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Understanding Preservice Science Teachers' Views about Engineers and Engineering in an Engineering-Focused STEM Course

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ABSTRACT

Engineering has been considered as a useful context for successful implementation of STEM education. However, teachers have limited opportunities to develop a sound understanding about engineers and engineering, which is necessary for developing students' engineering practices and design skills. In this case study, the main purpose was to examine 18 preservice science teachers' initial and final views about engineers and engineering in an undergraduate engineering-focused STEM course. Before and after an eight-week implementation including three engineering design activities, data were collected by the adapted version of Views on the Nature of Engineering Questionnaire and reflection papers. Findings revealed four categories: 1) views about engineers and engineering, 2) views about engineering design process, 3) views about the factors that affect engineering, and 4) views about science versus engineering. Based on the codes a scoring rubric was developed to categorize PSTs' views as uninformed, partially informed, and informed. Results showed that PSTs' views become more informed in each category. However, their views were still found as partially informed in some of the categories which shows the need for more emphasis on future research. The changes in their views were discussed with possible reasons and recommendations were provided for further studies.

Keywords: engineering design process, preservice science teachers, STEM, views about engineers and engineering

INTRODUCTION

Science, technology, engineering, mathematics (STEM) education has gained a growing popularity among both developed and developing countries such as USA, Canada, Australia, and Turkey with the motivation to increase student interest towards STEM careers and not to fall behind in the global economic arena (Moore et al., 2016). STEM education is considered to have the potential for fostering students' scientific literacy skills and skills to solve complex problems of the 21st century (NRC, 2014).

Engineering, as one of the disciplines in STEM education, can be defined basically as "the process of designing the human-made world" (NRC, 2009). The potential benefits of teaching engineering in K-12 have been reported, as follows:

1. improved learning and achievement in science and mathematics,
2. increased awareness of engineering and the work of engineers,
3. understanding of and the ability to engage in engineering design,

4. interest in pursuing engineering as a career, and
5. increased technological literacy (NRC, 2009, p. 49-50).

Similarly, in the most recent Turkish middle school science curriculum, there is a clear emphasis on engineering, and developing students' engineering skills and practices are among the aims of the curriculum (MNE, 2018). Moreover, engineering has been defined as central in many of the policy reports and research studies (Moore et al., 2014a, 2014b; Nathan et al., 2013; NRC, 2012, 2014) as it involves scientific and mathematical knowledge and skills (Moore et al., 2014a, 2014b).

Although engineering is one of the STEM fields that teachers are expected to teach in science classrooms, teachers' views of engineering are underestimated as compared to their views of science (Kim and Song, 2021). We believe that along with the investigations into how pre-service science teachers (PSTs) integrate each of the four STEM disciplines, research that concentrates on their views about the nature of each discipline (i.e., nature of engineering) is needed. To effectively incorporate engineering into K-12 education, teachers need to possess developed views of the nature of engineering. Up to now, far too little attention has been paid to explore teachers' views of the nature of engineering, especially at the elementary level (Deniz et al., 2020b). It is important to figure out how PSTs, the future practitioners of STEM education, view engineering to develop a complete understanding of what students ought to know about that discipline, especially in the Turkish context where incorporating engineering into teaching programs is in its infancy. Therefore, the findings of this study would provide contributions to literature on engineering views in Turkish context by revealing PSTs' initial and final views of engineers and engineering in an engineering-focused, semester-long STEM course. Specifically, the present study seeks to answer the research question: "What are PSTs' initial and final views of engineers and engineering in an engineering-focused STEM course?"

Theoretical Background: Nature of Engineering Frameworks

Engineering has been reported to be a part of K-12 education however, there is no consensus definition of the nature of engineering in the related literature. In the Framework for K-12 Engineering Education (NRC, 2012), engineering is defined majorly in terms of engineering practices (problem definition, model development and use, investigation, analysis and interpretation of data, application of mathematics and computational thinking, and determination of solutions) that engineers use as they design and its' commonalities with science. However, this framework lacks a clear identification of engineering knowledge and/or the nature of engineering and how they ought to be understood by the teachers and students.

Studies of Karataş et al. (2011, 2016) were among the first attempts to describe and use the term nature of engineering. In these studies, the researchers determined the elements related to the nature of engineering based on the literature. These elements included:

> "engineering solutions are tentative (Koen, 2003); they involve designing artefacts and systems (Bucciarelli, 2003; Dym et al., 2005; Lewin, 1983; Wulf, 2002); they depend on existing scientific and mathematical theories, as well as failures and successes in the field (Adams, 2004; Petroski, 1985); they are affected by cultural norms and the needs of society (Adams, 2004; Dym, 1999; Dym et al., 2005); they involve stepwise and iterative problem-solving activities (Koen, 2003); they require creativity, imagination, and the ability to integrate different scientific, mathematical, and social values and theories in novel ways (Adams, 2004; Petroski, 1985); they are complex human endeavours that require analytical thinking to make complex problems simpler (Dym et al., 2005; Koen, 2003; Matthews, 1998); and they should involve an holistic, open-system approach that requires the consideration of all aspects and perspectives of not only artefacts and consumers, but also the potential impact on individuals, society, and the environment" (Adams, 2004; Rogers, 1983; Rophl, 2002).

Karataş et al. (2016) measured university students' views of engineering by using an instrument they developed and called Views of Nature of Engineering (VNOE) Questionnaire. The participants' nature of engineering views revealed the categories of; engineering (definition and purpose of engineering), the design process (considerations in design, what engineers do, how do they do it), factors that affect engineering (different, same, depends), characteristics of good engineering, characteristics of a good engineer, and science versus engineering.

Providing a more comprehensive description of the nature of engineering, Pleasants and Olson (2019a) developed a framework based on philosophical, historical and sociological perspectives of the engineering discipline. The framework included nine features of engineering, which were also considered as aspects of the nature of engineering (Pleasants and Olson, 2019a, p. 154):

1. Design in engineering,
2. Specifications, constraints, and goals,
3. Sources of engineering knowledge,

Table 1. The aspects of the nature of engineering framework (Pleasants and Olson, 2019a)

