas et al., 2004).

Studies indicate that PD programs in engineering education may considerably affect teachers' understanding of engineering concepts and processes and their beliefs about teaching engineering (Cima et al., 2022; Rich et al., 2017; Smith et al., 2021). Furthermore, a collaboration between educators with backgrounds in engineering and teacher educators at faculties of education results in better outcomes for teachers (Cima et al., 2022; Nugent et al., 2010).

Despite the importance of and increasing emphasis on engineering education at the K-12 level, there is still limited research on teachers' willingness to integrate engineering into their classes. Researchers indicate that teachers' backgrounds affect their willingness to teach engineering even if they previously participated in a relevant PD program. Indeed, STEM teachers seem more willing to integrate engineering design into their classroom practices (Rich et al., 2017). Unfortunately, no previous research was available to the authors of this article that investigated Turkish teachers' willingness to teach engineering. Existing studies on engineering education seem to have focused on pre-service and in-service science teachers only, with no attempt to identify the reasons behind such willingness or unwillingness to teach engineering (see Bozkurt, 2014; Hacıoğlu et al., 2016; Hammack et al., 2020; Sungur Gül & Marulcu, 2014).

Researchers in the present study believe that we need to understand how teachers from all STEM disciplines, not just science teachers, feel about teaching engineering. Sengupta-Irving and Mercado (2017) support the idea of conducting more studies with teachers to understand their conceptualization of engineering, whether they see it as *a discipline* or *a teaching approach*. Hence, the current study explores the willingness of STEM teachers to teach an engineering course and the reasons for the willingness or unwillingness of teachers who have just started participating in a PD program on *STEM Education*. In this study, we name these teachers *STEM teachers* for two reasons. First, teachers have been teaching either one of the S/T/M disciplines at the middle or high school level. Second, they would be certified as *STEM teachers* if they completed the PD program. Thus, the following research questions comprise the main focus of this study:

1. Are STEM teachers willing to teach an engineering course?
2. What are the STEM teachers' opinions about who should teach an engineering course?
3. What are the reasons for STEM teachers' willingness or unwillingness to teach an engineering course?

Method

In this study, we used a mixed-methods research design, collecting data using a single tool (Ary et al., 2010). The quantitative part of the study aimed to identify common characteristics of those willing or unwilling to teach engineering. The qualitative part included systematically analyzing teachers' opinions and their rationale behind their willingness or unwillingness.

Participants

A large number of STEM teachers ($N = 434$) from 70 different schools across all seven geographical regions in Turkey participated in the study. The schools encouraged their STEM teachers to participate in the PD program (formally, *STEM Leader Teacher Professional Development Program*). Thus, the sample consisted of middle and high school STEM teachers who responded to an online survey sent out as an assignment during the program. Of the 434 teachers, only eight (2%) were middle school science and four (1%) were high school physics teachers. These teachers were excluded from the study as they did not constitute a significant portion of the sample. Nearly 50% of the sample was made up of mathematics teachers (56.64%, $n = 239$), and biology, computer education and instructional technology (CEIT), and chemistry teachers were represented almost equally (respectively 12.56%, $n = 53$; 19.43%, $n = 82$; 11.37%, $n = 48$).

STEM Leader Teacher Professional Development Program

Teachers in the sample were the participants of an online *STEM Leader Teacher Professional Development Program* planned to continue for 32 weeks with theoretical and practical work of about 92 hours. The purpose of the PD was to provide theoretical and practical competence in *STEM Education*. In the first component of the PD coursework, teachers were expected to watch three sets of videos: the theoretical framework of integrated STEM, procedures in STEM lesson planning, and how their co-teachers worked on developing solutions to an authentic STEM Education problem (formally, the Authentic Problems of the Knowledge Society) (see Asik et al., 2017). After watching an episode of the videos each week, teachers were given prompts to express their opinions on a relevant issue. In the second component of their coursework,

- teachers were asked to design integrated STEM lesson plans after an interdepartmental meeting at their schools,
- edit their lesson plans according to feedback provided by teacher educators and teachers at other schools,
- implement their lessons in the classroom and reflect on their STEM teaching practices, and
- write reflections on their planning stage and experiences in the classroom.

