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# Exploring sources of engineering teaching self-efficacy for pre-service elementary teachers

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## Abstract

**Background:** The Next Generation Science Standards (2013) put a special emphasis on engineering for K-12 science education. However, a significant number of elementary teachers still feel unprepared to integrate engineering into their science programs. It is, therefore, incumbent upon science educators to update their elementary science methods courses to accommodate engineering especially in the states which adopted the NGSS. In this study, we taught an engineering unit in an elementary science teaching methods course to examine what instructional components and learning experiences provided in the engineering unit enhance teachers' engineering teaching self-efficacy beliefs.

Our research questions addressed to what extent the engineering education intervention improved pre-service teachers' engineering teaching efficacy beliefs and what instructional components and learning experiences served as sources of self-efficacy contributing to the improvement of pre-service elementary teachers' engineering teaching efficacy beliefs. We also explored how pre-service teachers viewed the relative importance of the sources of teaching efficacy stemming from the engineering unit.

**Results:** The participants comprised 84 pre-service teachers enrolled in an elementary education program at a public university in the Southwestern United States. Data obtained from the Engineering Teaching Efficacy Beliefs Instrument (ETEBI) indicated that the pre-service teachers' personal teaching efficacy beliefs significantly improved after the engineering intervention; however, the engineering intervention had a small impact on teachers' engineering teaching outcome expectancy beliefs. Written reflections used to explore the sources of engineering teaching efficacy and the relative importance of each source showed that cognitive content mastery and cognitive pedagogical mastery were the major sources of engineering teaching self-efficacy among the pre-service elementary teachers.

**Conclusion:** Our study illustrated that integrating engineering design activities with explicit-reflective instruction on the nature of engineering concepts could enhance pre-service teachers' personal engineering teaching efficacy beliefs even though a relatively small impact was observed in their engineering teaching outcome expectancy beliefs. Also, the study indicated cognitive content mastery and cognitive pedagogical mastery were the most important sources of engineering teaching efficacy. Therefore, the study suggests that it is vital to integrate a variety of mastery and vicarious experiences in methods courses to support the development of teachers' engineering teaching efficacy beliefs. Besides, the current study could provide an example for integrating engineering education in methods courses.

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**Keywords:** Mixed methods research, P-12 engineering, pre-service elementary teachers, Self-efficacy, Sources of self-efficacy

## Introduction

Since the Next Generation Science Standards [NGSS], (2013) integrated engineering into the K-12 science curriculum, there has been a growing need for developing programs to equip K-12 teachers with the necessary theoretical and practical knowledge for engineering education. The NGSS calls for teachers to incorporate engineering core ideas and practices into their classroom teaching to help their students better understand the engineering discipline. However, a significant number of elementary teachers feel unprepared and uncomfortable in integrating engineering into their classroom teaching (Carr et al. 2012; Hammack and Ivey 2017; Trygstad et al. 2013). This is not surprising considering the previous studies reporting that teachers do not receive sufficient and formal training on engineering teaching throughout their education (Banilower et al. 2018; Lederman and Lederman 2014). Therefore, this new vision of science teaching apparently poses a challenge for K-12 teachers.

Several attempts have been made to support practicing teachers in engineering teaching in PD programs. However, there are relatively few teacher education programs offering courses to prepare prospective teachers to teach engineering and meet the demands of the NGSS (National Research Council [NRC] 2014). It has been shown that methods courses could support preservice teachers in developing the necessary knowledge and skills. For example, previous studies have indicated that science methods courses could improve teachers' teaching self-efficacy beliefs (e.g., Bursal 2012; Kaya et al. 2019; Kazempour and Sadler 2015; Palmer 2006; Velthuis et al. 2014). It is, thus, necessary to integrate the concepts and practices of engineering into methods courses to support PSTs with this challenging task.