Nature of engineering aspect	Description
Design in engineering	"While engineers might consider esthetics as part of their designs, the technologies they produce are primarily practical or functional in nature" (p. 154). "[engineering design] typically requires the coordinated efforts of teams of engineers, each with various specializations, as well as technicians and scientists" (p. 155).
Specifications, constraints, and goals	"Engineers must translate ill-defined goals into specifications that can be used to guide design work" (p. 155). "Design constraints are limitations placed on the designed technology in terms of safety, reliability, cost, or other factors" (p. 155).
Sources of engineering knowledge	"Engineers utilize knowledge from science and mathematics, but consensus exists that engineering is not merely applied science, and that it has a knowledge base of its own" (p. 156). "When engineers engage in design, they draw on their knowledge of existing technologies" (p. 156). "Unlike scientific theories, which are used to understand natural phenomena, engineering theories are used by engineers for the practical purposes of design" (p. 156).
Knowledge production in engineering	"An important mode of engineering knowledge production … is engineering research, sometimes called 'engineering science'" (p. 156). "The products of engineering science might include knowledge of how particular technologies function, or analytical tools and models that can be applied to a range of technological phenomena" (p. 156).
The scope of engineering	"… the work of engineers includes more than just technological design. Many engineers engage in engineering science rather than design… Other engineers act as overseers of projects… Instead of designing new technologies, engineers might also study existing technologies" (p. 157).
Models of design processes	"… engineering design process models vary in terms of their level of generality" (p. 157). "… there is the question of whether a generic engineering design process model is appropriate, given the breadth of engineering design work" (p. 157).
Cultural embeddedness of engineering	"Society influences engineering work, but engineers also affect society through the technologies they develop" (p. 158). "Even though the ways that technologies affect society are difficult to predict, engineers must nevertheless consider potential consequences" (p. 158).
The internal culture of engineering	"This might include characteristics of engineers such as perseverance and attention to detail, or the sorts of values that tend to underlie engineering work. It might also include typical problem-solving approaches used by engineers…" (p. 158). "Another more visible aspect of engineering culture is the high proportion of men in engineering, who make up 85% of the profession" (p. 158). "Similarly, certain minority groups are underrepresented within the engineering discipline, at least within the United States" (p. 158). "In describing the culture of engineering, an important complexity is that many specializations exist in engineering, each of which have their own subcultures" (p. 159).
Engineering and science	"…science and engineering are not identical. Scientific knowledge has utility for engineers but is not sufficient to guide design work. Engineering science shares many characteristics with the natural sciences but is directed toward different goals and thus uses different approaches" (p. 159).

4. Knowledge production in engineering,
5. The scope of engineering,
6. Models of design processes,
7. Cultural embeddedness of engineering,
8. The internal culture of engineering, and
9. Engineering and science.

The elaborations presented by the researchers on each of the aspects were provided in **Table 1**. Pleasants and Olson (2019b) also developed a quantitative instrument in another study to measure teachers' understanding of the scope of engineering, a particular nature of engineering aspect. The developed instrument specifically focused on the distinctions between engineering and non-engineering.

In a recent study, Deniz et al. (2020a) aimed to discern the aspects of nature of engineering from the existing literature, including the Framework for K-12 Engineering Education (NRC, 2012) and NGSS (2013). According to that study, the nature of engineering has the aspects of

1. "demarcation (What is engineering? What makes engineering different from other disciplines?),
2. engineering design process (EDP),

3. empirical basis,
4. tentativeness,
5. creativity,
6. subjectivity,
7. social aspects of engineering, and
8. social and cultural embeddedness" (p. 638-639).

Similar nature of engineering conceptions can also be found in the documents of National Academy of Engineering (NAE). According to NAE (2010), K-12 engineering education should have a focus on;

1. "EDP,
2. incorporating science, mathematics, and technology knowledge and skills, and
3. promoting engineering habits of mind, aligning with the skills of systems thinking, creativity, optimism, collaboration, communication, and attention to ethical considerations" (p. 45).

The aspects of the nature of engineering that have been reported in the research studies and policy documents are somehow very similar to each other and there have been some commonalities among the described characteristics of the nature of engineering. That being said, in this study, Karataş et al.'s (2016) framework and the questionnaire developed by them were utilized to interpret PSTs' views of engineers and engineering.

PSTs' Views about Engineers and Engineering

Previous studies on views about engineers and engineering have been emphasized mostly on students' ideas, conceptions, and perceptions of engineering (e.g., Capobianco et al., 2011; Chou and Chen, 2017; Fralick et al., 2009; Karataş et al., 2011), inservice teachers' conceptions of engineering (e.g., Deniz et al., 2020a; Hammack and Ivey, 2017; Pleasants and Olson 2019b; Pleasants et al., 2020) and how in-service teachers' conceptions related to engineering could be developed (e.g., Antink-Meyer and Meyer, 2016; Yoon et al., 2013). Within the limited number of studies on PSTs' conceptions or views of engineer and engineering, Kaya et al. (2017) explored how PSTs' views of engineering changed after enrolling in an elementary science teaching methods course. The researchers included a 3-week-long engineering unit which was around educational robotics in the science teaching methods course and tried to explore how PSTs' nature of engineering views changed after experiencing the engineering unit. PSTs' views on the nature of engineering were examined in terms of the nature of engineering aspects of demarcation, EDP, tentativeness, creativity, and social and cultural embeddedness and PSTs' responses were coded as uninformed, partially informed, or fully informed. According to the findings, the number of PSTs' holding uninformed and partially informed views on the aspect of the nature of engineering were decreased and fully informed views were increased prominently.

Ergün and Kıyıcı (2019) examined how PSTs' perceptions of engineering education and engineers changed after enrolling in a 14-week-long science education laboratory applications course, which was specifically designed to involve engineering design-based applications. In this pre-post design, mixed research study, PSTs' perceptions of engineering education and engineers were measured through Engineering Education Survey and Draw an Engineer Test. According to the quantitative findings, the participants' post scores on the sub-dimensions of importance of engineering, familiarity with engineering, and characteristics of engineering and engineers were significantly higher than the pretest scores. Moreover, the number of participants' who drew engineers as male instead of a woman, and as working individually instead of being a part of a team decreased. In the study, the analyses of PSTs' drawings also revealed that the engineering activities and the materials used by the engineers were mostly related to constructing and repairing at the beginning of the course and changed majorly into designing, developing, calculating, doing research/analysis, and doing experiments at the end of the semester.

In another study by Aydın-Günbatar et al. (2018), the effect of a 12-week design-based STEM course on preservice chemistry teachers' content knowledge, STEM conceptions, and engineering and engineering design views were investigated. The study revealed that prior to the course, almost all preservice teachers' conceptions of engineering and design processes were undeveloped or underdeveloped. Moreover, except one of them, all the participants developed their conceptions of engineering and design process after participating in the STEM course. For instance, the participants' views prior to the course that engineering aims to put something as a product changed into the view that the goal of engineering is to come to an end point such as a product, an idea, or a solution. However, Aydın-Günbatar et al. (2018) reported that the participants failed to recognize the iterative nature of the EDP even after taking the STEM course.

We believe that the number of existing studies exploring PSTs' conceptions and views of engineers and engineering (i.e., nature of engineering) is limited. In this study, we tried to examine PSTs' views through an open-ended questionnaire, which would provide a detailed understanding of future teachers' views about engineering and engineers.

