International Electronic Journal of Elementary Education
June 2024, Volume 16, Issue 4

The Effect of K-12 Engineering Education Focused Professional Development Program on Science Teachers' Teaching Engineering Self-Efficacy*

Filiz Demirci[a,**], Cengiz Özyürek[b]

Received : 21 May 2024
Revised : 27 June 2024
Accepted : 30 June 2024
DOI : 10.26822/iejee.2024.345

[a,**] **Corresponding Author:** Filiz Demirci, Hacettepe University, Department of Science Education, Ankara, Türkiye.
E-mail: filizdemirci6@gmail.com
ORCID: https://orcid.org/0000-0001-5610-5707

[b] Cengiz Özyürek, Ordu University, Department of Science Education, Ordu, Türkiye.
E-mail: cengizozyurek@odu.edu.tr
ORCID: https://orcid.org/0000-0002-9740-9667

* This study is derived from a part of Filiz Demirci's Ph.D. thesis conducted under the supervision of Prof. Dr. Cengiz Özyürek

KURA group
Copyright ©
www.iejee.com
ISSN: 1307-9298

Abstract

The study aims to investigate the influence of the online professional development (PD) program focused on pre-college engineering education on science teachers' teaching engineering self-efficacy. A nested mixed research design was employed to conduct the study, in which the basic qualitative design was integrated into a weak experimental design and data collection was interrelated. The quantitative dimension of the study utilized the engineering teaching self-efficacy scale, while the qualitative dimension utilized the teachers' reflections as a data collection instrument. Fourteen science educators were selected through purposive random sampling in a province in the Black Sea region of Türkiye. The study's results suggested that the self-efficacy of science teachers in teaching engineering was significantly enhanced by the PD program, which focused on engineering education. The qualitative results were consistent with the quantitative results. Considering the study's results, practitioners and researchers were provided with suggestions for future research in the field of teacher education or PD programs.

Keywords:

Science Teachers, Professional Development, Pre-College, Teaching Engineering, Self-Efficacy.

Introduction

The industry 5.0 revolution, which we are currently in the process of transitioning, and which offers great hope for sustainable living, has given rise to Society 5.0. In the context of this social revolution, which prioritizes human well-being, it is crucial and necessity to provide individuals with the necessary knowledge and skills to develop state-of-the-art technologies that strengthen human-machine collaboration. In the present day, it is crucial to adopt a multidisciplinary approach to education, particularly in fields like multi-criteria decision-making, optimization, soft skills (such as leadership, teamwork, and communication), and human-machine interaction. These abilities are necessary for resolving intricate issues. Put simply, the modern form of engineering education acts as a connection between many fields of study, ranging from the natural sciences to the social sciences. Its primary function is to produce people who possess the necessary skills and knowledge to meet today's requirements. Therefore, we view the integration of contemporary engineering education methods across various educational domains, from early childhood education to professional development (PD), as a crucial prerequisite for national progress.

Many countries have designed their curricula to educate individuals who are well-suited to the demands of the current era. In particular, they have developed curriculum contents that embrace an interdisciplinary approach, especially in the field of science education (National Academy of Engineering and National Research Council [NAE and NRC], 2009; NRC, 2010). The K–12 science curriculum in the US has specifically included engineering and engineering design standards in the Next Generation Science Standards (NGSS) at both the national level and in various states such as Massachusetts, Maine, and Oregon. In addition, the International Technology and Engineering Educators Association (ITEEA) has proposed standards for improving students' technology and engineering literacy. These standards include engineering knowledge, practices, and abilities. Therefore, ITEEA (2020) urged K–12 engineering educators to prepare in accordance with the requirements. Engineering may act as a connection for children in the K–12 education system to comprehend the concepts of mathematics and science (Moore et al., 2014). Engineering may specifically address the shortcomings in STEM education effectiveness and provide the foundation for the enhancement of more robust analytical abilities (Purzer & Shelley, 2018). The Turkish Ministry of National Education included engineering in both its proposed scientific curriculum (MNE, 2024) and its previous science curriculum (MNE, 2018), mandating students to approach challenges from an interdisciplinary standpoint. The growing significance and need for educational research in this domain have led to the inclusion of engineering in the scientific curriculum at both national and international levels.

Teacher self-efficacy in engineering impacts the knowledge and abilities of students in engineering practices. PD refers to a kind of learning that provides teachers with the chance to enhance their understanding of subject matter and teaching methods. By modifying their teaching practices, PD aims to have a beneficial impact on student achievements (Supovitz & Turner, 2000). In the academic field, there is a significant trend toward providing specialized training for teachers who are already working to incorporate engineering principles into their teaching. One such program is Engineering is Elementary (EiE), which is now undergoing national expansion in the United States. The Boston Museum of Science offers EiE PD programs to assist teachers in enhancing their comprehension of engineering ideas, skills, and pedagogy (Diefes-Dux, 2014). Another organization dedicated to integrating engineering and engineering thinking into K–12 education is INSPIRE (the Institute for Pre-College Engineering Education). In 2006, Purdue University in the United States was founded. INSPIRE offers a comprehensive PD program that includes a week-long in-person workshop, online feedback for communities of learners, and support for individual teacher performance (Liu et al., 2009). Similarly, researchers have identified several STEM PD initiatives that incorporate engineering, targeting K–12 teachers (Gunning, 2021), secondary teachers (Custer & Daugherty, 2009; Singer et al., 2016), and classroom teachers (Ceran, 2021).

Teachers have a crucial role in facilitating change in their schools. From this standpoint, enhancing the professional growth of teachers in engineering is crucial for bolstering the implementation of engineering in K–12 environments. Furthermore, if teachers' attitudes toward practices are not sufficiently favorable, they are reluctant to embrace innovations or modifications in their teaching methodologies. Webb (2015) also recognized two significant obstacles that hinder the achievement of pre-college engineering education. One factor contributing to the problem is the teachers' insufficient acquisition of topic knowledge and pedagogical abilities. Second factor is the teachers' lack of self-efficacy in their ability to effectively teach engineering.

Engineering teachers' self-efficacy is a significant notion that influences their teaching actions. Bandura (1997) posited that self-efficacy has an impact on individuals' cognitive processes, emotional states, self-driven actions, and behavioral patterns. Teachers' self-efficacy beliefs have a direct impact on classroom practices, as stated by Boriack (2013). Several studies in the literature indicate that teachers who possess a strong sense of teaching self-efficacy are more inclined to experiment with various teaching methods while also being more prone to implementing and sustaining successful tactics (Allinder, 1994; Bruce et al., 2010; Guo et al., 2012). Furthermore, a strong sense of teacher self-efficacy facilitates teachers' active and purposeful engagement in educational endeavors, thereby improving the overall quality of education and students' academic progress (Gündüz-Özsoy, 2017).

