European Journal of Education Studies
ISSN: 2501 - 1111
ISSN-L: 2501 - 1111
Available on-line at: www.oapub.org/edu

DOI: 10.46827/ejes.v9i10.4486 Volume 9 │ Issue 10 │ 2022

EXPLORATION OF PRE-SERVICE SCIENCE TEACHERS' ENGINEERING DESIGN PERFORMANCE DEVELOPMENT[i]

Asli Koculu,
Mustafa Sami Topcu[ii]
Department of Mathematics and Science Education,
Yıldız Technical University,
Istanbul, Turkey

Abstract:
In recent years, integration of engineering design with science teaching has often been preferred more since STEM Education (based on the integration of the science, technology, engineering and mathematics disciplines) has been an integral part of science education in many countries all over the world. Integrating engineering design with science teaching can be complex for science teachers because it has been relatively new and teachers have not been trained enough about it yet. Within this context, it is crucial to raise pre-service science teachers (PSTs) capable of integrating the engineering design process with science teaching effectively because they are implementers of future science teaching. In this manner, the purpose of this study is to explore pre-service science teachers' (PSTs) engineering design performance development through STEM Education. A case study design was used in the current research. The research group was 20 PSTs who enrolled in 'STEM Education' course at a public university in Istanbul, Turkey. The data were collected with open-ended forms including 9 steps of the engineering design process. In the data analysis process, open-ended forms including PSTs' responses about what they did in every step of engineering design for each STEM practices were analyzed with 'Engineer's Notebook Rubric'. Results showed that PSTs' engineering design performance improved considerably week by week during 'STEM Education' course.

Keywords: engineering design, STEM education, pre-service science teachers, science education

[i] This research was presented as oral presentation at 2021 ESERA conference in Braga, Portugal, August 30-September 3, 2021.
[ii] Correspondence: email akoculu@yildiz.edu.tr, mstopcu@yildiz.edu.tr

1. Introduction

In recent years, integration of engineering design with science teaching has often been preferred more in science teaching since STEM Education (based on the integration of the science, technology, engineering and mathematics disciplines) has been an integral part of science education in many countries all over the world. Science has been taught as integrated with different disciplines like mathematics and technology for a long time. However, the integration of engineering with science education is relatively new and still very much a work in progress (Katehi, Pearson & Feder, 2009). National Research Council (2012) emphasized that engineering and technology integration with science is important in terms of two critical reasons which are the reflection of the significance of understanding the human-built world and the recognization of the value of better integrating the teaching and learning of science, engineering, and technology integration. With engineering integration into science, students can have meaningful learning experiences by establishing a connection between theoretical knowledge and practice in the engineering design process (NGSS Lead States, 2013). Students' performances in engineering design can be developed with well-qualified science teachers during the engineering design process. However, science teachers do not have the required pedagogical content knowledge to integrate engineering design with science teaching (Kaya et al., 2019). Wendell, Swenson and Dalvi (2019) stated that teacher education programs are very important for preparing elementary teachers to teach engineering design. If pre-service science teachers can be raised as qualified with integrating engineering design into science teaching, they can implement the engineering design process effectively in their future classrooms and contribute to the development of their students. As Katehi, Pearson and Feder (2009) mentioned, learning standards, ways of guidance for teacher development and assessments for students' achievement in engineering design should be improved for engineering design applications. Pre-service science teachers' learning how to use engineering design to teach science is a complex endeavor (Capobianco & Radlof, 2021). In this manner, the purpose of current research is to explore PSTs' engineering design performance development through STEM Education and the research question is as follows:

- How do pre-service science teachers' engineering design performances develop through STEM education?

2. Engineering Design Process

In science teaching and learning, the increase of engineering design applications with STEM education is crucial in terms of presenting many important outcomes for students. Engineering design refers to "*the approach engineers use to solve engineering problems—generally, [is] to determine the best way to make a device or process that serves a particular purpose*" (National Research Council [NRC], 2009, p. 49). In the engineering design process, good design challenges include compelling real-life problems which have multiple solutions for motivating students to ask questions, search about problems, develop solutions, design prototypes or models, evaluate solutions, discuss and redesign (Benenson, 2001; Crismond, 2001; Sadler, Coyle, & Schwartz, 2000) and students follow these systematic and iterative steps (Berland, Steingut & Ko, 2014; Capobianco, DeLisi & Radloff, 2017; NRC, 2012; Wendell, Andrews & Paugh, 2019). According to Hynes et al. (2011), there are nine main steps of the engineering design process: (1) identifying the need or problem, (2) searching need or problem, (3) developing the possible solutions, (4) selecting the best possible solution, (5) constructing a prototype, (6) testing and evaluating the solution, (7) communicating the solution, (8) redesigning and (9) completing decision (Figure 1). These steps enable students to interact with engineering in hands-on activities as a practical application of science and math knowledge (Hynes et al., 2011). The engineering design process, which improves problem-solving skills in learning environments, forces individuals to understand the problems, distinguish, and understand processes that lead to solutions (Morrison, 2006). The practices of engineering design help students understand how science and engineering relate to real-world problems and apply their scientific knowledge to these problems (NRC, 2012).