Table 2. The weekly schedule of the implementation

Week	Content	Duration (min)
1	What is STEM? How can science teachers affect students' orientations toward STEM careers? What is engineering? What is EDP?	50+50
2	Talk with a guest engineer on EDP	50+50
3	Environmental-friendly streetlights design activity[a]	50+50
4	Wave machine design activity[b]	50+50
5 & 6	Bridge design activity[c]	50+50+50+50
7 & 8	Designing and presenting a lesson plan including engineering design activities	50+50+50+50

Notes: [a]http://www.fenegitimi.com/; [b]https://merakmakinesi.org/; [c]Taşdemir and Çalık (2017)

METHOD

Research Design and Study Group

This study used single case study design (Creswell, 2007) in order to describe the preservice elementary science teachers' views about engineering and engineers in an engineering-focused STEM course. The content of the course, and the participants taking the course constituted the boundaries of the case. The STEM course and PSTs taking the course were assumed to be a typical case and the lessons learned from this case were expected to be informative about the experiences of an average PST in an average STEM course (Creswell, 2007).

Purposeful sampling was used to reach participants. The study group involved 18 senior PSTs (16 female, 2 male), who have taken the STEM elective course in a public university. These PSTs will be elementary science teachers for grade 3-8 upon graduation. Gender proportion of participants is representative of the proportion in the population (Higher Education Council, 2020).

The Study Context

In Turkey, elementary science teachers are expected to graduate from a four-year undergraduate science education program. All science education departments are following a centralized undergraduate curriculum determined by the Higher Education Council. The science teacher education program consists of coursework including a number of elective and mandatory courses. Although mandatory courses have common content in different universities, the content of elective courses may vary. This study was conducted in an elective course offered in the fourth year of elementary science education program.

Goals of the course were to enhance PSTs' knowledge about STEM education, and to help them gain experience in terms of being engaged in and planning EDP activities. Current literature highlighted the importance of giving explicit instruction of the nature of engineering to students in addition to engaging them in engineering practices to develop students' understanding effectively (Deniz et al., 2020a; Pleasant and Olson, 2019b). Therefore, the content of the course included theoretical instruction, discussions and as well as design activities. The weekly schedule of the course activities was provided in **Table 2**.

The purpose of Week 1 was to provide a theoretical background about STEM and, specifically, engineering. In this week, definition of STEM, the need for STEM education, the brief history of STEM education, and the pedagogical approaches to STEM education were presented theoretically. Moreover, the role of engineering as a unifying context in STEM education was mentioned by introducing current engineering education integration frameworks. Then, the place of engineering in the Turkish science curriculum was discussed. Afterwards, the characteristics of engineers and engineering were discussed in small group and whole class discussions. In addition, some key terms were introduced like engineering habits of mind, product, design, EDP, criteria, constraint, prototype, optimization, and so on. EDP steps of Hynes et al., (2011), "identify need or problem, research need or problem, develop possible solutions, select best possible solution, construct a prototype, test and evaluate solution, communicate the solution, redesign" (p. 9), which were used in the later design activities in the course, were introduced and discussed.

The purpose of Week 2 was to help PSTs learn more about what engineers do in their professional life, namely in engineering companies. For this purpose, an electrical and electronics engineer, who has been working in a company for more than ten years, was invited to the course. PSTs were allowed to ask their questions about engineers and engineering. The guest engineer explained what they do in their company and how they go through EDP. The guest also emphasized the tenets of the nature of engineering, which are definition and purpose of engineering, characteristics of good engineer and engineering, EDP, factors affecting engineering and the similarities and differences between science and engineering by relating them with real life experiences.

The purpose of Weeks 3 to 6 was to engage PSTs in engineering design experiences through three different activities, namely, streetlight, wave machine, and bridge design activities. In these activities, PSTs were firstly expected to define the problem in a given situation. Then, they were asked to do a brief research to collect related information about the problem. They were given time to work on the possible solutions. Each PST was asked to draw a prototype of their own design. They presented their solution to their group members, and they determined the prototype to be tested after an optimization process. After completing the drawing of their groups' prototype, they tried to construct it with provided materials and the course instructor tested each prototype for their efficiency in terms of given constraints and criteria. Then, they were given extra time to revise and retest their prototypes. At the end of the activities, each group presented their design to the whole class and shared their experiences.

The purpose of Weeks 7 and 8 were to foster PSTs' integration of EDP into their own science teaching. For this purpose, they were asked to design a lesson plan for elementary level including engineering design activities. Each PST worked individually and at the end shared their lesson plans with other PSTs to be discussed in the classroom.

As it is suggested in the literature (Deniz et al., 2020a), the course was designed as explicit-reflective in nature. We explicitly introduced EDP steps and NOE aspects to the participants during introductory lectures. Both the instructor of the course and guest electrical and electronics engineer emphasized on the phases of the engineering design and the nature of engineering. Moreover, we asked participants to reflect on their engineering design experiences in terms of NOE aspects. This explicit-reflective emphasis on the nature of engineering and EDP was expected to contribute to the participants' views of NOE.

Data Collection Tool

To reveal PSTs' views about engineers and engineering, an adapted version of the VNOE Questionnaire (Karataş et al., 2016) was administered. VNOE, originally, included 11 open-ended questions related to the definition and purpose of engineering, the similarities and differences between science and engineering, EDP (what and how engineers do to complete a task) and the characteristics of good engineering and good engineers. The questionnaire was translated into Turkish by the authors and a few changes were made. First, participants were not asked to make drawings in the third item. Instead, they were asked to explain their images of engineers and engineering. Second, to ensure proximity of the items, the name of the bridge mentioned in the 8th item was changed with a Turkish bridge. Third, the last item, "Do you think your answers to the previous questions are likely to change if we ask them again next year?" was removed because the questionnaire was administered to the participants at the beginning and end of the semester, and we aimed to detect those changes at different times. Other items were used as in the original version. Two experts from the science education field reviewed the adapted version of the questionnaire and some minor revisions such as changing the wording for some of the items were made accordingly. VNOE was administered to PSTs before and after the 8-week implementation. The approximate time of filling the instrument was 40 min. The PSTs voluntarily agreed to participate in the study.