Bandura's self-efficacy construct has been reported to be associated with teachers' instructional decisions and teaching performances during the past three decades (e.g., Bandura 1997; Woolfolk and Hoy 1990). It has been indicated that teachers with a low sense of teaching efficacy often develop anxiety and poor attitudes toward the subject matter, tend to devote less instructional time to subject matters, and adopt more teacher-directed instructional approaches (e.g., Bandura 1997; Deehan 2016; Nie et al. 2013; Ramey-Gassert and Shroyer 1992). From this perspective, scholars have devoted considerable attention to finding ways to enhance teachers' efficacy beliefs (e.g., Pajares 1992; Tschannen-Moran et al. 1998). Although elementary teachers are currently expected to be well-prepared to be able to integrate engineering, it has been reported that elementary teachers often do not have a strong sense of teaching self-efficacy necessary to provide high-quality instruction and promote students' learning in engineering and STEM (e.g., Hammack and Ivey 2017; Perkins Coppola 2019; Yasar et al. 2006). In this sense, teacher education programs should ramp up their efforts to prepare prospective teachers to incorporate new content and practices in their future teaching. Given that teaching efficacy beliefs could be an important predictor of teachers' future classroom practices (Bandura 1997; Ramey-Gassert and Shroyer 1992; Woolfolk and Hoy 1990), this study focused on teachers' engineering teaching efficacy beliefs. The current study aims to identify what and how course components may improve prospective teachers' engineering teaching self-efficacy.

## Theoretical background

As an important aspect of social cognitive theory, perceived self-efficacy was described as one's judgments about his/her capability to perform the desired behavior (Bandura 1986). Bearing in mind that self-efficacy is a task-specific construct, many scholars have delved into the role of Bandura's self-efficacy construct in the teaching context (e.g., Bandura 1997; Guskey and Passaro 1994; Hoy and Woolfolk 1993; Morris et al. 2017; Tschannen-Moran et al. 1998). Teaching self-efficacy was described as a "teacher's belief in his or her own capability to organize and execute courses of action required to accomplish a specific teaching task in a particular context" (Tschannen-Moran et al. 1998, p. 233).

An important distinction has been made between personal self-efficacy and outcome expectancy (Bandura 1997), with the former related to judgments about abilities to perform actions necessary to achieve the desired outcome and preclude unwanted ones while the latter related to beliefs about desired outcomes being dependent on these performances. Scholars underlined that both personal teaching efficacy and outcome expectancy are vital to understanding teachers' sense of efficacy. Several studies reported that personal teaching efficacy and outcome expectancy develop independently of each other (e.g., Riggs and Enochs 1990; Tschannen-Moran et al. 1998). For instance, teachers may believe that students' high exam scores are completely dependent on their instructional performances (high outcome expectancy); however, they also believe that they are not sufficiently equipped to display those performances (low personal efficacy).

Relatedly, Tschannen-Moran et al. (1998) proposed an integrated model which suggests that teacher self-efficacy is shaped through interaction between analysis of personal teaching abilities and of the task in a particular teaching context. The resulting teaching efficacy beliefs have an impact on teachers' performances, how much effort they put forth to teaching tasks, and how long they endure the difficulties and failures associated with a teaching task. This model posits that teachers examine their teaching efficacy by analyzing information derived from four major sources as previously identified by Bandura (1997): enactive mastery experiences, vicarious experiences, social persuasion, and physiological and emotional states. These sources of self-efficacy play a significant role in identifying one's teaching self-efficacy expectations (Bandura 1997; Morris et al. 2017; Tschannen-Moran et al. 1998) (see Table 1). In a similar vein, Palmer's (2006) empirical study with pre-service teachers (PSTs) revealed three additional sources of self-efficacy specific to teaching contexts: cognitive pedagogical mastery, cognitive content mastery, and simulated modeling (see Table 1). Palmer argued that the sources of cognitive pedagogical and cognitive content are the forms of mastery experiences and simulated modeling should be considered as a form of vicarious experience.