Several research studies have been conducted to describe the outcomes of this program for both students and teachers (see Ersoy, 2018; Genek & Doganca Kucuk, 2020; Girgin, 2018; Saricam & Yildirim, 2020; Senkutlu, 2019).

Data Collection

The participants were asked to respond to two prompting questions during the beginning of the online PD program (second week of the 32-week program). The response rate was 56% (456 out of 814 teachers enrolled in the PD). The responses to the following open-ended questions constituted the data set for the current study.

1. If an engineering course is to be incorporated into the curriculum, which subject teachers should be asked to teach that course? Please, justify your argument.
2. Would you like to teach an engineering course or not? Please, explain your rationale.

Table 1
Codebook with the codes and definitions.

Reasons for willingness to teach engineering		Reasons for unwillingness to teach engineering	
Code	**Definition**	**Code**	**Definition**
Relevance of teacher's teaching subject.	The participant explains the relevance of engineering to their teaching subject. This explanation includes commonalities between engineering and teacher's subject content and practices.	Failure to reconcile one's teaching subject with the engineering discipline.	The participant emphasizes a lack of relevance of engineering disciplines to their subject. This includes explanations such as how engineering and their subject differ.
Relevance of teacher's background.	The participant discusses their background concerning engineering, mentioning the possible effect of graduating from a bachelor's or master's program in engineering or taking courses with engineering students.	Insufficient content/engineering knowledge.	The participant discusses their discomfort about their engineering knowledge and engineering content.
Teacher's association of their subject with a specific engineering branch.	The participant associates their subject with a specific engineering branch and discusses the teaching based on this engineering branch.	Absence of knowledge about the possible K-12 engineering curriculum.	The participant says there are no specified and agreed-upon engineering curricula, which are challenging to evaluate.
Importance of pedagogical knowledge.	The participant discusses the value of pedagogical knowledge by stating that teachers should have the competence and experience to design effective teaching and learning environments.	Expecting engineers to lead the course.	The participant believes that engineers should lead the teaching of such an engineering course.
Integrated subject knowledge.	The participant discusses the importance of knowledge of another STEM subject in addition to their own for teaching engineering.		
A holistic vision of engineering education.	The participant describes their vision of engineering education as one based on engineering practices such as using models, project design, and construction of evidence-based arguments while using knowledge from various disciplines.		

Data Analysis

First, researchers removed 22 responses from the data set as they had no relevance to the prompting questions. Second, researchers categorized data, recognized patterns, and combined similar categories as a team to create an initial codebook (see Table 1). The content analysis was conducted individually by three researchers to identify the recurring themes. The data analysis team had regular meetings to discuss any additional unanticipated codes (Lincoln & Guba, 1985). For inter-rater reliability, each researcher analyzed the same ten teacher responses individually and reached an agreement rate of 87.5%. A collaborative analysis of the same ten responses was followed, which resulted in a final 95% coder agreement.

Trustworthiness, as an essential aspect of qualitative validity, was ensured through frequent peer debriefing sessions and prolonged exposure with the participants (Creswell, 2013). We frequently met during the data analysis period, cross-checked the analyses, discussed observations, and planned future sessions accordingly. To further ensure trustworthiness in this study, three out of four researchers worked actively in the PD program, which enabled us to have prolonged exposure with the participants to understand their teaching context better.

Quantitative Findings

The first research question investigated teachers' willingness or unwillingness to teach a possible engineering course. Analysis of statistical data indicated that a majority of the teachers (69.9%, $n = 295$) were keen on teaching an engineering course, while a smaller group of the participants (30%, $n = 127$) stated their unwillingness to do so. Table 2 provides the percentages and frequencies of teachers' willingness and unwillingness to teach engineering concerning their subjects.

STEM teachers were also asked who should teach a proposed engineering course (Figure 1). They expressed multiple teaching subjects in their responses. Mathematics teachers appeared in 249 responses, a considerably higher figure considering the actual number of mathematics teachers participating in this study was only 239. Physics and science

Table 2
Teachers' willingness/unwillingness to teach engineering according to their teaching subjects.