Data Analysis

The VNOE data obtained at the beginning and end of the course were subjected to a qualitative analysis in three steps. In the first step, the categories and subcategories determined by Karataş et al. (2016) guided our initial data coding process. Both authors performed initial coding based on eleven categories and related subcategories in the six themes (engineering, the design process, factors that affect engineering, characteristics of good engineering, characteristics of good engineering, and science versus engineering) defined by Karataş et al. (2016). In the second step, PSTs' answers given under each category were analyzed inductively in detail. In this process, the codes of Karataş et al. (2016) as well as newly emerged codes were used. Some of the repeating codes and categories were eliminated or merged, and the final categories and codes were determined. For example, PSTs' answers initially coded under the sub-categories of "definition of engineering" and "purpose of engineering" were similar or complementary. Therefore, these two sub-categories were unified and named as "scope of engineering". The final version of the codes and categories together with the sample quotations can be found in **Appendix A**. The categories emerged in our study concerning the nature of engineering are:

1) views about engineers and engineering,
2) views about EDP,
3) views about the factors that affect engineering, and
4) views about science versus engineering.

In this process, 35% of the whole data was analyzed by both researchers according to the coding list they developed. Several meetings were arranged to come to a consensus about the codes. Among the two authors' coding, 85% agreement was obtained.

In the third step, a scoring rubric was created based on the available codes under each category. PSTs' answers were labeled as uninformed, partially informed, or informed (**Table 3**). A science education faculty member provided expert opinion to the created levels and definition of the levels in the rubric. Then, to create profiles of the PSTs' views before and after the STEM course, their answers were scored based on the developed rubric. To

Table 3. Scoring rubric for assessing PSTs' views about engineers and engineering

Category	Sub-category	Uninformed	Partially informed	Informed
Views about engineers and engineering	Scope of engineering	Provide irrelevant/ insufficient description (or could not provide any description at all)	Describe the scope of engineering as only creating a product/system/ knowledge	Describe the scope of engineering as solving real life problems through creating or revising a product/system/ knowledge
	Characteristics of good engineering	Could not mention any specific characteristics of the product, process, or impact of the engineering	Only mention the features of the developed product/system/knowledge such as strength, aesthetic, or originality	Mention the features of product/system/knowledge as well as the process of the design (e.g., methods and tools used), or the impact of the engineering (e.g., to the environment)
	Characteristics of good engineer	Only mention technical skills (e.g., design skills) or intrapersonal skills (e.g., analytical thinking)	Mention technical skills and intrapersonal skills	Mention technical skills, intrapersonal, and interpersonal skills (e.g., cooperation skills)
EDP	Considerations in design	Could mention only one of the criteria (e.g., strength) or constraint (e.g., budget, time)	Mention both criteria and constraints	Mention both criteria and constraints by differentiating them and giving examples
	What engineers do in EDP	Think that engineers build or fix different technologies as skilled laborers (construction workers or technicians) do rather than designing	Think that engineers only design the prototypes and do calculations	Think that engineers have different roles and duties in different parts of EDP beginning from planning, testing to marketing
	How engineers accomplish to complete EDP	Could not provide any clear explanation regarding the completion of EDP	Explain only individual work such as making calculations and planning	Explain that in different parts of the process, there is a need to carefully plan and implement the iterative EDP processes with a team including engineers who have different expertise
Factors affecting engineering		State that two different companies are likely to come up with the same solution for the same engineering problem	State that two different companies may come up with multiple solutions for the same engineering problem without mentioning the factors causing the differences	Emphasize the subjectivity and creativity of engineers, differences in the opportunities and vision of the companies that cause reaching different solutions to the same problems
Science versus engineering		Fail to mention that engineering and science are two different disciplines or that engineering, and science share some similar characteristics	Mention that science and engineering have both commonalities and differences without clearly defining these similarities and differences	Mention the similarities (e.g., methods, techniques, tools used) and differences between (the body of knowledge used and produced) science and engineering as well as the relationship between them

compute inter-rater reliability of the scoring rubric, two commonly used strategies, which are Intraclass Correlation Coefficient (ICC) and Cronbach's alpha, were utilized. Both authors rated twenty percent of the participants' answers. The average measure of ICC was .965 with a 95% confidence interval from .821 to .998 ($F(3,9) = 28.294$, $p < .001$). Based on the 95% confidence interval, ICC scores between 0.75 and 0.90 were found as indicative of good reliability (Koo and Li, 2016). Therefore, a good degree of reliability was found between measurements. Besides ICC, internal consistency was calculated through the most commonly used Cronbach's alpha procedure (Cronbach et al., 1972). Cronbach's alpha reliability was calculated as .965. The results of the ICC and Cronbach's alpha provided evidence for the reliability of the developed rubric. The whole data analysis process was illustrated in **Figure 1**.

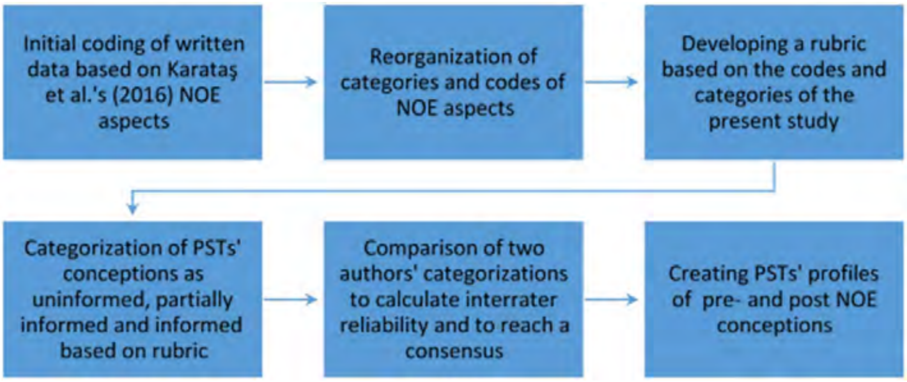

Figure 1. Data analysis process

FINDINGS

Findings are presented for the four categories (views about engineers and engineering, views about EDP, views about the factors that affect engineering, and views about science versus engineering) obtained from the analysis of PSTs' responses to open-ended questions. **Table 4** presents how PSTs' views about engineers and engineering changed across the four categories.