Self-efficacy in teaching engineering is critical to teachers' education (Hynes, 2009). Yoon et al. (2014: 464) describe engineering teaching self-efficacy as "a teacher's personal belief in their capacity to have a positive impact on students' engineering learning." Although teacher self-efficacy is a notion that is resistant to alteration, it might be beneficial for teachers to enhance their teaching efficacy in teaching engineering ideas by actively engaging in engineering activities (Ivey et al., 2016).

Comprehensive research is crucial in order to guarantee that educators are proficient in this field, as it has a direct impact on the manner in which they instruct students in the field of engineering. Many studies have investigated the self-efficacy beliefs of teachers in engineering education. These studies include the works of Hammack (2016), Ivey et al. (2016), Marquis (2015), Sibuma et al. (2018), Yoon et al. (2012, 2014), and Webb (2015). For instance, Webb (2015) found that participating in PD programs for engineering education resulted in an enhancement in teachers' self-efficacy in their ability to teach engineering. Webb also found that the rise in teachers' self-efficacy was primarily due to their mastery experiences and the development of a growth mindset through the adoption of the engineering design process. According to Marquis (2015), three primary school teachers who taught 5th grade and used a LEGO Education renewable energy curriculum experienced an increase in their self-efficacy in teaching engineering. They specifically observed this improvement in the presentation aspect of the teaching module and their knowledge of engineering pedagogy. Similarly, Utley et al. (2019) found that engineering PD had a positive impact on classroom teachers' engineering knowledge and increased their self-efficacy in teaching engineering ideas. Unlike the findings in the literature, Hammack (2016) discovered that 542 K–5 elementary science teachers lacked the necessary readiness to incorporate engineering into their classrooms. They exhibited low pedagogical content knowledge and self-efficacy in teaching engineering, had limited understanding of engineering and engineering design, and faced inadequate opportunities, materials, training, and time to enhance their ability to teach engineering.

In his model of a PD program, Desimone (2009) used Bandura's (1977, 1982) socio-cognitive theory. According to Desimone, a PD program that incorporates six essential elements (content knowledge, active learning, coherence, duration, and collective participation) has the potential to enhance teachers' knowledge and skills. This, in turn, can indirectly impact teachers' teaching self-efficacy, ultimately leading to improvements in their teaching practices and student learning outcomes. There is a scarcity of research in the existing body of literature that investigates the self-efficacy and belief of teachers in their ability to teach engineering (Hammack, 2016; Ivey et al., 2016; Marquis, 2015; Sibuma et al., 2018; Utley et al., 2019; Vessel, 2011; Yoon et al., 2012, 2014; Webb, 2015). While there are several teacher PD programs available for engineering, such as The Infinity Project, EiE, and INSPIRE, as well as various studies conducted by Boots (2013), Daugherty (2010), Guzey et al. (2014), Liu et al. (2009), Reimers et al. (2015), and Webb (2015), we have not come across any online PD study specifically focused on K–12 engineering education for science teachers to examine their self-efficacy in teaching engineering. The study aims to enhance science teachers' engineering teaching self-efficacy (TES) and improve their teaching behaviors in the classroom through the implementation of an online PD program. Additionally, we anticipate that these teachers will successfully integrate engineering education practices into their classrooms, fostering meaningful and sustainable learning for their students.

Furthermore, by examining the impact of the online teacher PD program on science teachers' engineering teaching self-efficacy, we aim to provide valuable insights for researchers, practitioners, school administrators, and policymakers doing future studies in this field. Specifically, our goal is to ensure that the outcomes benefit teachers in both rural and urban settings, enabling them to access and learn from the teaching approaches shown on our website. The goal of this research was to examine the impact of an online teacher PD program that specifically focuses on engineering education on the self-perceived ability of science teachers to teach engineering. The following problem statements were addressed:

- Is there a statistically significant difference between the pre-test and post-test scores of the Teaching Engineering Self-Efficacy Scale (TESS) of science teachers who participated in the online PD program focused on K-12 engineering education?
- How is the engineering teaching self-efficacy of teachers with different developmental levels during the PD program?

Method

Research Model

The study is a "nested mixed research design," using both quantitative and qualitative methods (Creswell & Plano-Clark, 2011). We used the quantitative method to examine the impact of the engineering education-focused teacher PD program on their engineering teaching self-efficacy, and the qualitative method to elicit how this development unfolded throughout the process. The "One Group Pre-Test and Post-Test Design" (Fraenkel et al., 2012) integrated the basic qualitative design as one of its weak experimental methods.

The qualitative dimension of the study employed a basic qualitative approach, as described by Merriam (1998). In this study, the impact levels (low, high, etc.) of the K–12 engineering education focused PD program on teachers' engineering teaching self-efficacy beliefs were each depicted in depth, the process was described, and the results obtained were compared with each other.

Participants

The participants were service science teachers employed in a province located on the Black Sea coast of Türkiye during the academic year 2022-2023. We used one of the mixed sampling methods, the purposive random sampling technique (Teddlie & Tashakkori, 2009). The sampling method considered the following criteria to obtain detailed information from a small and carefully selected sample:

- Working range 5th to 8th grade as a science teacher,
- Having completed the Volunteer Participation Form,
- Having answered the Engineering Teaching Self-Efficacy Scale,
- Having available classrooms for the engineering education practices, since teachers will carry out practices with students for at least two class hours within the scope of the study and
- Being highly motivated to actively participate in the research.

The purposive sampling method included eighteen science teachers who met the above criteria in the study group (Patton, 2002). However, four teachers left the study at the start of the PD program, leaving a total of fourteen teachers for the experimental design. Using the maximum diversity sampling method, we selected the study group for the qualitative dimension of the research from the teachers who participated in the PD program. Using this method, we formed three distinct clusters from the experimental design results, then selected teachers from each cluster to compare and interpret their qualitative findings. Thus, we addressed the research problem by framing it within a more comprehensive framework, highlighting the similarities and differences among the teachers chosen from various groups.

Instruments

Teaching Engineering Self-Efficacy Scale (TESS): The Teaching Engineering Self-Efficacy Scale (TESS), developed by Yoon et al. (2012, 2014), is known in the literature as the first valid and reliable scale to measure US K–12 teachers' self-efficacy in teaching engineering (Hammack, 2016; Ivey et al., 2016). The TESS has a six-point Likert scale ranging from strongly disagree (1 point) to strongly agree (6 points), for a total of twenty-three items. Additionally, the scale includes a total of four sub-dimensions: a) Engineering Pedagogical Content Knowledge; b) Engineering Engagement Self-Efficacy; c) Engineering Disciplinary Self-Efficacy; and d) Engineering Outcome Expectancy (Table 1).