**Table 1** Frameworks for sources of self-efficacy

| **Bandura's (1997) Sources of self-efficacy framework** | | |
|---|---|---|
| Enactive mastery experience | | Past perceived successes at performing/completing a teaching task. |
| Vicarious experience | Symbolic modeling | Watching a teacher model's successful classroom implementations via visual media. |
| | Effective actual modeling | Observing a teacher model's successful classroom implementations. |
| | Cognitive self-modeling | Imagining themselves performing teaching practices successfully |
| | Self-modeling | Watching and reflecting upon teachers' own teaching performances (videotaped lessons) |
| Social persuasion | | Constructive feedback and positive talk about one's teaching performances provided by a mentor, peer, or instructor |
| Physiological and emotional states | | Experiences of strong reactions such as stress, anxiety, or excitement to teaching-related tasks |
| | | **Palmer's (2006) Sources of self-efficacy framework** |
| Mastery experience | Cognitive pedagogical mastery | Enhanced understanding of pedagogical approaches and methods necessary to teach the subject matter |
| | Cognitive content mastery | Enhanced understanding of subject matter content knowledge |
| Vicarious experience | Simulated modeling | An instructional model in which prospective teachers play the role of students in teaching and engaging in class activities |

In this study, we designed an engineering unit for pre-service elementary teachers, considering the above-mentioned sources of efficacy beliefs. Our aim was to examine the sources of teaching efficacy within the engineering education context. Morris et al. (2017) underlined that these sources of self-efficacy do not have a direct effect on the evolution of teaching efficacy but rather their effects are moderated by reflecting upon and interpreting their experiences. In that sense, cognitive processing of efficacy information is critical in assessing how the sources of efficacy information produce teachers' sense of self-efficacy (e.g., Morris et al. 2017; Tschannen-Moran et al. 1998). Thus, the participant PSTs in the current study were invited to reflect on their experiences that they had gained during the engineering unit in order to examine their judgments about how the sources of efficacy information provided in this intervention influenced their perceived engineering teaching self-efficacy beliefs.

## Literature review

Teaching self-efficacy has received significant attention from teacher educators and researchers because of its pivotal role in the understanding of teachers' classroom behaviors and their implementations of new pedagogical ideas (e.g., Klassen et al. 2011; Pajares 1992; Woolfolk and Hoy 1990). Studies have consistently indicated that teachers with a high sense of teaching self-efficacy tended to become more engaged in and more receptive to curricular innovations (e.g., Ghaith and Yaghi 1997; Guskey 1988; Nie et al. 2013; Tschannen-Moran and McMaster 2009). Nie et al. (2013), for instance, found a strong correlation between teacher efficacy and attitude toward implementing constructivist instructions. For this reason, it is important to use the self-efficacy construct in order to gain insight into the development of PSTs' future teaching perspective (Ashton and Webb 1986).

Several scholars inquired into the factors contributing to the development of teaching self-efficacy. Many scholars concurred that teacher education and professional development programs should consider the factors motivating teachers to involve in programs and the processes through which change in teachers' pedagogical approaches occur (Menon and Sadler 2016; Tschannen-Moran et al. 1998). In this line of research, several scholars showed different results in terms of the relative importance of the sources of teaching efficacy. Palmer (2006) found that cognitive pedagogical mastery and cognitive self-modeling (visualizing oneself teaching) were the most effective sources for PSTs' science teaching self-efficacy. Although the PSTs had an opportunity to teach science topics, none of them mention their enactive mastery experience as an important source of self-efficacy. This result led him to conclude that different forms of mastery experiences such as cognitive content and pedagogical content mastery, and vicarious experiences such as simulated modeling can be applied to PSTs. Continuing in this line of research, Webb and LoFaro (2020) indicated cognitive pedagogical mastery and vicarious experiences had a significant effect on PSTs' engineering teaching efficacy. Likewise, Menon and Sadler (2016) found that cognitive content and pedagogical mastery, and vicarious experiences were important factors affecting PSTs' teaching efficacy beliefs in a physical science content course. To be more specific, the study indicated that enhanced science conceptual understanding, engaging in active learning experiences, teaching strategies that the instructor used in the course, and instructor's characteristics as a teacher were the most important sources of science teaching self-efficacy. In another study, Phan and Locke (2015) explored the sources of self-efficacy of EFL (English as a Foreign Language) teachers. The study demonstrated social persuasion and vicarious experiences were the most influential experiences rather than enactive mastery experiences. However, Bautista (2011) found that enactive mastery experiences were the most influential source of self-efficacy contributing to the early childhood PSTs' science teaching efficacy beliefs. Also, the study indicated that cognitive pedagogical mastery, symbolic and cognitive self-modeling were also important sources of the PSTs' efficacy beliefs. Given that the majority of these studies focused on teaching efficacy beliefs in the contexts of science, mathematics, and literacy education, little is known about what experiences shape prospective teachers' engineering teaching efficacy beliefs.