Table 4. Number and percentage of PSTs holding uninformed, partially informed, and informed views about engineers and engineering

Categories/sub-categories	UI [n (%)]		PI [n (%)]		I [n (%)]	
	Pre	Post	Pre	Post	Pre	Post
Views about engineers and engineering						
Scope of engineering	7 (39)	0 (0)	10 (56)	11 (61)	1 (6)	7 (39)
Characteristics of good engineering	4 (22)	1 (6)	12 (67)	13 (72)	2 (11)	4 (22)
Characteristics of good engineer	9 (50)	4 (22)	7 (39)	12 (67)	2 (11)	2 (11)
Views about engineering design process						
Considerations in design	7 (39)	3 (17)	6 (33)	7 (39)	5 (28)	8 (44)
What engineers do in engineering design process	4 (22)	1 (6)	13 (72)	8 (44)	1 (6)	9 (50)
How engineers accomplish to complete engineering design process	7 (39)	3 (17)	11 (61)	7 (39)	0 (0)	8 (44)
Views about the factors that affect engineering	4 (22)	2 (11)	6 (33)	2 (11)	8 (44)	14 (78)
Views about science versus engineering	3 (17)	1 (6)	5 (28)	3 (17)	10 (56)	15 (83)

Notes: UI: Uninformed; PI: Partially informed; I: Informed

Views about Engineers and Engineering

Under the category of views about engineers and engineering, three sub-categories emerged: scope of engineering, characteristics of good engineering, and characteristics of a good engineer. Overall, regarding the views about engineers and engineering, the number of PSTs holding uninformed views decreased majorly and PSTs holding informed views increased in number at the end of the course (**Table 4**). At the beginning of the course, 7 (39%) of the PSTs could not provide a description of the scope of engineering (uninformed views) and more than half of the PSTs (10, 56%) described engineering only as a profession creating new products or systems without further explanation such as how and why the new products and systems are developed (partially informed views). Only 1 (6%) of the PSTs held informed views and could be able to state that engineering aims to solve a real life problem. At the end of the course, the number of the PSTs holding informed views increased to 7 (39%), which indicates that nearly half of the PSTs were able to define engineering as an endeavor to find a solution to a real life problem through creating or revising a product, system, or knowledge. Although some of the PSTs' responses regarding the scope of engineering were still limited at the end of the course, it was apparent that there was an improvement in their responses according to our scoring rubric. Below PST11's definition of engineering before and after the course are provided, respectively:

> "Engineering is an area of complex thinking which utilizes mechanical and electrical materials" (PST11, uninformed, initial view).

> "Engineering is an endeavor to create new products or improve the existing ones by utilizing varying perspectives with the aim to find a solution to a specific problem" (PST11, informed, final view).

Regarding the characteristics of good engineering, the majority of the PSTs were holding partially informed views, which refer- in our scoring rubric- to the views that mention only about the quality of the developed product but not the process or impact of engineering. The number of PSTs in the partially informed category increased slightly from 12 (67%) to 13 (72%). In addition, PST responses mentioning neither the product, process nor the impact of the engineering were coded as uninformed; and their numbers decreased from 4 (22%) to 1 (6%) after the course. The number of PSTs having informed views increased from 2 (11%) to 4 (22%). While only one of the PSTs was holding uninformed views at the end of the course, only the minority of the PSTs emphasized the impact of engineering work and process on environment or society while describing good engineering as well as the quality of the product and the process. PST4 was one of the respondents who described the characteristics of good engineering at the end of the course by emphasizing on all three of the product, process, and the impact of the engineering work. Moreover, PST2's initial response is an example of an uninformed view:

> "I would call it good engineering if it creates a product that meets the needs of people and the criteria of the engineering process; however it would be bad engineering if the impact of engineering on nature was not considered" (PST4, informed, final view).

> "To me, if it provides a solution to a problem then it is good engineering" (PST2, uninformed, initial view).

The final subcategory was related to PSTs' views about characteristics of good engineers. Their responses were categorized as uninformed if they only mention the technical skills of engineers and as informed if they mention both the technical skills/characteristics, and the intrapersonal and interpersonal skills/characteristics of engineers. 9 (50%) of the PSTs were able to mention only technical skills/characteristics of engineers before the course; therefore, their responses were coded as uninformed. After the course the number of PSTs holding uninformed views decreased to 4 (22%). The number of PSTs holding partially informed views increased from 7 (39%) to 12 (67%) and informed views stayed the same at 2 (11%) at the end of the course. The participants in the partially informed category mentioned only the technical and intrapersonal skills/characteristics and neglected the interpersonal skills/characteristics of engineers. Below are the examples of PST responses representing uninformed, partially informed, and informed views before and after the course:

> "Engineers should be patient and diligent" (PST12, uninformed, initial view).

> "Good engineers are creative, have design skills and mathematical knowledge" (PST15, partially informed, final view).

> "Good engineers are expected to be the ones who are patient and creative and also have research and inquiry, problem solving and cooperative skills" (PST8, informed, final view).

Views about EDP

PSTs' views about EDP are categorized under three sub-categories; consideration in design, what engineers do in EDP, and how engineers accomplish to complete EDP. In general, the number of PSTs having uninformed views decreased, while the number of PSTs having informed views increased in all sub-categories. However, a considerable percentage of the participants have partially informed views both before and after the course.

In terms of considerations in design category, 7 (39%) PSTs were able to mention only one or two criteria such as strength, being environment friendly, being aesthetic, and being useful, or one or two constraints such as materials, duration of the process, and cost before the course. Their views were limited in depth, because they could not realize that engineers should consider many criteria as well as constraints caused from availability of time, materials and so on to be successful in an engineering work. The number of PSTs having uninformed views decreased to 3 (16%) after the course. On the other hand, the number of PSTs having informed views increased from 5 (28%) to 8 (45%) after the course. As PST16 mentioned what engineers should consider in planning of new bridge construction, they were able to state various criteria and constraints after the course.

> "Engineers should consider the strength and safety of the bridge. They should also keep in mind the needs of the society for this bridge, like what should be the size of it to reduce the traffic problem. Besides, they should decide the strength of the materials to be used without increasing the budget sharply. They should also consider environmental conditions while selecting appropriate materials and deciding the type of the bridge. They should also have aesthetic concerns while designing. Lastly, they should plan to use human resources carefully" (PST16, informed, final view).

Although the percentage of PSTs having informed views increased, the percentage of PSTs having partially informed views were still around thirty percent after the course. Although they stated that engineers should consider both criteria and constraints, they could not elaborate their answers.

In terms of what engineers do in EDP, PSTs' views become more informed after the course. 4 (22%) participants were imagining engineers as skilled laborers (construction workers or technicians) before the course. Those PSTs mentioned that in a bridge construction process, engineers do the construction part of the bridge like construction workers.

> "Engineers do the constructing part of the bridge. They lay the foundations of the bridge" (PST6, uninformed, initial view).

The number of PSTs having uninformed view decreased to 1 (6%) after the course. On the other hand, the number of PTSs having informed views increased from 1 (6%) to 9 (50%) after the course. They started to realize that engineers have many different roles and duties in different parts of EDP beginning from planning, testing to marketing. Throughout the course what engineers do in EDP is explicitly and implicitly emphasized. Although they did not have a clear idea about what engineers do, they started to understand engineers' duties and job descriptions. However, a considerable number of PSTs have still partially informed views, although their number decreased from 13 (72%) to 8 (44%). These PSTs think that engineers only do calculations and estimations, and design the prototypes as typically PST12 stated:

> "Mathematical calculations, design and modeling is done by engineers" (PST12, partially informed, initial view).