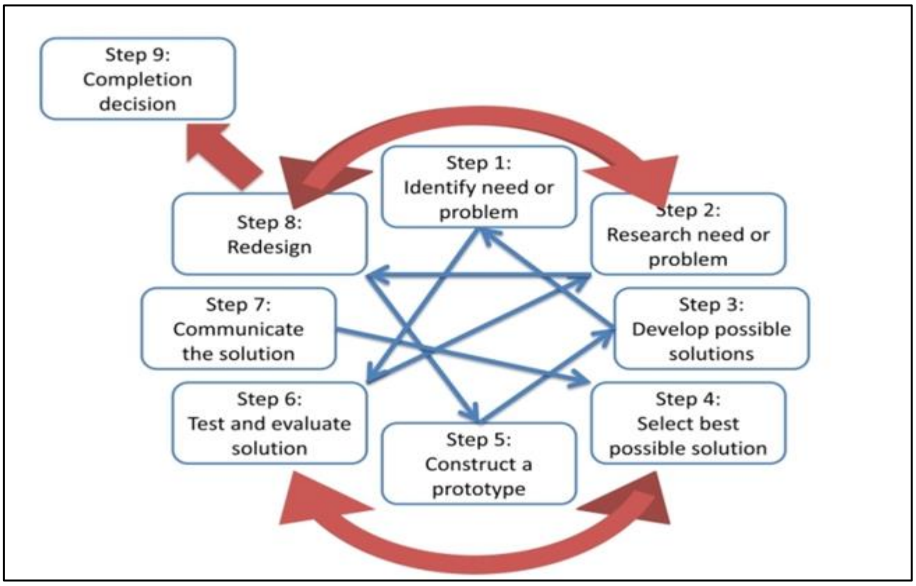


Figure 1: Engineering Design Process (Hynes et al., 2011)

3. Method

3.1 Research Design

This research was designed as a case study which is one of the qualitative research methods. According to Yin (2013), a case study investigates a phenomenon within its real-life context and provides an in-depth descriptive and exploratory analysis of individuals, groups or events to researchers. This study is an exploratory analysis of PSTs' engineering design performance development week by week. The current research was designed in the way that PSTs made different STEM practices as a group by following the steps of the engineering design process for 4 weeks.

3.2 Research Group

The research group of the present study consists of 20 PSTs who studied at a public university in Turkey. PSTs chose the 'STEM Education' course and participated in the study voluntarily. PSTs did not take courses or training about STEM until they participated to 'STEM Education' course. Since PSTs will teach science by integrating the engineering design process to 5^{th}-8^{th} grade levels students in elementary and middle schools after they graduate from university, they were chosen as the research group in this study.

3.3 Research Context and Implementation

This research was carried out with 20 PSTs who enrolled in "STEM education" course at a public university in Istanbul, Turkey. The implementation lasted 5 weeks. In the first week of 'STEM Education' course, general information about STEM education and some examples of implementations were given by the instructor. STEM practices started in the second week. The practice period of the study consisted of four weeks (2 hours per week). The practice process was conducted in the context of "Mechanic and Static" subject. During 4 weeks, PSTs made different STEM practices collaboratively in groups consisting of 5 students by following the steps of the engineering design process (Table 1) (Hynes et. al., 2011). Moreover, as a group, PSTs filled up open-ended forms including the nine steps of the engineering design process by considering how they can complete each step of STEM practices and discussing the logical reasoning of the prototypes that they constructed with their group mates during STEM practices.