For this reason, the focus of this study was on PSTs' engineering teaching self-efficacy beliefs. Pajares (1992) argued that research on PSTs' efficacy beliefs is deemed necessary to provide information for the development of curricula and teacher education courses. In this respect, the current study explored the sources of engineering teaching efficacy in a science methods course to inform teacher education programs on what sources of efficacy information affect PSTs' engineering efficacy beliefs. The NGSS recommends the integration of engineering into science instruction; however, teachers are not yet prepared to implement the requisite knowledge and practices for successful integration. The 2012 National Survey of Science and Mathematics Education (NSSME) uncovered that less than 5% of elementary teachers had completed engineering coursework and that the majority of them stated that they did not feel adequately prepared for teaching engineering (Trygstad et al. 2013). Likewise, a national survey of practicing teachers illustrated that only 3% of elementary teachers reported high confidence in teaching engineering (Banilower et al. 2018). These findings are not surprising when considering the previous studies indicating that teachers had a lack of content knowledge and even had misconceptions about engineering (Cunningham et al. 2006; Hsu et al. 2011; Kang et al. 2018). Cunningham et al. (2006), for instance, demonstrated that teachers envisioned engineers as construction workers who mainly make buildings or as repairmen who fix technologies. Kang et al. (2018) investigating elementary teachers' understanding of the NGSS science and engineering practices illustrated that even though teachers self-reported that they were engaging their students in engineering design activities, none of the elementary teachers could explain the NGSS engineering design practices and the ways to incorporate them into engineering activities.

Given teachers' insufficient knowledge about engineering and previous training, it would not be surprising if they hold low teaching efficacy beliefs. Indeed, several studies indicated that teachers had low self-efficacy beliefs in teaching engineering. In this strand, Hammack and Ivey (2017) found that teachers had low efficacy beliefs in their engineering and engineering design knowledge. It is, therefore, required for teacher educators to equip prospective teachers with the knowledge and skills necessary to increase their teaching efficacy beliefs. To date, several studies have attempted to integrate engineering/STEM in the existing science and/or mathematics methods courses (Bartels et al. 2019; Kaya et al. 2017; Ortiz et al. 2015; Perkins Coppola 2019). Perkins Coppola (2019), for instance, designed an engineering unit for a science methods course in which PSTs were engaged in the engineering design process to solve a problem. The PSTs also developed and taught engineering lessons during school-based field experiences. The study, which examined the effect of the engineering education intervention on PSTs' engineering teaching efficacy beliefs, showed that although the PSTs' personal engineering teaching efficacy beliefs improved after participating in the intervention, the study indicated no significant improvement in their outcome expectancy beliefs. Since K-12 engineering education is still an emerging research area, only a handful of research studies have investigated engineering teaching efficacy beliefs. In addition, little work specifically addressed the factors affecting prospective teachers' engineering teaching efficacy beliefs (e.g., Hammack and Ivey 2017; Perkins Coppola 2019; Webb and LoFaro 2020). Therefore, we attempted to explore the sources of self-efficacy that contribute to the development of the PSTs' engineering teaching efficacy in an engineering education intervention. Also, we investigated the changes in PSTs' engineering teaching efficacy beliefs to examine if such sources provided in the engineering unit significantly improve their engineering teaching efficacy. Specifically, the following research questions guided our study.