The pattern of the progress in views about how engineers accomplish to complete EDP is also similar to the other two sub-categories. The number of PSTs having uninformed views decreased, while the number of PSTs having informed views increased. However, a considerable amount of them still have partially informed views. The PSTs having partially informed views focus on individual work of engineers like making calculations and planning as typically PST5 stated:

> "I think disciplined work is important. Moreover, engineers should do more research, use their imagination, and make careful calculations to be successful in their work" (PST5, partially informed, final views).

Although none of them consider engineering as a process, requires careful planning and implementation of the iterative EDP processes with a team including engineers who have specialty in different parts of the process at the beginning of the course, 8 (44%) of them understood the iterative process and the importance of group work in the successful completion of EDP.

> "It is not enough just to imagine the product you designed. You need to prototype your design, test it a few times, and eliminate the errors quickly together with a successful team" (PST1, informed, final view).

Overall, PSTs' views about EDP became more informed after the course. Although some of them do not have any idea about what EDP is and what engineers do in this process at the beginning of the course, they started to give more information at the end of the course. They understood the iterative process included in the EDP. However, PSTs should be supported more in understanding EDP, because there are still many PSTs having partially informed views even after the course.

Views about the Factors that Affect Engineering

The participants were asked to envision that if two different engineering firms were given the same task, would the product be more or less the same or not. PSTs' views about the factors affecting engineering developed after taking the course. Although 8 (44%) PSTs had informed views before the course, the number of PSTs having informed views increased to 14 (78%) after taking the course. That means they realized that the end product of engineering is not absolute. There may be multiple solutions to a single problem. According to their statements, the most important factors causing these differences are subjectivity and creativity of engineers, the availability of resources and the vision of the engineering companies. For example, PST9 made an emphasis on the creativity of engineers as an influential factor causing different solutions.

> "Although the criteria are the same, the product would not be the same. In fact, it would be pretty much different. Because engineers' creativity and background are different. Moreover, materials used by them differ" (PST9, informed, final view).

Some of the PSTs still could not explain the reasons causing the difference, although they thought that the end-product would not be the same. However, the number of those PSTs decreased from 6 (33%) to 2 (11%) after the course. Similarly, the number of PSTs thinking that the products would be the same decreased from 4 (22%) to 2 (11%) after the course. These PSTs argued that since the given criteria and constraints are the same, different firms' solutions would be the same.

Overall, PSTs' views developed in this category. Throughout the STEM activities, PSTs were asked to work in groups to find solutions to given problems. They observed how each group member came up with different solutions related to the problem due to the differences in their imagination. Therefore, they started to consider the influence of individual differences on the design process more after the STEM course.

Views about Science versus Engineering

PSTs' views about science versus engineering became more informed after the course. The number of PSTs having informed views increased from 10 (56%) to 15 (83%). More PSTs realized that although engineering is different from science, they also have similarities. Thus, they mentioned both similarities and differences of science and engineering after the course. They stated that both science and engineering use similar methods, and tools. PSTs referred to more general methods of problem solving like reasoning, trial and error, or experimentation rather than any specific scientific method. PSTs stated that both of them do research, and design something like products or experiments. Moreover, more PSTs started to think both science and engineering includes iterative processes. After the STEM course, PSTs realized that engineers use similar methods, techniques, and skills.

In addition to similarities, PSTs stated some differences such as science is theoretical, engineering is practical; science produces knowledge, engineering produces products; ND science is more exhaustive. Moreover, the PSTs realized that constraints have an important role in the product of engineering, although the constraints do not influence the answers reached through the scientific processes but the scientific process itself. PST10 tried to express these issues as follows:

> "It is not necessary to obtain a product in science. It may remain in the form of theory, principle, etc. It cannot reach something that has constraints in line with what is desired in science. In engineering, there must be a product at the end of the process and this product has constraints" (PST10, informed, final view).

The number of PSTs having partially informed views decreased from 5 (28%) to 3 (17%). PSTs having partially informed participants also mentioned science and engineering have both similarities and differences, but they could not clearly explain these similarities and differences. PSTs having uninformed views either considered science and engineering as the same endeavor or totally different disciplines. The number of PSTs having uninformed views decreased from 3 (17%) to 1 (5%) after taking the course.

DISCUSSION

Findings of the study revealed that for all the four categories (i.e., views about engineers and engineering, views about EDP, views about the factors that affect engineering, views about science versus engineering), the number of PSTs holding uninformed views decreased and the PSTs holding partially informed and informed views increased at the end of the semester. Moreover, except for the characteristics of good engineering and engineer, the number of PSTs holding informed views were the highest compared to uninformed and partially informed views in each of the sub-category. Below we presented the discussion of our findings regarding the participants' views of engineers and engineering in the four main categories.

Views about Engineers and Engineering

Regarding the views about the scope of engineering, there were no PSTs holding uninformed views at the end of the course. Moreover, the number of PSTs holding informed views increased considerably. On the other hand, the number of PSTs holding partially informed views stayed nearly the same. These findings indicate that the STEM course was effective for improving PSTs views but not necessarily for each of the PSTs taking the course. More specifically, the STEM course was effective for changing PSTs' uninformed views into informed views, however, it was not effective enough for transforming partially informed views to informed views. In other words, more than half of the PSTs were aware at the end of the course that engineering aims to create products, knowledge, or process but they were not able to mention that the created products, knowledge, or process are for solving a real life problem. Similar findings were obtained by Kaya et al. (2017) that the number of PSTs holding uninformed views about the demarcation of engineering decreased and the number of PSTs holding informed views increased at the end of a 15-week long engineering design intervention. However, the number of partially informed views stayed nearly the same. Moreover, within the context of a semester-long engineering-focused course, Deniz et al. (2020a) reported that elementary teachers' pre and post scores for the views about demarcation of engineering were the lowest among the six aspects of the nature of engineering. Our findings can be interpreted together with the current literature that this sub-category is one of the most difficult sub-categories to be developed among the others. Further studies should focus more on finding alternative ways to develop PSTs' views about the scope of engineering.

PST views about the characteristics of good engineering and engineer mostly evolved from uninformed to partially informed. At the end of the course, all of the PSTs except one were able to mention that good engineering produces a product, system, or knowledge. However, the number of PSTs emphasized on the process of engineering or the impact that the product has on the environment and society while describing the characteristics of engineering was still low. Similar findings were obtained by Kaya et al. (2017) with preservice elementary teachers that the least development in participants' views of engineering was in the social and cultural embeddedness aspect of engineering. In another study by Wheeler et al. (2019), analysis of observational data obtained in five science teachers' classroom practices revealed that ethical aspects of engineering such as impact on environment and society were among the aspects that science teachers allocated less time on. In our study, although one of our EDP activities was specifically about solving an environment-related problem, unexpectedly, a low number of PSTs considered the environmental impact of engineering work. In addition to the emphasis on the quality of the product itself or the steps of EDP, a clear emphasis during engineering design activities on the impact of engineering work on environment and society might have revealed more participants holding informed views. Moreover, using design activities which require using outdoor spaces and collecting real data from the environment might help to develop PSTs' views about the environmental aspects of engineering.