In 2019, Demirci (2022) conducted the adaptation of TESS into Turkish with the data obtained from a total of four hundred forty-six teachers, two hundred eighty-one (63%) science teachers, and one hundred sixty-five (37%) technology and design teachers working in forty-eight different provinces across Türkiye.

Table 1
Teaching Engineering Self-Efficacy Scale

Scale and Subscale	Definition of Subscale	Cronbach α
Engineering Pedagogical Content Knowledge	Teachers' personal belief in their ability to teach engineering to facilitate student learning, based on knowledge of engineering that will be useful in a teaching context.	0.96
Engineering Engagement Self-efficacy	Teachers' personal belief in their ability to engage students while teaching engineering.	0.93
Engineering Disciplinary Self-efficacy	Teachers' personal belief in their ability to cope with a wide range of student behaviors during engineering activities.	0.92
Engineering Outcome Expectancy	Teachers' personal belief in the effect of teaching on student learning of engineering.	0.89
Teaching Engineering Self-efficacy	Teachers' personal belief in their ability to positively affect students' learning of engineering that reflects the multifaceted nature of self-efficacy of teaching engineering.	0.98

Written Reflection: The reflections were texts collected during the PD program to obtain in-depth information on teachers' efficacy beliefs in teaching engineering. We asked teachers to complete reflection on the PD website three times: at the start of the program, during its duration, and at its conclusion. We asked the teachers to assess their "belief in competence for teaching engineering" based on the following five competency dimensions: 1) implementing the activities effectively in the classroom; 2) dealing with possible difficulties that your students may encounter; 3) preparing course materials related to the subject, 4) achieving the targeted student products; and 5) assessing and evaluating them.

Data Collection Process and Implementation

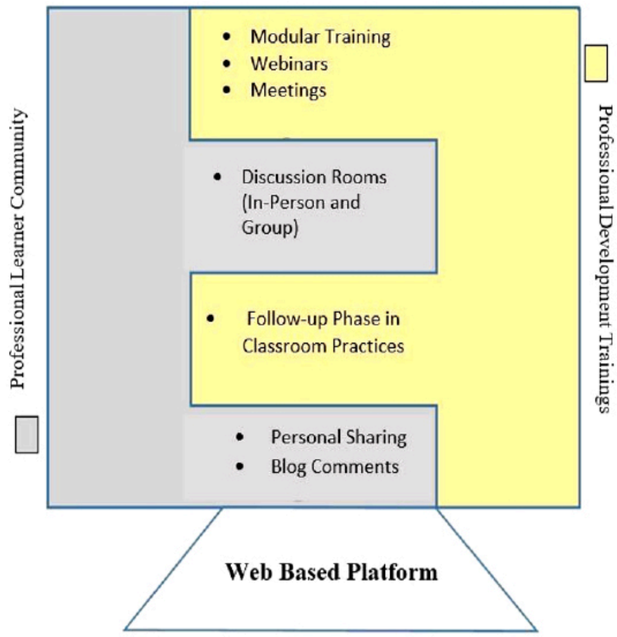
Pilot Study

The pilot study, which tested the applicability of the PD program, data collection tools, and research protocol, involved seven randomly selected science teachers. The pilot study concluded that the teachers could respond to the developed training modules and data collection tools, such as the scale and reflection. We also incorporated a feature in all the PD program's content documents, enabling teachers to acquire tangible copies of the materials. We created video recordings to accommodate teachers who couldn't attend the meetings. Furthermore, we re-planned the content presentation for the actual implementation to span five weeks, taking into account that a shorter and more concise PD program positively impacted teachers' motivation. The technical failure in the PD program's second stage, which involved the professional learner community, necessitated the creation of a backup platform to mitigate potential technical issues during the actual implementation phase. Therefore, we backed up all content of the PD program and implemented the necessary measures.

Main Study

Figure 1

The Visualization of Online K–12 Engineering Education-Focused PD Program



The online PD program's website consisted of two parts: a) PD training; and b) professional learner community (Figure 1). The overall goal of the first phase of the PD program, PD training, was to provide science teachers with a variety of resources on the web platform to improve their engineering teaching self-efficacy and enable them to communicate with experts. Under the guidance of experts, we presented some best practices in engineering teaching and encouraged teachers to share their classroom experiences with their colleagues. Additionally, they presented a progressive training module that explains how teachers can use engineering as a context for science subjects, prepare lesson plans, assess, and evaluate students' learning outcomes, and conduct virtual meetings to provide information on integrating and teaching engineering in science subjects.

The second phase of the PD program, the professional learner community, was a platform for teachers to come together to reflect on what they had learned in the training sessions, how to implement the training in the classrooms, their classroom experiences, and the materials they used. During this phase, the program encouraged teachers to share their experiences of implementing engineering-integrated lesson plans that benefit students. Figure 2 presents an example of this practice. The platform also provided discussion rooms where teachers could consult with experts and colleagues about issues and challenges, they had faced in their classroom practice. Table 2 presented the contents of the PD program, and the following section presented the contents of the modular training.

Table 2

The program focuses on K–12 engineering education and includes an online PD process and content.

Week	Content Title
1	Ethics Committee Approval and MNE Application Permission
2	Pre-Test (TESS)
3	Module 1, 2 and 3
4	Classroom Implementation Development of Individual Lesson Plans Collaboration with Colleagues
5	Classroom Implementation Development of Individual Lesson Plans Collaboration with Colleagues Reflection
6	Development of Lesson Plans Collaboration with Colleagues Reflection
7	Post-Test (TESS) Reflection Giving Incentives and Closing (Attendance Certificate and Virtual Gift Card)

Module 1:

- Details about the program's content
- Why teach engineering in K–12?
- The importance and necessity of K–12 engineering education
- Engineering discipline, nature, concepts, and skills
- Engineering professions
- Framework for quality K–12 engineering education
- The engineering design process
- Example lesson plans for engineering integration

June 2024, Volume 16, Issue 4, 453-466

Module 2:

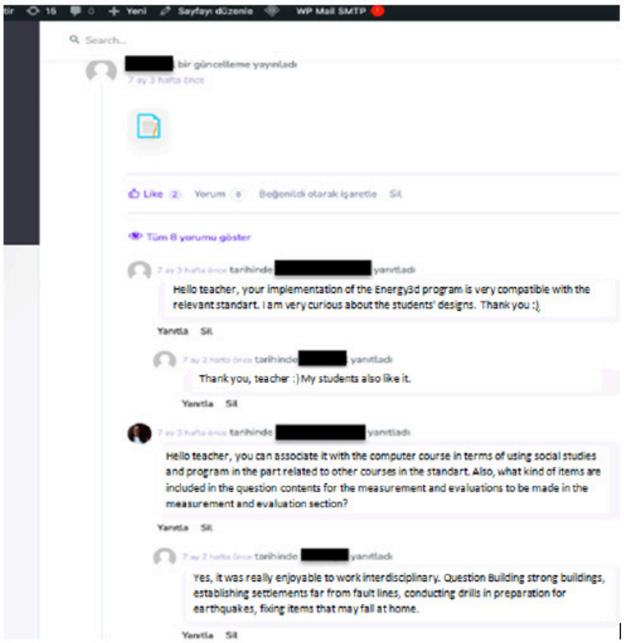
- The relationship between science and engineering
- Engineering integration in science education
- The US's national and various states' engineering standards
- Türkiye's curriculums containing the engineering standards
- Context-based engineering education
- Teaching strategies in engineering
- Measurement and evaluation in engineering
- Digital tools for engineering integration

Module 3:

- Computer-Aided Design (Energy3d) program

Figure 2

An Example of Teachers' Collaboration with the Professional Learning Community



In the PD program, Bandura's (1997) four sources of self-efficacy were considered to enhance teachers' self-efficacy in engineering teaching. Therefore, we aimed to improve:

- Mastery experiences by implementing an engineering-integrated activities in teachers' classrooms.

- Vicarious experience by sharing teachers' successful experiences with colleagues in the professional learner community where they had implemented similar engineering instruction, as well as by experts sharing their own successful experiences.

- Verbal persuasion by sharing example lesson plans with teachers during PD training and by providing encouragement, and support through information sharing during meetings.

- Psychological and affective states by setting up the supportive environment to support teachers' physiological and emotional well-being by reducing stress and anxiety.

Data Analysis

For quantitative data, we used the paired sample t-test because the pre-test and post-test data from TESS met the parametric test assumptions (Can, 2014). Additionally, when the quantitative analysis revealed a statistically significant difference between the groups, we calculated the effect size (d) to understand the magnitude of this effect. We interpreted the effect level as very high if the effect size (d) value exceeded 1.0 (Morgan, 2004). The study adopted a significance level (p) of 0.05.

Additionally, we calculated normalized gains (g) using Hake's (1998) formula, as well as the pre-test and post-test mean scores from the TESS, as follows:

g = (post-test - pre-test) / (100 - pre-test)

We evaluated teachers' teaching engineering self-efficacy (TES) levels by taking the average score from the entire twenty-three-item scale into account. The TESS allows for a minimum score of 1 point and a maximum score of 6 points. Additionally, we classified the gain values from TESS as "low" for scores between 1.00 and 2.66, "medium" for scores between 2.67 and 4.33, and "high" for scores between 4.34-6.00.

This study employed the K-means clustering analysis method, a non-hierarchical method. We analyzed the qualitative data of three teachers selected through the clustering analysis process. We used descriptive analysis to analyze the qualitative data obtained from teacher reflections. Descriptive analysis consists of four stages: a) creating a framework for descriptive analysis; b) processing the data according to the thematic framework; c) describing the findings; and d) interpreting the findings (Yıldırım & Şimşek, 2013). When necessary, we enriched these findings by providing direct quotations from the reflection statements. We presented the teachers' reflections using their pseudonyms (Alice, Brenda, and Casey) and abbreviated source titles (for example, A-R1: [A]lice Teacher-[R]eflection[1]st Reflection).

Findings

Quantitative Findings

We used the paired samples t-test to address the first problem statement, "Is there a statistically significant difference between the pre-test and post-test scores of the Teaching Engineering Self-Efficacy Scale (TESS) of science teachers who participated in the online PD program focused on K-12 engineering education?" The results are presented in Table 4. Table 3 presents the descriptive analysis statistics of the study group.

Table 3
Descriptive Analysis Results

TESS	*M*	Minimum	Maximum	*SD*
Pre-Test	4.48	2.95	5.74	2.83
Post-Test	5.82	4.91	5.95	1.05

*: n=14

Table 4
Paired Samples T-Test for TESS

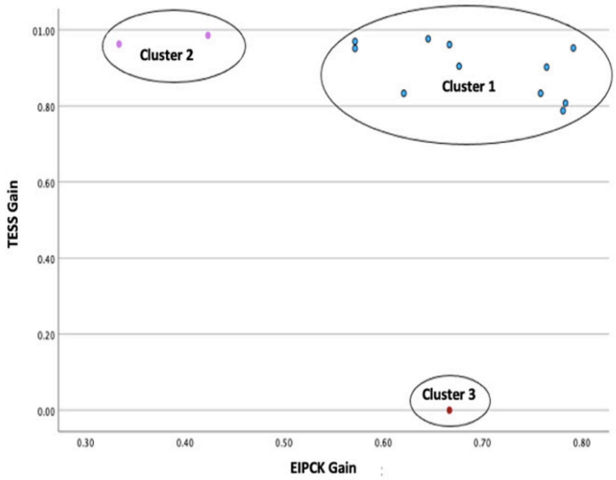
Test	*M*	*Sd*	*df*	*t*	*p***	*d****
TESS	1.33	0.83	13	6.05	0.00	1.62

*: n=14, **: p<0.05, ***: d = t/n

As shown in Tables 3 and Table 4, the t-test result shows that there was a statistically significant difference between the pre-test (M = 4.48, SD = 2.83) and post-test mean scores (M = 5.82, SD = 1.05) obtained from the TESS in favor of the post-test ($t_{(13)}$ =6.05, p = 0.00). In addition, the effect size illustrated that this difference was at a very high level (d = 1.62) (Morgan, 2004).

Furthermore, K-means cluster analysis was used to determine the membership of each teacher in the clusters. K-means cluster analysis (Anderberg's center of gravity ranking method) allows the selection of several clusters by making meaningful groupings (Aldenderfer & Blashfield, 1984). Three groups were identified as a result of the cluster analysis. To verify these independent groupings, an analysis of variance (ANOVA) was used to examine the differences between the clusters. Additionally, the clusters were independent for both dependent variables[1] (F = 12.03, p < 0.05). The findings of the clustering analysis were presented in Figure 3.