1. To what extent does an engineering education intervention improve PSTs' engineering teaching efficacy beliefs?
2. What instructional components and learning experiences do act as the sources of engineering teaching efficacy?
3. How do PSTs interpret the relative importance of the sources of teaching efficacy provided within the engineering education intervention?

## Methodology

### Research design

This study employed a mixed-methods approach focused on identifying sources of engineering teaching efficacy in an engineering unit and whether these sources of efficacy information significantly contribute to the development of PSTs' engineering teaching efficacy beliefs. The mixed-methods design approach was adopted due to the exploratory nature of the study and the complexity of the self-efficacy construct (Morse and Niehaus 2009). This method combines quantitative data obtained from a self-efficacy teaching instrument with qualitative data gathered from written reflections on the instructional components and learning experiences contributing to teaching self-efficacy. While the quantitative data offered a direction and an indication of tendencies in the current study, the qualitative component enabled us to identify which sources of engineering teaching efficacy were associated with the change in PSTs' engineering teaching efficacy beliefs.

### Participants

Participants were selected through a combination of purposive and convenience sampling methods. Given that the focus of this study was on pre-service elementary teachers' teaching efficacy, purposive sampling was used to ensure to obtain a representative sample that characterizes the population of pre-service teachers. Convenience sampling enabled us to select participants on the basis of accessibility and availability. Therefore, the participants in this study comprised 84 pre-service elementary teachers enrolled in a science teaching methods course at a public university in the Southwestern United States. They were all in their senior year of the elementary education program. Approximately 86.9% ($N$=73) of the participants were female and 13.1% ($N$ = 11) were male ($SD$ = .34). The participants' age ranged between 21 and 51 years with a mean of 26.21 years ($SD$ = 6.8). The data were gathered from three sections of the course taught by the same instructor (the first author).

### Research context

This study was conducted in a science teaching methods course designed for PSTs enrolled in an elementary education program at a large university in the Southwestern United States. The semester-long course mainly focused on preparing PSTs to teach science concepts to elementary students.

The course content was aligned with K-5 NGSS evidence statements. Throughout the intervention, the PSTs were exposed to engineering design challenges and the explicit and reflective nature of engineering instruction. Even though the NGSS put emphasis on engineering practices, little emphasis was given to the nature of engineering aspects. For this reason, we developed a framework that sheds light on the nature of engineering aspects based on the analysis of the NGSS recommendations (Deniz et al. 2020, see Appendix A). Specifically, the framework addresses the engineering design process, demarcation of engineering from other disciplines, and the nature of engineering aspects comprising empirical, creative, subjective, collaborative, and socially and culturally embedded nature of engineering aspects. Although the engineering unit intensively focused on engineering and teaching engineering, integration of engineering in science teaching was also addressed during the engineering unit. The NGSS suggests the integration of engineering in the K-12 science curriculum in two ways: engineering as an important content area and as a pedagogical teaching approach to teach science. With this in mind, pedagogical discussions on how to use engineering as a context in which students can be engaged in the application of their scientific knowledge were included.