Table 1: Implementation of STEM Practices

Weeks	**Implementation**	**Engineering Design Process**
1^{st} week	General information about STEM education	
2^{nd} week	'Space Vehicle' prototype which is able to descend to Mars planet without being damaged by using different materials pipette, plastic bag, string, band and paper.	**Step 1:** Identify the need or problem **Step 2:** Research need or problem **Step 3:** Develop possible solutions **Step 4:** Select the best possible solution **Step 5:** Construct a prototype **Step 6:** Test and evaluate the solution **Step 7:** Communicate the solution **Step 8:** Redesign **Step 9:** Completion decision
3^{rd} week	'Spacecraft Milo' prototype which is capable of moving on the inclined surface of planets' land without falling from the surface, having a sensor to perceive foreign objects in front of it, and exploring on planets.	
4^{th} week	'Earthquake Resistant Building' prototype by testing the effect of balanced and unbalanced forces on objects' movements.	
5^{th} week	'Swing Bridge' prototype.	

3.4 Data Collection

In this study, the data collection tool was the open-ended forms, including 9 steps of the engineering design process (Table 1) (Hynes et al., 2011). For each STEM practices, PSTs filled up these forms by explaining what they did in every step of the engineering design process while they were making each different STEM practices collaboratively in groups for 4 weeks.

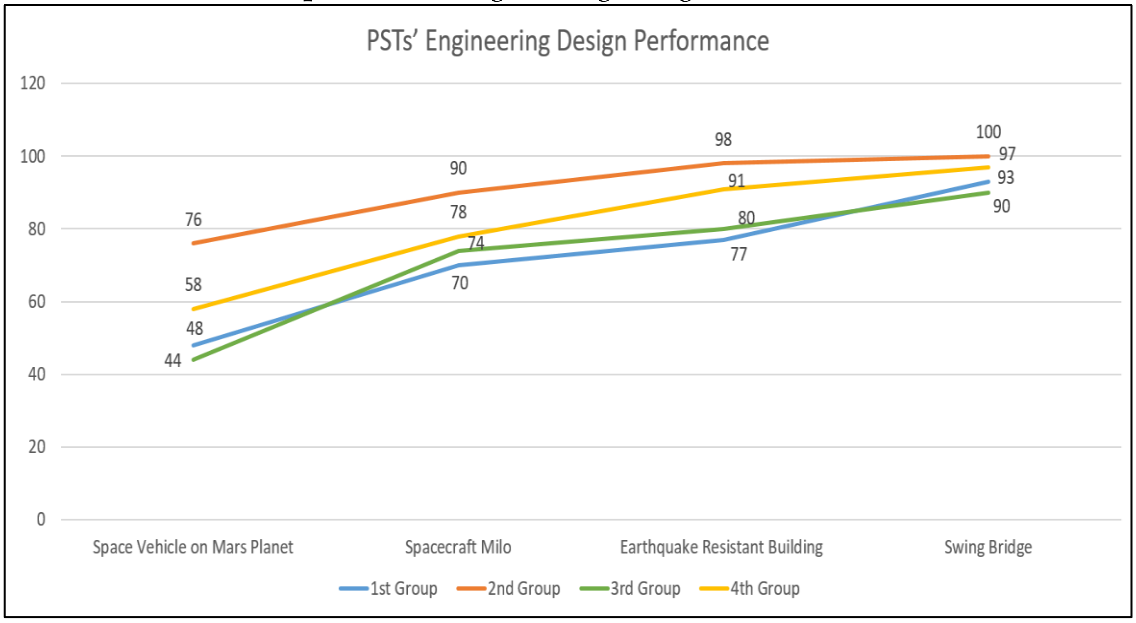
3.5 Data Analysis

In data analysis of forms including responses of PSTs about what they did in every step for each engineering design, Engineer's Notebook Rubric, developed by Kelley (2013), was used. This rubric is a 1-3 numeric scale with 1= low, 2= medium, and 3= high level of performance and its grade point ranges are assigned to these three level scales. In level scales of the rubric, low level is designated as 6 points or below; medium level equals either 7 or 8 points, and high level equals 9 or 10 points. The total grade point of the rubric is 100 points (Kelley, 2013). The rubric consists of detailed explanations about low, medium, and high level of performance at steps of the engineering design process. Forms, filled up by PSTs as a group for each engineering design, were graded by researchers according to 'Engineer's Notebook Rubric' and total grade points for each group in every engineering design were calculated.