Figure 3
Scatter Plot of Teachers' Development Gains



Qualitative Findings

In order to address the second problem statement, "How are the engineering teaching self-efficacy of teachers with different developmental levels during the professional development program implemented?" descriptive analysis was used for qualitative data. The findings are presented in three subtitles below.

Qualitative Findings of Teacher Alice

At the end of each week of the PD program, Alice evaluated her competence in teaching engineering and presented her reflections in the categories of coping with challenges, preparing course materials, learning outcomes, and assessment and evaluation.

While evaluating her competence regarding the process of implementing the activities in the classroom, the teacher made statements showing that her level of self-efficacy gradually increased. For example, in her first reflection on implementing the activities in the classroom, the teacher wrote "I can sometimes, but not always" in the next reflection she wrote "quite adequate" and in the last reflection she wrote "extremely effective".

> *A-R1: "I can apply the activities in my class sometimes, but not always. Most of the time I can cope with the possible difficulties my students may face."*

> *A-R2: "As a result of the knowledge I have gained so far, I find myself very competent for teaching engineering."*

> *A-R3: "I can implement the activities in my classroom in a very effective and efficient way."*

In addition, towards the end of the professional development program, Alice found herself more and more competent in preparing lesson materials appropriate to the teaching outcomes and in assessing and evaluating them. For example, in the teacher's first reflection on the preparation of course materials, she wrote: "By using these activities, I can achieve most of the student products I aim for. I can measure and evaluate them." This statement can be interpreted as a statement indicating that she preferred to use ready-made course materials rather than developing them herself. In the teacher's next reflection, with the statement "I can prepare course materials and measure and evaluate them." it is understood that she can prepare the course materials herself and evaluate the student products. In the teacher's last reflection on this subject, she wrote: "I can prepare and produce course materials in the most perfect way. I can measure and evaluate them properly." This shows that the teacher's opinion about her own competence was quite high. In particular, we observed that she provided detailed explanations related to the curriculum in the last statement, with a focus on ensuring student outcomes.

In general, when Alice's reflections written on a modular basis were examined, it was seen that she found herself more competent in engineering teaching towards the end of the professional development program. All these qualitative findings were consistent with the findings that were classified the levels of teacher's teaching engineering self-efficacy which were medium for pre-test (*M:* 4.17) and high for post-test (*M:* 5.91), with a gain rate high (95%).

Qualitative Findings of Teacher Brenda

Brenda's reflections, in which she evaluated her competence in teaching engineering at the end of each week of the professional development program, were presented in the categories of learning outcomes, coping with challenges, and assessment and evaluation.

When the teacher's reflections were examined, it was seen that she found herself competent to play an effective role on the problem-solving skills of her students through engineering teaching practices. Her opinion on her competence was expressed at a similar level in general.

> *B-R1: "With my students, we can design models to solve a problem we have defined about the environment."*

> *B-R2: "By defining a problem with my students, we can develop models to solve the problem. If the model we develop does not solve the problem, we can make a new design."*

> *B-R3: "Engineering activities make students aware of life problems that they may encounter in daily life."*

Furthermore, in Brenda's third reflection paper, she also addressed the challenges of implementing engineering integrated activities:

> *B-R3: "In line with my lesson plans, I can also deal with possible difficulties while applying engineering activities in my lessons. For example, when designing a high-speed train related to magnets, I first let my students who have never been interested in high-speed trains watch videos on the internet. I can do these activities with my students using all kinds of materials."*

Unlike her previous reflections, findings from Brenda's final reflection showed that she would be able to apply engineering activities effectively in the classroom for meaningful learning for her students. In addition, in her final reflection, she explained in detail that she could deal with various difficulties in terms of cognitive learning difficulties (low interest in the subject and lack of prior knowledge) and supplying teaching materials.

Finally, it was also seen that the teacher provided detailed explanations about how to measure the student outcomes she aimed to provide to the students.

> *B-R3: "I can evaluate the engineering activities I implement in my class by using appropriate assessment and evaluation tools. For example, I can measure the transportation vehicle we designed with magnets using the project rubric."*

Brenda's modular reflections indicated that she became more competent in teaching engineering as she progressed through the professional development program. It can be said that in the qualitative findings, the teacher found herself competent with detailed explanations especially in her last reflection. All these qualitative findings were consistent with the findings that were classified the levels of teacher's teaching engineering self-efficacy which were medium for pre-test (*M:* 2.95) and high for post-test (*M:* 5.95), with a high gain rate (99%).

Qualitative Findings of Teacher Casey

Casey's reflections, in which she evaluated her competence in engineering teaching at the end of each week of the professional development program, were presented in the categories of learning outcomes, preparation of course materials and assessment and evaluation.

Finding of the teacher's reflections showed that she found herself competent in terms of playing an effective role in her students' problem solving and creative thinking skills through engineering teaching practices, and she evaluated this competence at a similar level in each reflection.

> *C-R1: "I can teach my students the steps to follow in finding solutions to the problems they face in daily life."*

> *C-R2: "I can encourage students to think creatively in order to achieve the targeted student outcomes."*

> *C-R3: "I can help students deal with real-world problems from a scientific and mathematical perspective."*

Additionally, Casey stated that she found herself generally competent in preparing the course materials. In the teacher's second reflection, she mentioned possible difficulties in supplying the materials, while in her last reflection, she stated that she found herself competent in how to overcome this difficulty.

When Casey's weekly reflections were analyzed, it was seen that she generally argued that she would take into account the existing deliverables related to measurement and evaluation. Especially in her last reflection, the statement "I would use preferred assessment tools" was another finding indicating that her knowledge of the assessment tools used in engineering education had increased during professional development.

In general, Casey's reflections written on a modular basis demonstrated that she found herself similarly competent in engineering teaching throughout the professional development program. All these qualitative findings showed to be consistent with the findings that were classified the levels of teacher's teaching engineering self-efficacy which were high for both pre-test (*M:* 4.91) and post-test (*M:* 4.91), with no gain (0%).