The engineering unit included lectures and associated engineering design activities. The engineering unit was taught by the first author. During the engineering unit, the PSTs experienced the engineering unit as if they were elementary students and reflected upon their experiences from a teacher perspective. At the beginning of the unit, PSTs went through the entire engineering design process to complete an engineering design challenge. They were first invited to read a children's engineering book presenting a scenario including a mechanical engineering problem and the criteria for design solutions. The PSTs were then expected to figure out the engineering problem and design specifications. To solve the problem, the PSTs were needed to build a coaster car that should travel as far as possible and must follow a straight line. They first brainstormed and sketched at least three alternative designs on paper. Then, they agreed upon one viable design option as a group and then, engaged in constructing their prototypes. They were given inclined planes to test whether their designs meet the design criteria. While testing their designs, they were asked to collect data by measuring the distances that their coaster car travels in a straight line and then, draw a graph. After evaluating their designs based on empirical data, they were given a chance to refine their designs. Throughout the engineering design process, the instructor explicitly introduced the nature of engineering aspects to the PSTs and modeled how to teach these aspects to elementary students. The lecture content included the introduction of the nature of engineering aspects. The PSTs were given an opportunity to reflect upon their engineering design experiences from the perspective of the nature of engineering aspects. The instructor engaged the PSTs in a discussion with respect to the benefits of the explicit nature of engineering instructions for the development of students' conceptions about the nature of engineering. Besides, the instructor addressed the NGSS connections including engineering practices, core ideas, and crosscutting concepts. Lastly, they watched a video of an elementary teacher successfully integrating the engineering design process into her lesson.

In the next session of the intervention, the instructor used Lego Mindstorms EV3 Educational Robotics kits to engage the PSTs in the engineering design process through programming. They were asked to program their robots to navigate autonomously to accomplish the several challenges through using EV3 Programming Language. The PSTs engaged in an iterative design process similar to real computer and software engineers. After each group accomplished their challenges, they reflected upon their experiences in terms of the design process and the nature of engineering aspects. The lecture content of this session included the introduction of the common students' misconceptions and stereotypical views regarding engineering. We had a short discussion on how to assess students' engineering views and how to minimize their misunderstanding. Besides, the PSTs watched a video of a teacher integrating an iterative design process into his lesson for K-5 students. Throughout the engineering unit, several picture books related to engineering, nature of engineering, and/or engineering design process were read aloud. Several of these books also addressed science concepts that were relevant to the design activities. Besides, the engineering unit was supported through reading assignments related to the engineering integration that the PSTs completed before the lessons and had a discussion about them on an online discussion platform. At the end of the lesson, the PSTs were provided with various engineering resources including sample lessons, sample engineering challenges, YouTube channels which include the videos of sample engineering lessons, and children's engineering books.

## Data collection

The data were collected through the engineering teaching efficacy beliefs instrument which measures PSTs' engineering teaching self-efficacy beliefs and the written reflections to identify the sources of engineering teaching efficacy.

### *The engineering teaching efficacy belief instrument (ETEBI)*

The Science Teaching Efficacy Belief Instrument Version B (STEBI-B) (Enochs and Riggs 1990) was modified by the authors who were researchers in the field of science and engineering education (Yesilyurt et al. 2019) to examine teachers' engineering teaching efficacy beliefs. We decided to use this measurement as a basis to develop our instrument because as Bandura (1981) put forward, the construct of self-efficacy is situation-specific, general measures of sense of self-efficacy could not be informative, thus this instrument provides a measure of teaching self-efficacy for a particular content area. For that reason, the items on the STEBI were modified by replacing the terms "science" or "science teaching" with "engineering" or "engineering teaching" to develop the Engineering Teaching Efficacy Belief Instrument (ETEBI) (see Appendix B).

Similar to the STEBI, the ETEBI includes two subscales: personal engineering teaching efficacy (PETE) and engineering teaching outcome expectancy (ETOE). The factorial structure of the instrument was investigated by the authors prior to the study based on the data obtained from 347 PSTs using exploratory factor analysis (Yesilyurt et al. 2019). Given that Bandura's self-efficacy construct has two dimensions: personal self-efficacy and outcome expectancy, we relied on the already established validity of the original instrument, and two factors were requested in the factor analysis. The factor analysis with oblique rotation was performed as the two subscales were found to be correlated. Two items (items 10 and 13) that loaded on a third factor were dropped from further interpretation. Thirteen PETE items and 8 ETOE items having factor loadings higher than .40 were retained. The Cronbach's $\alpha$ coefficients for PETE and ETOE subscales were .89 and .80, respectively. The final ETEBI consists of 21 items designed on a five-point Likert-type scale that ranges from strongly disagree (1) to strongly agree (5).