	Willing teachers		Unwilling teachers		
Teaching subjects	***n***	**%**	***n***	**%**	**Total**
Mathematics	180	75.3	59	24.7	239
CEIT	52	63.4	30	36.6	82
Biology	32	60.4	21	38.6	53
Chemistry	25	52	23	48	48
Total	295		127		422

Note. CEIT refers to computer education and instructional technology teachers.

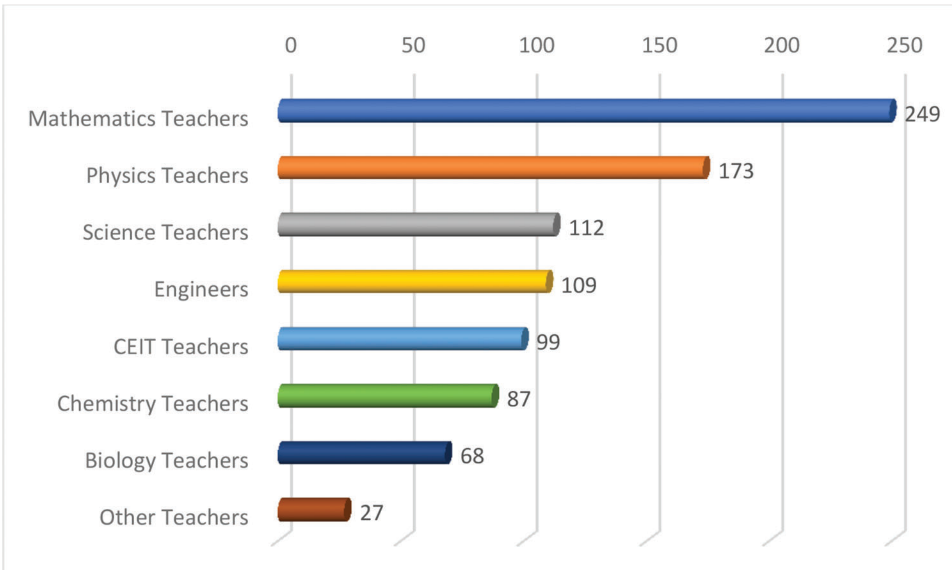

Figure 1. STEM teachers' opinions about who should teach the engineering course.

teachers were the second and third choices, respectively. Several teachers ($n = 109$) stated that engineers should be teaching an engineering course. Based on the participant responses, the "other teachers" category in Figure 1 was created to refer to teachers in vocational schools, art and design teachers, geography teachers, and primary school teachers.

A possible engineering course is suggested to be taught by teachers from multiple disciplines, which implies participants' willingness to collaborate in teaching engineering. Such collaboration with other staff members appears in almost half of the participant responses. While 220 (52.1%) of the responses included a scenario with one subject teacher teaching the engineering course, 31.9% ($n = 135$) of them reflected collaboration among different subject teachers, and 15.9% ($n = 67$) collaboration of a team of different subject teachers and engineer(s) to teach the proposed engineering course.

Qualitative Findings

In the open-ended questionnaire, STEM teachers were asked to state the underlying reasons for their willingness or unwillingness to teach an engineering course. In the following sections, each code for willingness and unwillingness is presented with excerpts from the STEM teachers in the same order they appear in the codebook in Table 1.

Reasons for Willingness to Teach Engineering at the K-12 Level

Relevance of Teacher's Subject

Among the reasons for willingness to teach an engineering course, the *relevance of the teacher's subject* was most strongly emphasized by the participant teachers. The main points raised with this were concerns about the relevance of the teaching degrees of the participants to engineering content and practices. Under this code, the participants evaluated their competence based on general skills and practices related to engineering. Overall, there was a tendency among teachers to perceive engineering as an independent discipline rather than a combination of different engineering branches. For example,

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one CEIT teacher talked about the engineering skills they focused on while teaching their subject and explained why they would be willing to teach such a course as follows:

Excerpt 1: Engineering skills taught in their course [CEIT teacher]

(1): I try to improve my students' engineering skills in coding, especially in robotics lessons. For example, we start our first Lego lesson at kindergarten by describing the wheel and gear concepts. Then, while learning the crane system in primary and secondary school, we design robots that move independently. We hope that these robots will solve the problem. Our lesson content and basic engineering principles overlap and can be carried out together.