Discussion and Conclusion

A teacher's actual teaching methods can be influenced by personal beliefs about their capacity to teach engineering effectively (Parker et al., 2020; Yeşilyurt et al., 2021). Since teacher self-efficacy is a critical belief component that influences teacher behavior and student outcomes, it is imperative to enhance the effectiveness of pre-college engineering education by increasing the self-efficacy of teachers in teaching engineering (Epstein & Willhite, 2017; Kelley et al., 2020; Menon et al., 2024). According to the quantitative results of the study, teachers' engineering teaching self-efficacy (TES) was enhanced by the online professional development program that concentrated on K-12 engineering education. This result is in accordance with the results of prior professional development studies on engineering integration (Crawford et al., 2021; Ficklin et al., 2020; Kouo et al., 2023; Marquis, 2015; Parker et al., 2020; Rich et al., 2017; Utley et al., 2019; Webb, 2015). For instance, Kouo and colleagues discovered that teachers demonstrated a higher level of assurance in their capacity to instruct engineering activities during a professional development program that was specifically tailored to K-12 engineering education. Crawford et al. (2021) also determined that teachers demonstrated substantial increases in self-efficacy after the completion of the professional development course, as evaluated by the Engineering Teaching Self-Efficacy Scale. Ficklin et al. (2020) discovered that the self-efficacy of K-5 teachers teaching engineering was influence positively by professional development for elementary school teachers in a rural school in southeastern North Carolina. Nevertheless, the study conducted by Sibuma et al. (2018)'s pilot study determined that pre-college teachers' self-efficacy was not enhanced by in-service training on STEM education. This different finding in the literature may be attributable to the fact that all teachers take short (2-2.5 hours) professional development sessions. Moreover, professional development activities, including follow-up sessions, coaching, and mentoring, have the potential to enhance the self-efficacy of teachers (Boriack, 2013). The online teacher professional development program was developed in accordance with four variables that Bandura (1997) posits influence self-efficacy: a) mastery experiences, b) vicarious experiences, c) verbal persuasion, and d) psychological and affective state. Teachers' contribution to classroom practice may have facilitated the acquisition of mastery experience. The acquisition of vicarious experience may have been influenced by participation in professional learner communities and observation of colleagues' practice. Focused support and feedback for the development of verbal persuasion may have provided through the sharing of expert leadership content, counseling and encouragement by colleagues. Furthermore, the supportive environment in the professional development process may have helped to improve teachers' physiological and emotional well-being by reducing stress and anxiety.

The professional development program has the dual purpose of improving the self-efficacy of teachers and improving their engineering integration pedagogical content knowledge (EIPCK). The development of teachers in engineering education can be directly correlated with their positive development in EIPCK. Teachers' active participation in the online professional development program and their improved understanding of how to integrate engineering concepts into their instruction may have contributed to an increased sense of preparedness and, as a result, self-efficacy in their capabilities. Additionally, researchers have suggested that the designing in science courses improved personal teaching self-efficacy (Cantrell et al., 2023). The lesson plans that teachers developed during the professional development process may have contributed to their increased self-efficacy.

The purpose of this study was to assess the self-efficacy of engineering educators in engineering education by analyzing their reflections at the initial, midpoint, and final stages of the professional development program. The quantitative research results indicate that educators who attained high scores on the engineering teaching self-efficacy scale were able to improve their capabilities through professional development through self-reflection. We interpret that the study's written reflection may have helped them build their self-efficacy by getting them to think about how they teach and how they think about their own thoughts. To be more precise, educators who reported high levels of engineering teaching self-efficacy development (moderate before implementation, high after) were more likely to report feeling competent when faced with challenges, assisting students in their cognitive development, and evaluating the quality of student work. The engineering self-efficacy of teachers can be improved through positive reinforcement and exposure to shared techniques in professional learner communities (Crawford et al., 2021; Gunning et al., 2024). The professional development program may have facilitated the sharing of the experiences and instructional materials of teachers among colleagues, thereby enhancing their capacity to address the challenges of engineering education more effectively.

The purpose of the written reflections was to determine the extent to which science educators were capable of teaching engineering self-efficacy during the professional development program. We determined that the teachers' reflections supported the quantitative results. Teachers' proficiency in the preparation of lesson materials and the execution of engineering activities in the classroom had improved by the end of the professional development program. This dimension of self-efficacy is theoretically significant, as teachers who have achieved high levels of TES reported feeling highly competent in overcoming the challenges they would face in the classroom. In addition, we conducted an analysis of the explanations provided by teachers in their reflections regarding their perceived efficacy in overcoming the learning challenges of their students. This is another substantial piece of evidence that illustrates the high level of self-efficacy that educators in the field of engineering education possess. These results are consistent with those of previous research. Numerous studies have shown that educators who have high levels of teaching self-efficacy are more likely to maintain and enhance effective strategies and are less inclined to experiment with novel teaching methods (Allinder, 1994; Bruce et al., 2010; Guo et al., 2012). In addition, educators who exhibit high levels of teaching self-efficacy are more likely to establish objectives that are more straightforward, avoid difficult assignments (Gökdağ-Baltaoğlu & Güven, 2019), and exhibit inadequate effort and forbearance when faced with obstacles and threats (Bruce et al., 2010).

Furthermore, educators who demonstrate a strong sense of self-efficacy are more likely to be self-efficacious in their capacity to effectively engage students in the comprehension of engineering principles and the problem-solving process (Menon et al., 2024). The responses of all teachers indicated that they were confident in their ability to develop the inventive thinking and problem-solving abilities of their students. This discovery is in accordance with Bandura's (1997) assertion that the cognitive abilities of students are substantially influenced by the belief of teachers in their capacity to teach effectively. It also supports the idea that the self-efficacy of teachers in engineering education can be improved through professional development.

A sub-dimension of engineering teaching self-efficacy is the teacher's capacity to implement a variety of assessment strategies (Demirci, 2022; Yoon et al., 2012, 2014). Within the context of engineering education, this research revealed that teachers' perspectives on assessing student work vary. Teachers who have invested more time and energy in their TES careers have more concrete ideas about what and how to assess, whereas those who have invested less time and energy in the field have said that they are open to trying new approaches. Additionally, Allinder (1994) asserted that educators are considerably more inclined to experiment with alternative instructional methodologies. This finding demonstrates that teachers' self-efficacy in their abilities to acquire student goods and evaluate and analyze them grew as a consequence of reflective writing that included thorough explanations. The teachers' self-efficacy in this regard may have been enhanced by the fact that they expanded their knowledge of the materials to be used in the assessment and evaluation of student products in engineering education and shared the materials with their colleagues in the community of professional learners by collaborating with the professor in engineering education.

Limitations and Future Studies

Several recommendations for future research can be made by addressing the limitations of this study. Firstly, the research was restricted in its ability to acquire data through classroom observations due to the fact that it was conducted through an online professional development program. The observation method can be employed to acquire comprehensive information regarding the self-efficacy of engineering teachers in their teaching. A way to address this limitation in the future would be implementing qualitative methodologies to evaluate teachers' interactions with peers or experts in the online professional learner community based on the data collected from the website platform. This could offer a more precise level of specificity for the development of teachers' knowledge and beliefs.