To examine the changes in the PSTs' engineering teaching efficacy beliefs after the engineering education intervention, they were invited to complete the ETEBI instrument at the beginning and at end of the intervention using a pre/post-design. The participants were given ample time to fill out the ETEBI. However, it took approximately 15 min to complete it.

#### *Written reflections*

At the end of each session, the PSTs were asked to write reflections about their experiences and aspects of the engineering unit that helped them feel more confident to teach engineering. Specifically, the PSTs were invited to provide a detailed explanation to the following open-ended question: "Has anything in this session of the engineering unit helped to make you more confident to teach engineering? Please explain why?". The reflection paper took approximately 15–20 min to complete. The purpose of the use of written reflections was to gather data about the sources contributing to the engineering teaching self-efficacy and the relative importance of each source.

### Data analysis

The analysis of the ETEBI data was performed using the Statistical Package for Social Science (SPSS 25.0). To measure the effectiveness of the engineering unit implementation on the PSTs' PETE and ETOE beliefs, the two paired samples t-test, which allows intra-group comparisons, was employed to compare the differences in the means of pre- and post-ETEBI scores.

The PSTs' responses relevant to the instructional components and learning experiences influencing their teaching efficacy beliefs were isolated and categorized using Bandura's (1997) and Palmer's (2006) sources of self-efficacy frameworks. Using sources of self-efficacy categories as our framework, we examined the PSTs' learning experiences during the engineering unit and which components of the engineering unit are associated with sources of self-efficacy categories that enhanced their engineering teaching efficacy beliefs. The PSTs' expressions with regard to sources of their improved engineering teaching self-efficacy were evident in their statements with regard to increased confidence to teach engineering, change in their conceptions of engineering, engineering teaching views, and their plans to use the ideas and resources presented during the engineering unit in their future classrooms. However, it is important to keep in mind that the engineering unit did not include enactive mastery, effective actual modeling, and self-modeling experiences. The relative importance of each source was analyzed by the frequency of responses concerning each source.

To establish reliability, the written reflections were independently analyzed and coded by the three researchers who had experience in engineering education, self-efficacy, and qualitative data analysis. The inter-rater reliability was established as kappa = .88 ($p < .0005$). Besides, thick descriptions of data were provided for each category using contextual descriptions with enough detail in order to increase the transparency of findings (Geertz 1973).

**Table 2** Means, standard deviations, and paired sample t-test

| Engineering teaching efficacy beliefs | | Mean | SD | df | t | Sig. |
|---|---|---|---|---|---|---|
| PETE | Pre | 41.51 | 8.19 | 83 | − 8.6 | .000* |
| | Post | 47.58 | 8.01 | | | |
| ETOE | Pre | 26.67 | 3.17 | 83 | − 3.21 | .002* |
| | Post | 27.85 | 3.78 | | | |

## Findings

The paired samples t-test was performed to investigate whether there was a significant change in the PSTs' engineering teaching self-efficacy beliefs. The paired samples t-test analysis revealed that there was a statistically significant improvement in PETE beliefs; $t(83)= -8.6$, $p < .05$ (see Table 2). Also, the effect size (Cohen's d) for the PETE scale was found to be large ($r = .81$; $d > .8$) (Cohen 1988). Therefore, the results indicated that the PSTs' PETE beliefs significantly improved after the engineering education intervention. Although paired samples t-test analysis showed a statistically significant improvement in ETOE beliefs; $t(83)= -3.21$, $p = .002$, the effect size for the ETOE scale was found to be small ($r = .19$; $d < .2$). This means that the intervention had a relatively small impact on the PSTs' ETOE beliefs.

Written reflections supported the findings from the ETEBI instrument since 92% of the PSTs reported that their confidence to teach engineering improved after the engineering unit. Consider the following responses from the participant students:

> Before this week's lecture on engineering, I had little knowledge on the topic of engineering, let alone how to teach it to elementary students. But after the engineering lessons, we had, definitely, I f*eel I have more confidence* in teaching engineering.