Some CEIT teachers mentioned the integrated nature of engineering and tried to demonstrate how their teaching subject can be utilized to promote this integration. One of them emphasized their solid theoretical background in different engineering disciplines by saying, "*Informatics is a course that has relevance to every field of science—from the heat and temperature taught in science to the derivatives taught in mathematics.*" Another CEIT teacher stated that the skills they developed while teaching their subject enabled them to carry out interdisciplinary work:

Excerpt 2: Nature of the subject taught [CEIT teacher]

(2): By nature, engineering has to do with not just one field but also mathematics, geometry, science, physics, informatics, and technology… As CEIT teachers, we can teach this course in schools. People who are interested in informatics are knowledgeable about computers; they are the people who can carry out interdisciplinary work and combine [these disciplines] with each other. They are elaborative and possess creative thinking skills.

As expected, teachers express their idea of engineering as a quantitative discipline using mathematics as the logical framework because engineering requires mathematics, physics, and computer science expertise. Consequently, most mathematics and physics teachers associate their teaching subjects with engineering, thinking that they serve as a foundation, leading them to view themselves as capable of teaching such an engineering course. Interestingly, this way of thinking also appears as a reason for unwillingness, especially in those teaching subjects other than mathematics, physics, and science.

Excerpts 3 and 4: Importance of one's discipline

(3): Physics teachers can offer engineering classes since most engineering backgrounds are physics-based. [Physics teacher]

(4): Mathematics and science teachers can collaborate in teaching this course just like they would if they were to construct a building, where the math teacher would make the calculations, and the science teacher would set the location of the building. People in these two branches have strong enough backgrounds to carry out the project. [Mathematics teacher]

Relevance of Teacher's Background

The teachers in the study showed a tendency to consider the relevance of their academic background while evaluating their competence in teaching a possible engineering course. They thought receiving formal engineering training, either through getting a bachelor's or master's degree in engineering or taking engineering-related courses at university, provides an advantage in acquiring appropriate content and pedagogical knowledge. The long-term advantage of studying in an engineering-related department, precisely the opportunity to study together with engineering students and to take similar courses, was expressed by one CEIT teacher as follows:

Excerpt 5: University background [CEIT teacher]

(5): In college, I took several courses that engineering students also took. We were constantly exposed to similar content (e.g., C#, C++, Python). Therefore, I believe we can acquire general engineering knowledge without experiencing many difficulties and try to improve ourselves in this area.

Teacher's Association of Their Subject with a Specific Engineering Branch

This code derived from the responses explaining why STEM teachers wanted to teach an engineering course. It was observed that the teachers tended to evaluate teaching competencies by associating their teaching subject with a specific engineering branch rather than adopting a holistic view of engineering. Not surprisingly, such a trend was more commonly observed among biology and chemistry teachers, and they seem to have identified a variety of engineering branches like mechatronics, genetic, chemical, and metallurgical engineering as areas that corresponding school curricula refer to, and that they have knowledge about.

Excerpts 6 and 7: Specific engineering branches [biology teachers]

(6): Biophysics lessons can be included in the curriculum so that we can relate more easily to daily problems, such as why we become herniated when we lift weights or which muscle groups we exercise when carrying a load with our arms. In addition, physics and biology teachers can teach an engineering course by designing it together.

(7): Specifically, physics and mathematics teachers, and in some cases, biology and chemistry teachers, can teach the possible engineering course included in the national curriculum. In physics classes, nature is observed and translated into mathematical operations. The engineer brings the phenomenon to life. Physics and mathematics are closely linked to engineering. As a biology teacher, I believe that we can encourage our students to be curious about, especially in fields like genetic engineering, biotechnology, food engineering, and environmental engineering, through a curriculum that encourages collaboration, problem-solving, production, and research instead of memorization. I think I can lead and teach such a course.