While describing the characteristics of a good engineer, PSTs mostly mentioned intrapersonal and technical skills (and characteristics) of engineers. That is, most of the PSTs view engineers stereotypically as highly competent, hardworking, creative, and smart people However, most of them did not consider interpersonal skills such as leadership or cooperation skills while describing a good engineer at the end of the semester. This finding indicates that the PSTs still considered engineering as an individualistic profession rather than a profession that requires teamwork and collaboration among people with various expertise. Existing studies on preservice and in-service teachers' views of engineers have reported similar findings that the participants emphasize more on individualistic and technical skills and characteristics rather than social characteristics while describing a good engineer (Ergün and Kıyıcı, 2019; Hammack and Ivey, 2017). During the STEM course that was designed and implemented in the present study, the PSTs were totally free in their groups to assign duties to group members. Also, there were times some of the group members were more active than the others in the group. Therefore, they did not experience any negative effects of losing any group members. Designing more structured cooperative learning environments in STEM courses may foster PSTs' views of good engineers and lead to a more comprehensive view of engineers having social skills as well as the individualistic and technical skills.

Views about EDP

At the end of the course, the number of PSTs holding uninformed views of EDP decreased and PSTs holding informed views increased for each of the subcategories of considerations in design, what engineers do in EDP, and how engineers accomplish to complete EDP. Moreover, the number of the participants in the informed category was the highest compared to uninformed and partially informed categories after the course. These findings indicate that the STEM course was effective for the enhancement of PSTs' views of EDP. More specifically, almost all of the participants in this study were aware that engineers consider some criteria and constraints in EDP. Furthermore, at the end of the course, half of the PSTs were able to explain that rather than only doing calculations and designing prototypes, engineers have different roles and duties in different stages of EDP. Also, half of the PSTs were able to explain that engineers accomplish to complete EDP by carefully planning and implementing the iterative EDP processes with a team of engineers. One explanation for the noticeable development in PSTs' views of EDP was that the STEM course was designed as explicit-reflective in nature, that is, EDP steps were introduced explicitly (Deniz et al., 2020a) and the PSTs were supported throughout the course to experience the EDP steps in three different STEM activities related to real life. In other words, the design-based and engineering focused STEM activities might provide PSTs with the opportunity to practically apply EDP skills into the process of finding solutions to real life challenges. That might in turn foster their conceptions and views of EDP. Similar findings were obtained by Aydın-Günbatar et al. (2018) with a group of preservice chemistry teachers. In their study, Aydın-Günbatar et al. (2018) explicitly taught the engineering design stages (brainstorming, research, design, construction and testing, redesign, evaluation) proposed by Wheeler et al. (2014) and exposed the participants to five different chemistry-related STEM activities in an engineering-focused STEM course. They reported that at the end of the course, all of the participants except one developed their views of engineering and EDP in particular.

Both Aydın-Günbatar et al. (2018) study and the analysis of the data obtained from PSTs in the present study provided empirical evidence that explicit teaching of EDP could develop PSTs' views of EDP in terms of considerations in design, what engineers do in EDP, and how engineers accomplish to complete EDP.

Views about the Factors that Affect Engineering

PSTs' views of the factors that affect engineering developed at the end of the STEM course. Most of the PSTs pointed out that the two products produced by different companies would be different. This shows that PSTs realized the subjective nature of engineering. It is emphasized in different VNOE frameworks that there is no single best solution to an engineering design problem (Deniz et al., 2020a; Karataş et al., 2016). When their explanations causing this difference were examined, it was found that most of them highlighted the creativity of engineers. They stated that different engineers in the team of different companies have different states of mind and imagination. Therefore, they understood the major role of creativity and imagination of engineers in solving an engineering design problem. The subjective NOE aspect was the aspect in which students made considerable progress in other similar studies as well (Aydoğan and Çakıroğlu, 2022; Deniz et al., 2020a). Similarly, in our study, this category is one of the categories that almost all of the PSTs have informed views after the STEM course. Only a small minority of them mentioned that the two products would be similar, and the reason was reported as the similarity of the groups' task requirements.

In general, PSTs developed an understanding about subjectivity and creativity in engineering. However, there are also other various factors that might cause differences and similarities between engineering products that were not considered by PSTs. For instance, the majority of the PSTs did not mention the possibility that the two groups of engineers may have to carry out EDP with different constraints and specifications. Yet, which constraints and specifications are determined by engineers to be considered in EDP majorly influence the produced technology (the product or process) (Cross, 2000; Pleasants and Olson, 2019b). Moreover, those who stated that engineers themselves are the critical factor that creates the difference between the two products, mostly focused on imagination and none of them mentioned about the other important characteristics of engineers that may influence EDP such as value systems, social and cultural background, ethical considerations, and communications skills (Adams, 2004; Fromm, 2003). Karataş et al. (2016) found similar results that the engineering students who stated the existence of multiple ways of solving the same engineering problem referred only to the creativity of engineers and did not recognize the other factors causing the diversity in engineering solutions. More emphasis on the other factors causing differences could be beneficial to develop a better understanding.

Views about Science versus Engineering

It is important for science teachers to understand the relationship between science and engineering to be able to teach engineering in science classrooms as indicated in the Turkish science curriculum (MNE, 2018). The number of PSTs having informed views after the STEM course was the highest in this category. The PSTs noticed that science and engineering have both commonalities and differences. Although engineering is different from science, the logic behind the systems engineering approach and the scientific discovery have resemblance (Lewin, 1983). They understood and clearly explained this resemblance. PSTs stated that both of them do research, and design something like products or experiments. Moreover, more PSTs started to think both science and engineering includes iterative processes. In their previous coursework, the PSTs had experience on doing scientific investigations by following iterative processes in different courses such as laboratory applications in science. Therefore, they were already familiar with the methods and skills used and procedures followed in scientific investigations. After experiencing the EDP in the course, PSTs realized that engineers use similar methods, techniques, and skills. They also realized that the steps followed in EDP are not straightforward as in the hypothesis testing process.

PSTs also stated the differences between science and engineering. They mostly thought that science and engineering have different goals so yield different products, and engineers use the products of science (scientific knowledge) to create engineering products (artifacts). However, they failed to recognize that engineering is also concerned with knowledge production, although it is in a different form from scientific knowledge (Pleasant and Olson, 2019b). The knowledge produced in engineering is specifically for use in design, and engineers need this knowledge base specific to engineering (Pleasant and Olson, 2019b).