Secondly, the study group comprised only female teachers. Future research could investigate gender differences. In addition, these researchers could evaluate the self-efficacy of teachers by considering factors such as their educational degrees. Therefore, the knowledge of potential factors that may influence the self-efficacy of K-12 teachers in engineering teaching can be used to enhance the practices of teacher self-efficacy development in this field.

Thirdly, the professional development program employed in this investigation was constructed in accordance with Bandura's four self-efficacy components. In this study, we utilized the TESS as a measurement tool. In future research, modular trainings covering the sub-dimensions of this measurement tool (TESS) can be developed and its impact on engineering teachers' self-efficacy can be investigated in more depth.

Fourthly, the study group of this research was limited to teachers who were identified as fulfilling the criteria for participation in the online professional development program and were highly motivated. Analyzing the self-efficacy development of teachers with low initial motivation may yield valuable insights for future research.

Lastly, this study was limited an online professional development program to efficiently supervise and monitor the science teachers' professional development. The online K-12 professional development program that was devised in this study is applicable to both pre-service and in-service teachers who specialize in science, classroom teaching, and technology. In the field of engineering education, it is anticipated that these longitudinal trainings, particularly those that involve teachers from numerous regions, will improve research.

Acknowledgement

This study was funded by The Scientific and Technological Research Council of Türkiye (TÜBİTAK) through 2214-A International Research Fellowship Program for Ph.D. Students. The opinions expressed are those of the authors and do not necessarily represent those of the TÜBİTAK.

Footnotes

[1]The cluster analysis incorporates 'Engineering Integration Pedagogical Content Knowledge (EIPCK)' from the dissertation that provided the study's data.

References

Allinder, R. M. (1994). The relationships between efficacy and the instructional practices of special education teachers and consultants. *Teacher Education and Special Education*, *17*, 86-95.

Bandura, A. (1977b). Self-efficacy: Toward a unifying theory of behavioral change. *Psychological Review*, *84*(52), 191-215.

Bandura, A. (1982). Self-efficacy mechanism in human agency. *American Psychologist, 37*(2), 122-147.

Bandura, A. (1997). Self-efficacy: The exercise of control. W. H. Freeman and Company, New York, USA.

Boots, N. K. (2013). Examining teachers' perspectives on an implementation of elementary engineering teacher professional development. Ph.D. Thesis, Purdue University, Learning, Design and Technology, USA.

Boriack, A. C. (2013). Teachers' perceptions of effective science, technology, and mathematics professional development and changes in classroom practices. Ph.D. Thesis, Texas A&M University, USA.

Bruce, CD., Esmonde, I., Ross, J., Dookie, L. & Beatty, R. (2010). The effects of sustained classroom-embedded teacher professional learning on teacher efficacy and related student achievement. *Teaching and Teacher Education, 26*, 1598-1608.

Can, A. (2014). Quantitative data analysis in the scientific research process with SPSS. Pegem Akademi Publishing, Ankara.

Cantrell, P., Young, S., & Moore, A. (2003). Factors affecting science teaching efficacy of preservice elementary teachers. *Journal of Science Teacher Education, 14*(3), 177–192.

Ceran, E. (2021). Elementary school teachers' developing pedagogical content knowledge and beliefs about integrated STEM education through a professional development knowledge. Ph.D. Thesis, Marmara University, The Graduate School of Educational Sciences, The Department of Elementary Education, Istanbul, Türkiye.

Crawford, C., Obenland, C., & Nichol, C. (2021). An analysis of the effect of long-term professional development on teacher engineering self-efficacy and its impact on classroom instruction. *The Journal of STEM Outreach*, *4*(1), 1-10.

Creswell, J. W. & Plano Clark, V. L. (2011). *Designing and conducting mixed methods research* (2nd ed.). SAGE Publications.

Custer, R. L. & Daugherty, J. L. (2009). The nature and status of stem professional development: Effective Practices for Secondary Level Engineering Education. National Center for Engineering and Technology Education, Utah State University, USA.

Daugherty, J. L. (2010). Engineering professional development design for secondary school teachers: A multiple case study. *Journal of Technology Education*, *21*(1), 10-24.

Demirci, F. (2022). Adaptation of teaching engineering self-efficacy scale into Turkish. *Pedagogical Perspective, 1*(2), 128-141.

Desimone, L. M. (2009). Improving impact studies of teachers' professional development: Toward better conceptualizations and measures. *Educational Researcher*, *38*(3), 181-199.

Epstein, A., & Willhite, G. L. (2017). Teacher efficacy in an early childhood professional development school. *International Electronic Journal of Elementary Education*, *7*(2), 189–198.

Ficklin, K., Parker, M., & Shaw-Ferguson, T. (2020). Qualitative research on the influence of engineering professional development on teacher self-efficacy in a rural K-5 setting. *Contemporary Issues in Technology and Teacher Education, 20*(4), 687-703.

Fraenkel, J., Wallen, N. & Hyun, H. H. (2012). How to design and evaluate research in education. McGraw Hill, Boston, USA.

Gökdağ-Baltaoğlu, M. & Güven, M. (2019). Relationship between self-efficacy, learning strategies, and learning styles of teacher candidates (Anadolu University example). *South African Journal of Education, 39*(2), 1-11.

Gündüz-Özsoy, A. (2017). Examining the relationship between self-efficacy beliefs and change resistance behaviors of teachers working in state high schools. Master's Thesis, Marmara University, Department of Educational Sciences, Istanbul.

Gunning, A. M. (2021). Studying in-service teacher professional development on purposeful integration of engineering into K-12 STEM teaching (research to practice). American Society for Engineering Education 2021 Annual Conference, July 26-29, Virtual Meeting.

Guo, Y., Connor, C. M., Yang, Y., Roehrig, A. D. & Morrison, F. J. (2012). The effects of teacher qualification, teacher self-efficacy and classroom practices on fifth graders' literacy outcomes. *The Elementary School Journal, 113*(1), 3-24.

Guzey, S. S., Tank, K., Wang, H. H., Roehrig, G. & Moore, T. (2014). A high-quality professional development for teachers of grades 3-6 for implementing engineering into classrooms. *School Science and Mathematics, 114*(3), 139-149.

Hammack, R. J. (2016). Elementary teachers' perceptions of engineering, engineering design, and their abilities to teach engineering: a mixed methods study. Ph.D Thesis, Faculty of the Graduate College of the Oklahoma State University, USA.