In both excerpts, the biology teachers mention specific engineering branches and seem eager to cooperate with teachers from other disciplines. The teacher in Excerpt 7 positions themself in the back row, behind mathematics and physics teachers in engineering teaching.

Importance of Pedagogical Knowledge

In the study, most of the STEM teachers with a positive attitude toward teaching engineering emphasized the importance of pedagogical knowledge. They did not like the idea of engineers teaching or leading instruction in a K-12 classroom. The responses reflected a strong teacher identity:

Excerpt 8: Teacher identity [CEIT teacher]

(8): I think I am capable of teaching engineering classes. However, I do not find it suitable for engineers to teach them. Teaching is a different profession that requires a relevant background; therefore, it cannot be achieved without understanding student psychology.

The teachers knew that pedagogical and content knowledge were pillars of teaching knowledge. Most of them mentioned that they could teach engineering in K-12 after receiving the necessary training because they already had relevant pedagogical knowledge to teach at that level. The teachers suggested some alternative ways to train in-service and pre-service teachers:

Excerpts 9 and 10: Suggestions about a possible PD program [mathematics teachers]

(9): I think an engineering course can be taught by mathematics, physics, and computer science teachers equipped with the necessary skills gained through an in-service training program. Pre-service teachers should be trained in collaboration with education and engineering faculties, and the course can be integrated into the curriculum afterward.

(10): Both mathematics and science teachers can teach the engineering course at the elementary level, provided they receive intense teacher training beforehand. Unfortunately, teacher seminars were given at short intervals for years, and the content was not well-planned.

Teachers who teach engineering should develop their knowledge of engineering. In addition, they should receive product and project development training and complete an engineering internship.

A Holistic Vision of Engineering Education

Some participants, particularly mathematics teachers, acknowledged the need to include an engineering course in the curriculum. The course would enable students to do more practical work using the theoretical knowledge they have gained in other courses. For example, one mathematics teacher teaching at the middle school level talked about mathematical concepts and suggested that more real-life practice with those concepts be provided in that prospective engineering course:

Excerpt 11: Real-life applications [mathematics teacher]

(11): Engineering is the real-life application of mathematics. For example, in 8th grade, while discussing the concept of slope, we discussed the relationship between a bridge and its cables and things to consider when designing pavements for disabled individuals. This concept is still abstract for students to comprehend, however. Therefore, students must design small-scale models for learning more about such principles.

Integrated Subject Knowledge

Some teachers described the integrated nature of engineering in alternative ways. They emphasized the need for knowledge of different STEM disciplines and collaboration among teachers as a fundamental condition to be met. Interestingly, all the teacher responses categorized under this code were from mathematics teachers. The selected responses focus on collaboration between different disciplines, teachers, and engineers.

Excerpts 12 and 13: Collaboration to integrate [mathematics teachers]

(12): As a mathematics teacher, I believe an engineering teacher should have excellent math knowledge. However, a teacher who teaches engineering should also have a strong command of physics and other branches of science, including technical sciences. Therefore, physics and science teachers are the most qualified to teach such a course. As I mentioned at the beginning, advanced mathematics knowledge is also necessary. At this point, it would be most beneficial for physics, science, and mathematics teachers to work on the task together. In other words, preparation for an engineering course can be part of STEM education, and science, physics, chemistry, biology, CEIT, and mathematics teachers can exchange ideas just like they do regularly in [interdepartmental] meetings.

(13): A lesson co-taught by the subject teacher and an engineer enables students to learn to use the theoretical knowledge taught by the teacher and the practical methods suggested by the engineer. In addition, it encourages them to discuss new knowledge and see how engineers work in real life. This way, it will be more beneficial for students in the long run than a lesson taught by an engineer only.

Two mathematics teachers with an integrated approach to the teaching of engineering described an *engineering teacher* as:

Excerpts 14 and 15: An engineering teacher [mathematics teachers]

(14): A mathematics teacher with sufficient knowledge of physics.

(15): Either a mathematics teacher competent in science or a science teacher competent in mathematics.