Overall, PSTs had informed views about science versus engineering after the STEM course. However, the number of PSTs having informed views before the course was also high. Participants of this study were PSTs in their last semester of their teacher education program. They took many courses about the nature of science (NOS). While there are some courses which aim mainly to teach NOS, there are also other courses that utilize NOS and relate it with other concepts. Therefore, although it is not assessed in the scope of this study, they were expected to have informed views about NOS. Therefore, their NOS views would have contributed to their views of NOE.

Investigating the relationship between views of NOS and views of NOE can be enlightening to understand the high levels of understanding revealed in this category both before and after the STEM course.

Limitations and Future Work

This study has some limitations to be considered while interpreting the current results. First, the implementation lasted eight weeks and four of it were devoted to EDP activities. Engineering is an iterative process and exposure to EDP in limited times may not lead to meaningful learning (Schunn, 2009). Students need to be given the opportunity to redesign to develop better views about engineers and engineering (Schunn, 2009). In this study, PSTs were given enough time only in one of the activities (bridge design) to redesign their solutions in the second week. If there would be a chance to let them study on the same project for the whole semester and give enough time for each step of EDP, they would develop a more complete understanding of engineers and engineering. Moreover, the findings of the study are limited to the specific context of this study. There is only one group consisting of volunteer PSTs selecting the elective course. Applying this implementation to a different group of PSTs with a different educational background might yield different results.

In the present study, similar to the previous research (e.g., Aydın-Günbatar et al., 2018; Pleasants and Olson, 2019a; Pleasants et al., 2020) working with other group members and taking continuous feedback from the instructors throughout EDP experiences helped PSTs develop their views of EDP during the STEM elective course. However, it would be speculative if we report that the designed STEM course with more focus on experiencing EDP is fully effective in developing PSTs' views of engineers and engineering for all of the subcategories. Further attempts to develop PSTs' views about engineering and engineers are advised by especially including more explicit references to moral and cultural issues in engineering design activities.

CONCLUSION

This study investigated PSTs' views of engineering and engineers before and after an elective engineering-focused STEM course. The results indicated that overall PSTs views of engineering and engineers improved after the course and the number of PSTs holding uninformed views decreased for each of the subcategories. The PSTs' views became more informed, although there is a need for more improvement. As it was suggested in the related literature, offering courses in preservice education have the potential to help PSTs develop sound views about engineers and engineering (Aydın-Günbatar et al., 2018; Pleasants et al., 2020). This study provides empirical evidence that providing PSTs with explicit NOE instruction and engaging them in EDP activities is effective to develop their views of engineering and engineers. However, there were still stereotypical views of engineers among PSTs at the end of the course. Although most of the PSTs were aware of the cognitive skills required in engineering, they mostly ignored the sociocultural aspect of engineering. Therefore, in order to develop a more complete view of engineers and engineering, the value-added nature of engineering should be taught to PSTs through explicit emphasis on the social and environmental norms in the designed activities.

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APPENDIX A

Table A1. Subcategories and codes/subcodes for VNOE

Sub-categories	Codes (Sub-codes)	Exemplar
Views about engineers and engineering		
Scope of engineering	Creating/improving products, identifying and solving problems, integration of different disciplines, involving different branches, discovering how and why things work, making things/life easier, contribution to country development	I think engineering is the profession of people who can find practical solutions to the problems by utilizing technology, mathematics, and science.
Characteristics of good engineering	Product oriented (aesthetic, profitable, meeting the needs, strength, usefulness, originality), process oriented (methods and tools, implementation process), impact oriented (environment, society)	[Good engineering] can be determined by the resulting product. The product should be useful. [Good engineering] can be distinguished from the method and algorithm used in works. I would call it good engineering if it gives no harm to the environment in any way.
Characteristics of good engineer	Technical skills/characteristics (adapting to recent developments, scientific and technical knowledge, design skills, inquiry, and research skills), intrapersonal skills/characteristics (hardworking, solution oriented, open minded, dedicated, patient, disciplined, imaginative and creative, diligent, analytical thinking, have an agile mind, problem solver, self-confidence), interpersonal skills/characteristics (leadership, cooperative)	The engineer should follow the developments in his/her field and keep up with these developments. You have to be a very careful and disciplined person in order to complete the work and avoid mistakes. Engineers should be able to cooperate with other workers in the team.
Views about engineering design process		
Considerations in design	Criteria (meeting the needs, environment friendly, strength, usefulness, in harmony with the surrounding, added value of the product, aesthetic), constraints (materials, duration of the process, cost)	It is necessary to determine the deficiencies in existing bridges and accordingly why a new bridge is needed. Engineers should create a product that meets the constraints and criteria at the most affordable cost.
What engineers do in engineering design process	Design, making estimations and calculations (estimations and calculations, strength, cost-effectiveness, time demand), planning and construction, testing prototypes, marketing	The design and modeling of the bridge is done by engineers. It is engineers' responsibility to make the bridge strong and durable.
How engineers accomplish to complete engineering design process	Collaboration of different specializations, testing prototypes through iterative cycles, careful planning, and implementation, as a teamwork	[They succeed] by working in collaboration with other fields. For example, working with an economist or accountant if s/he wants the cost to be less, or with an architect if s/he wants it to be aesthetically pleasing. Engineers would be successful if they work together harmoniously as a team.
Views about the factors that affect engineering		
Factors causing differences	People/engineers (knowledge and skills, imagination, and creativity), company opportunities and resources, vision, and mission of the company	Although the products obtained serve the same purpose, they would not be the same design because the imagination comes into play in design and the products will be different because everyone's imagination is different. The two companies have different practices according to their own purposes.
Views about science and engineering		
Similarities	Progressive, mutual relationship with technology, solving real life problems, requires creativity and imagination, includes curiosity, Inventing, methods, techniques, and skills used, includes iterative processes	Both improve with technology, and both improve technology. They are similar in terms of the methods and techniques (reasoning, experiment, etc.) they use.

Table A1 (Continued).

Sub-categories	Codes (Sub-codes)	Exemplar
Relationships	Science and engineering are complementary, using scientific knowledge to create products	Engineering benefits from science. Science can also benefit from engineering. They are intertwined.
Differences	Science produces knowledge, engineering produces products and solutions, science is theoretical, engineering is practical, tentativeness and subjectivity, science is more exhaustive	It is not necessary to obtain a product in science. It may remain in the form of theory, principle, etc. It cannot reach something that has constraints in line with what is desired in science. In engineering, there must be a product at the end of the process and this product has constraints.

Note. The underlined codes or sub-codes are illustrated in the provided exemplar.