Hynes, M. M. (2009). Teaching middle-school engineering: an investigation of teachers' subject matter and pedagogical content knowledge. Ph.D Thesis, Math, Science, Technology, and Engineering Education, Tufts University, USA.

International Technology and Engineering Educators Association [ITEEA] (2020). Standards for technological and engineering literacy: The role of technology and engineering in STEM education. https://www.iteea.org/stel.aspx- (Access: 06.13.2021)

Ivey, T., Colton, N., Thomas, J. & Utley, J. (2016). Integrated engineering in elementary education: tackling challenges to rural teacher training. Proceedings of the ASEE 123rd Annual Conference and Exposition, June 26-29, New Orleans, USA.

Kelley, T. R., Knowles, J. G., Holland, J. D. & Han, J. (2020). Increasing high school teachers self-efficacy for integrated STEM instruction through a collaborative community of practice. *International Journal of STEM Education,* 7(14), 1-13.

Kouo, J., Dalal, M., Lee, E., Berhane, B., Emiola-Owolabi, O., Ladeji-Osias, J., Beauchamp, C., Reid, K., Klein-Gardner, S. & Carberry, A. (2023). Understanding the impact of professional development for a cohort of teachers with varying prior engineering teaching experience. *Journal of Pre-College Engineering Education Research*, *13*(1), 38-54.

Liu, W., Carr, R. L. & Strobel, J. (2009). Extending teacher professional development through an online learning community: a case study. *Journal of Educational Technology Development and Exchange, 2*(1), 99-112.

Maine Department of Education [MDE] (2019). Standards & instruction-science & engineering. https://www.maine.gov/doe/learning/content/scienceandtech-(Access: 11.13.2019).

Marquis, S. D. (2015). Investigating the influence of professional development on teacher perceptions of engineering self-efficacy. Ph.D. Thesis, The University of Southern Maine, Public Policy, USA.

Massachusetts Department of Education [MDE] (2006). *Massachusetts science and technology/engineering curriculum framework*. Malden, MA: Massachusetts Department of Education.

Menon, D., Wieselmann, J. R., Haines, S., & Asim, S. (2024). A Meta-Synthesis of the Literature on Science & Engineering Teaching Self-Efficacy: Current Gaps and Future Research Directions. *Journal of Science Teacher Education*, 1–24.

Merriam, S. B. (1998). Qualitative research and case study applications in education revised and expanded from case study research in Education. Jossey-Bass Publishers, San Francisco, USA, 275 pp.

Ministry of National Education [MNE] (2018). Science Course Curriculum (Primary and Secondary School Grades 3, 4, 5, 6, 7 and 8). Presidency of the Board of Education and Discipline, Ankara.

Ministry of National Education [MNE] (2024). Science Course Curriculum (Grades 3, 4, 5, 6, 7 and 8th): Education Model of Türkiye Century. Ankara: Presidency of the Board of Education. Retrieved from https://gorusoneri.meb.gov.tr/ (Access: 05.19.2024).

Moore, T. J., Glancy, A. W., Tank, K. M., Kersten, J. A., Smith, K. A. & Stohlmann, M. S. (2014). A framework for quality K-12 engineering education: Research and development. Journal of Pre-College Engineering Education Research, *4*(1), 1-13.

National Academy of Engineering [NAE] & National Research Council [NRC] (2009). Engineering in K-12 education: understanding the status and improving the prospects. Ed: Katehi, L. Pearson, G., Feder, M., The National Academies Press, Washington, USA.

National Research Council [NRC] (2010). Standards for K-12 engineering education? Washington, DC: The National Academies Press, Washington, USA.

NGSS Lead States. (2013). Next generation science standards: for states, by states. National Academies Press.

Oregon Department of Education [ODE] (2014). Science standards. https://www.oregon.gov/ode/educator-

Parker, M., Ficklin, K., & Mishra, M. (2020). Teacher self-efficacy in a rural K-5 setting: Quantitative research on the influence of engineering professional development. *Contemporary Issues in Technology and Teacher Education, 20*(4), 704-729.

Purzer, S. & Shelley, M. (2018). The Rise of Engineering in STEM Education: The "E" in STEM: Research Highlights in STEM Education, Ed.: Shelley, M., Kiray, A, ISRES Publishing, Iowa State University, Ames, USA, 38-56.

Reimers, J. E., Farmer, C. L. & Klein-Gardner, S. S. (2015). An introduction to the standards for preparation and professional development for teachers of engineering. *Journal of Pre-College Engineering Education Research, 5*(1), 40-60.

Sibuma, B., Wunnava, S., John, M. F. & Dubosarsky, M. (2018). The impact of an integrated Pre-K STEM curriculum on teachers' engineering content knowledge, self-efficacy, and teaching practices. *IEEE Integrated STEM Education Conference*, Princeton, USA, 224-227 pp.

Supovitz, J. A. & Turner, H. M. (2000). The effects of professional development on science teaching practices and classroom culture. *Journal of Research on Science Teaching, 37*(9), 963-980.

Teddlie, C. & Tashakkori, A. (2009). *Foundations of mixed methods research: integrating quantitative and qualitative approaches in the social and behavioral sciences*. SAGE.

Utley, J., Ivey, T., Hammack, R. & High, K. (2019). Enhancing engineering education in the elementary school. *School Science & Mathematics,* 119(4), 203-212.

Vessel, K. N. (2011). Examination of engineering design teacher self-efficacy and knowledge base in secondary technology education and engineering-related courses. Ph.D. Thesis, Southern University and A&M College, Ann Arbor, USA.

Webb, D. L. (2015). Engineering professional development: elementary teachers' self-efficacy and sources of self-efficacy. Ph.D. Thesis, Portland State University, Educational Leadership: Curriculum and Instruction, USA.

Yesilyurt, E., Deniz, H., & Kaya, E. (2021). Exploring sources of engineering teaching self-efficacy for pre-service elementary teachers. *International Journal of STEM Education*, *8*(1), 1–15.

Yıldırım, A. & Şimşek, H. (2013). Qualitative research methods in social sciences, Seçkin Publishing, Ankara, 446 pp.

Yoon, S. Y., Evan, M. G. & Strobel, J. (2014). Validation of the teaching engineering self-efficacy scale (TESS) for K-12 teachers: A structural equation modeling approach. *Journal of Engineering Education,* 103(3), 463-485.

Yoon, S. Y., Evans, M. G. & Strobel, J. (2012). Development of the Teaching Engineering Self-Efficacy Scale (TESS) for K-12 teachers. Proceedings of the ASEE Annual Conference and Exposition, June 10-13, San Antonio, USA.