Reasons for Teachers' Unwillingness to Teach Engineering at the K-12 Level

Failure to Reconcile One's Teaching Subject with Engineering

Nearly 34% of the STEM teachers said they did not want to teach an engineering course. These teachers generally thought the engineering course was irrelevant to their teaching areas or background. Several mathematics teachers stated that engineering was closely linked to mathematics, but physics teachers should be teaching such a course. According to the teachers, physics education required a high level of mathematics knowledge; having mathematics knowledge was not considered sufficient to teach engineering; in-depth knowledge of physics was also necessary. Some biology, chemistry, and CEIT teachers said engineering course content had to do more with mathematics and physics in excerpt 17.

Excerpts 16 and 17: Irrelevance of the teaching subject to the teaching of engineering

(16): As a mathematics teacher, I cannot teach engineering courses. Physics and science teachers can carry out this task more effectively. After all, a good knowledge of mathematics is also necessary to teach physics, which is an advantage in this case. [Mathematics teacher]

(17): It may be appropriate for mathematics and physics teachers to teach an engineering course since engineering has mathematics as its basis, a field in which physics teachers should also have competence. I am a biology teacher, and I do not think I will succeed in teaching the main engineering principles in this course. [Biology teacher]

Insufficient Content and Engineering Knowledge

Some teachers believed that their unwillingness was due to their lack of field knowledge, but their responses also reflected their unwillingness to participate in a possible PD program in engineering education.

Excerpt 18: Insufficient subject knowledge [CEIT teacher]

(18): It would not be suitable for only one teacher to teach the engineering course. Since engineering involves more than one discipline, science, mathematics, computer, and visual arts [cf. technical drawing] teachers should also be involved. This way, each teacher would be encouraged to make his or her contribution to the program, which would increase effectiveness. However, as a computer teacher, I cannot assume the responsibility of teaching engineering classes alone, as my knowledge of science and mathematics disciplines is not strong enough to accomplish this.

Absence of Knowledge about the Possible K-12 Engineering Curriculum

A few teachers argued that they had no idea about the K-12 engineering curriculum and its content and were unwilling to teach a possible engineering course. Because they did not know much about the engineering field, some were concerned about what a possible course content would be like and what would be expected of them.

The excerpt below is classified under the *insufficient content and engineering knowledge* code; however, it is a good example that can trigger a productive discussion on the unspecified scope of the possible engineering curriculum.

Excerpt 19: Scope of the engineering curriculum [chemistry teacher]

(19): The scope of the engineering course to be integrated into the curriculum was not specified, and it is unknown whether the inclusion will cover a single engineering branch or multiple branches. Even though there is an engineering branch closely related to my teaching subject, I do not have sufficient knowledge of engineering in general.

Expecting Engineers to Lead the Course

A few of the teachers thought that engineers should lead such a course. They suggested that an engineer should lead the preparation process and in-class practice with the assistance of the subject teacher. The teacher in the excerpt below views themself as incompetent to teach an engineering course, but the teacher was willing to assume the role of the facilitator:

Excerpt 20: Engineer as the leader in the classroom [CEIT teacher]

(20): I believe engineers should be teaching this course with support from subject teachers, especially if it involves a lot of details and applications. The two should be present together [in the classroom] in case the engineer has difficulty empathizing with children. The subject teacher is usually more experienced in that area and can, therefore, choose methods and strategies to be used in the classroom accordingly. Pre-service teacher training does not focus on teaching engineering methodology, which will inevitably render subject teachers ineffective in engineering courses.

Discussion

The purpose of the current study was to investigate the willingness or unwillingness of STEM teachers to teach a possible engineering course and the reasons underlying their preferences. Data from this study were analyzed accordingly to identify the views of teachers from different STEM disciplines teaching at middle and high school levels. At first, it was hypothesized that most teachers would not be interested in teaching in a field they had not taught before. However, most of the STEM teachers in this study believed that teachers could teach engineering courses at the K-12 level, and they would be willing to teach an engineering course themselves. The level of teacher willingness and the underlying reasons vary considerably according to the subject taught.