4. Results

Graph 1 shows both the total grade points of all groups for each engineering design and their performance development during 4 weeks. According to the results in this graph, 1st, 3rd and 4th groups have low level performance (48, 44 and 58 points respectively) while 2nd group shows medium level performance (76 points) in the first engineering design activity (Space Vehicle on Mars Planet). In the second engineering design activity (Spacecraft Milo), 1st, 3rd and 4th groups have medium level performance (70, 74 and 78 points respectively) while 2nd groups shows high level performance (90 points). In the third engineering design activity (Earthquake Resistant Building), 1st and 3rd groups has medium level performance (77 and 80 points respectively) while 2nd and 4th groups shows high level performance (98 and 91 points respectively). In the fourth engineering design activity (Swing Bridge), all groups (1st, 2nd, 3rd and 4th groups) have high level performance (93,100, 90 and 97) points respectively). As it is understood from Graph 1, PSTs' engineering design performance developed week by week. 3rd is the most developing group in the engineering design process. Their points were 44 in the first engineering design activity (Space Vehicle on Mars Planet) and were 90 in the last engineering design activity (Swing Bridge). In addition, 2nd group has the best engineering design performance during STEM practices.

Graph 1: PSTs' Engineering Design Performance



On the other hand, even though PSTs' scores in each step increased from first to last STEM practices, results showed that their scores in steps of identifying a need or problem, researching the need or problem, and communicating a solution were generally high level (9 or 10 points) while developing possible solutions, selecting the best possible solution, and constructing a prototype were generally low level (6 points or below) at first and second activities. Moreover, PSTs had medium scores on the steps of testing and evaluating the solution, redesigning and completing decisions (7 or 8 points) during the first and second STEM practices. PSTs developed their performance in each step of the engineering design process and their scores at each step increased at the end of STEM implementation.

5. Discussion and Conclusion

In this research, PSTs' engineering design performance development was examined through STEM education. PSTs practiced how to design by constructing theoretical and practical knowledge during 'STEM Education' course. Results showed that PSTs' engineering design performance improved considerably week by week. Apedoe et al. (2008) in their study revealed that high school students learned chemistry subjects (e.g. atomic interactions and reactions) effectively by using iterative steps of engineering design. In the present century, acquiring knowledge or skills is not the only expected outcome of science education. Individuals should be able to put their knowledge or skills into practice and integrate their knowledge or skills with daily or professional life. This can happen by engaging students in the engineering design process. However, most science teachers do not feel confident in teaching science by using an integrated STEM approach (Cunningham & Carlsen, 2014). According to Williams et al. (2016), teachers believe that it should be given priority to their professional development developing engineering education because teachers haven't enough training about how they educate their students about engineering topics and do not feel confident about implementing engineering design activities. Kim, Oliver and Kim (2019) showed in their research that PSTs' confidence in teaching engineering increased through their experiences with engineering design activities. Therefore, preparing pre-service teachers for teaching science with engineering design is an important requirement at present. When PSTs, who are future elementary and middle school science teachers, are raised as well-equipped with engineering design, they can raise individuals capable of developing solutions for coping with real-world problems in this age of innovation.

Engineering design learning experiences have gradually increased with STEM Education in all grade levels including pre-school, elementary, secondary, high schools and universities in recent times, but there are few studies about how pre-service science teachers' knowledge and practices about engineering design can be developed. Therefore, this research is important in terms of presenting an innovative way to develop PSTs' engineering design performance. In addition, this research contributes to the literature in terms of helping PSTs construct knowledge and gain experience in the engineering design process. In order to develop students' engineering design performance, science teachers' engineering performances should be promoted. Teacher education programs are crucial for raising well-equipped PSTs who have theoretical knowledge and practices about the engineering design process. If pre-service science teachers can be raised as well-qualified in engineering design, they can implement the engineering design process successfully in their future classrooms and contribute to the development of their students' engineering design performance. Thus, this study will be the pioneer in future research about PSTs' performance development in engineering design with STEM education approach. In addition, the findings of the research can give ideas to science teacher educators, teachers and experts who decide on teacher training programs and curricula about the improvement of engineering design performance and construction of knowledge of the engineering design process.

Conflict of Interest Statement

The authors declare no conflicts of interest.

About the Authors

Asli Koculu is a Research Assistant of Science Education at the Yıldız Technical University, Istanbul, Turkey. Her research interests are STEM education, design-based education, environmental education, education for sustainable development. (Orcid: orcid.org/0000-0002-9103-2563)

Mustafa Sami Topcu is a Professor of Science Education at the Yıldız Technical University, Istanbul, Turkey. His research interests are socio-scientific issues, argumentation, epistemological beliefs and practices, and STEM education. (Orcid: orcid.org/0000-0001-5068-8796)

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