Results indicate that mathematics and CEIT teachers were enthusiastic about teaching an engineering course. They evaluated their competency to teach engineering in terms of the relationship between their teaching subject and the engineering field or by reflecting on their academic background. The influence of such factors was spotted in previous studies on teachers' integrating different STEM disciplines into their classrooms (Hsu et al., 2010; Wang et al., 2011). Rich and colleagues (2017) found that teachers with some interaction with engineering and computing in the past tended to have high self-efficacy and were willing to carry out engineering and computing activities in the classroom.

It is apparent from the findings that mathematics teachers constituted the group most willing to teach engineering. These teachers evaluated their competency in teaching engineering by emphasizing the close relationship between engineering and mathematics. Fitzallen (2015) maintains that STEM applications provide a rich context for teaching mathematics, and it is mostly engineering (E), among other STEM disciplines, that offers an opportunity to work on diverse engineering tasks and problems. Moreover, for teachers, mathematics seems to be the field with the most interdisciplinary content (Smith et al., 2021). Another important finding was that mathematics teachers perceived engineering more holistically without specific reference to individual engineering disciplines. This could be another reason why there was a high number of willing mathematics teachers despite the absence of *engineering* or *engineers* references in the middle and high school mathematics curricula in Turkey (MoNE, 2018). It is also encouraging to see that these mathematics teachers were eager to combine mathematics teaching with engineering, although the significance of mathematics is somewhat overlooked in STEM integration in most of the developed STEM programs (Shaughnessy, 2013).

The second willing group was the CEIT teachers. In their responses, they emphasized the strong relationship between technology and engineering and the engineering tasks they had already implemented in their classes, which indicates their confidence in teaching engineering. English (2017) argues that technology is not an underrepresented component of engineering teaching among STEM disciplines. Analysis of engineering curricula shows technology was incorporated into the national curricula before engineering in many countries, including Turkey (Marulcu & Barnett, 2016) and England (Benson, 2009).

On the other hand, chemistry and biology teachers mainly evaluated their competence to teach engineering, considering specific engineering fields related to their teaching subjects. Without a holistic approach, these teachers usually could not identify any significant relationship between their subject area and engineering and therefore ended up focusing on a specific engineering field. In a sense, they are restricted by the Turkish high school chemistry and biology curricula, where there is an emphasis on only a few engineering branches. PD programs in engineering education can enable teachers to establish the necessary link between their teaching subject and engineering (Nathan et al., 2011; Smith et al., 2021).

Another important finding was that almost half of the participant teachers were eager to collaborate in teaching the *undefined* engineering course. Integrated STEM education aims to collaborate STEM disciplines in various contexts to solve a problem or carry out a project without undermining the importance of the central STEM subject (Corlu et al., 2014). Although there are various approaches aiming to integrate engineering and other STEM disciplines considering the pedagogical, epistemological, and methodological arguments identified by Purzer and Quintana-Cifuentes (2019), some challenges still exist, as how effectively engineering can be represented among STEM disciplines and how underrepresentation of engineering can be overcome to ensure *science for all* (English, 2017). Corlu (2014) defines integrated teaching knowledge as the combination of a teacher's content and pedagogical knowledge in their teaching subject and working knowledge acquired in another STEM subject through participation in PD programs and work on design and teaching of integrated STEM classes. In the current study, some teachers referred to the sufficient physics content knowledge possessed by mathematics teachers. They seem to be emphasizing the importance of integrated teaching knowledge as a tool that can combine the teaching subject with engineering and contribute to the effectiveness of engineering teaching. Studying the changes in teachers' attitudes after participation in a STEM PD program is essential because integrating STEM disciplines into teaching is, after all, the common goal of such programs on *STEM Education*.

Teachers' willingness to teach a relatively unknown and currently non-existent engineering course reflects their appreciation of the teaching profession and provides an insight into their teacher identity. According to Mayer (1999), teacher identity is affected by beliefs about teaching and how one feels about being a teacher. Walkington (2005) asserts that a positive teacher identity implies favorable learner characteristics like being a "flexible, lifelong learner confident in him-herself and able to participate in ongoing change" (p. 54). These characteristics were evident in the teacher responses, specifically in the enthusiasm they showed to be trained to teach engineering, to collaborate with a team of teachers and sometimes with engineers, and to teach a non-existent course in the Turkish context. The participants also came up with alternative suggestions for more effective training of teachers on engineering teaching, such as collaboration of education and engineering faculties to develop an engineering apprenticeship program for teachers. NASEM (2020) supports the collaboration of engineering and initial teacher education programs to develop teachers' engineering knowledge. A similar suggestion was made by Van der Veen et al. (2018), too, who believe pre-service teachers should take courses from engineering departments to prevent a shortage of physics teachers in the Netherlands.

In Turkey, almost 400,000 individuals qualified as teachers, through either a bachelor program in education or a postgraduate teaching program, registered for a central exam in 2019 to be eligible to teach in public schools (Student Selection and Placement Center, 2019). This number increases each year, with the increase in new graduates. However, due to the high unemployment rate in the teaching field, Turkish teachers might be more sensitive about being members of this profession. Some stated that the government should train teachers to teach engineering instead of employing engineers as teachers. They justified this idea by mentioning the high teacher unemployment rate in the country.

The unwilling STEM teachers based their unwillingness on their failure to relate their teaching subjects to engineering, having limited knowledge of mathematics and physics, and experiencing a lack of engineering knowledge. Hacıoğlu and colleagues (2016) pointed out that only a small minority of teachers take engineering as college coursework. Banilower and colleagues (2013) worked with teachers to explore their opinions on how to teach engineering concepts. Only a few science teachers stated that they were well-prepared for this task. It was interesting to observe that teachers did not have a holistic approach to teaching engineering, so they could hardly see the inter-related nature of engineering, precisely its relation to real life, as discussed in the STEM integration framework (Moore et al., 2014).

Engineering is a broad field, and several different engineering branches may prevent teachers from being enthusiastic about teaching this course. In their responses, the teachers maintained that teaching engineering requires specific subject knowledge and awareness of the relationship between mathematics and physics. Such remarks point to the advanced mathematics and physics knowledge these teachers possess. This integrated teaching knowledge (Corlu, 2014) contributes to their willingness and unwillingness to teach engineering. Therefore, mathematics and physics teachers seem to be their colleagues' favorites as engineering teachers.

The current study is not without its limitations. First, mathematics teachers constituted the majority, while there were significantly fewer science teachers. Our sample may limit the findings about the overall tendencies of a general teacher population participating in a STEM PD program. Moreover, the teachers were informed about the high workload of the PD program beforehand; therefore, they were eager to learn and experiment with new approaches and practices from the beginning.

The study was based on the expressed willingness of STEM teachers to teach engineering. As Sinatra et al. (2012) also pointed out in their study, expressing willingness to act does not necessarily mean the participants will be acting that way in real life. Moreover, there was the risk of participants giving favorable responses only to keep in good with the PD organizers.

Despite these limitations, the findings from the current study are expected to have important implications for teachers to undertake engineering education at the K-12 level in the future. The teachers in the study were eager to teach a possible engineering course both on their own and in collaboration with engineers and/or teachers from different disciplines. Therefore, attention should be paid to further PD of teachers already working in the classroom and pre-service teachers through engineering-focused PD programs (NASEM, 2020). These programs should also support teachers' collaboration within and across disciplines (Cima et al., 2022).

Conclusion

Conceptualization of teachers' attitudes toward engineering education could serve as a benchmark when designing teacher education programs. We believe that teachers should be introduced to the nature of engineering (DiFrancesca et al., 2014; Pleasants & Olson, 2019) by establishing clear links with other disciplines and real-life applications. This way, they can be supported to gain stronger self-efficacy beliefs and confidence to integrate engineering into their classes (Cima et al., 2022). In particular, the current study is expected to open a discussion about mathematics teachers' approaches to engineering and how the curriculum planners and designers could be motivated to integrate engineering into the mathematics curriculum. In conclusion, introducing engineering and engineering design into the Turkish national science curriculum has been a significant development in recent years. However, further research should be conducted on the integration of engineering courses into other K-12 subjects with the collaboration of different stakeholders, including teachers, engineers, and engineering and teacher educators.

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