> I am looking forward to teaching engineering in my class using this process (the engineering design process). *This lecture has made me feel more confident about* what I need to do to teach engineering and how my lessons should be planned. I feel that my students will gain a clearer understanding of the discipline and will enjoy the process more as a result.

However, several students indicated that they were still worried about classroom implementations. As one participant stated: "But I have to admit that *I am still nervous* about teaching engineering because I don't know how it is going to work with elementary students." Another participant emphasized the need for teaching experiences to improve their confidence: "I feel I still need more experience. I wish we had a chance to teach and receive some feedback." These expressions were consistent with our findings concerning outcome expectancy.

The total number of sources of self-efficacy mentioned (*n*total = 243) was more than our sample (*N* = 84) because we collected two written reflections from each student at the end of each session of the unit and also, some students indicated more than one source in their reflections. In the following, each category of the source of teaching efficacy was presented with excerpts from students' written reflections (words or phrases are shown in italics to indicate the key points) (see also Table 3).

Of the mastery experiences mentioned, cognitive content mastery (*n* = 64) and cognitive pedagogical mastery (*n* = 62) were found to be the most important sources of engineering teaching self-efficacy among the participant PSTs. Cognitive content mastery refers to improved subject matter knowledge in a given area. In this regard, the responses including an improved conceptual understanding of engineering and improved ability to answer students' questions were placed in the category of cognitive content mastery. In this category, the participants particularly indicated how an improved understanding of engineering, engineering design process, and nature of engineering aspects facilitated their gains in confidence about teaching engineering. One of the participants, for example, seemed to benefit from the introduction on the aspects of the nature of engineering: "I feel more confident in teaching engineering because I *understand the phases in designing products to solve human problems and what is important to remember is to use empirical evidence to improve the design*". Another participant emphasized the creative aspect of engineering as follows: "*I've learned the design process,…, also creativity is an important component of engineering*, so it is essential that I set my own engineering design projects up in my classroom in a way that allows for students to use their *own* creativity while still guiding them using the engineering design process."

Several PSTs emphasized the benefits of learning the interrelationships among STEM disciplines as one participant stated:

> We made the connection between engineering, science, and technology, something I struggled to understand well. *Once I learned that the definition of engineering was the use of science to create solutions to societal issues, and tech is the result of these solutions, it made more sense how to incorporate the different aspects into lessons* that create authentic situations that make the science concepts relevant to the students' lives and prior knowledge.

Also, most PSTs indicated that learning about the phases of the engineering design process helped them improve their confidence. One participant, for example, stressed:

> *Learning the engineering design process was helpful to me* in terms of becoming more confident in teaching engineering. The process involves identifying a problem, developing possible solutions, selecting a solution, building a prototype, and testing the prototype. The improving step especially is vital for students, it gives them the ability to strengthen their understanding of the engineering process and have a more effective product.

Another important finding was related to the effect of engineering instructions on the PSTs' conceptions about engineering. Several participants underlined the change in their conceptions that they had had prior to the engineering lessons regarding engineering activities. One of the PSTs, for example, noted how the hands-on activities helped correct her misconceived views as the following statement illustrates:

> I always assumed that if someone was an engineer, they would be required to use their knowledge to build things better than they were before. *This class showed that there is more to engineering than just building things.* In simple terms, engineers solve problems. For instance, as for the robot lesson, my initial thought was that the engineering portion would be just building the robot itself. However, this was incorrect. *The engineering portion was determining the correct coding to instruct the robot what to do in order to solve the specific problem. The importance of problem-solving was my main takeaway from the lesson in regard to teaching engineering.*

Another source of efficacy observed in the PSTs statements was cognitive pedagogical mastery which is about improved pedagogical knowledge. Therefore, the responses included in the category of cognitive pedagogical mastery pointed out an enhanced understanding of the teaching strategies or procedures to teach engineering. Most participants described the hands-on engineering activities, explicit and reflective nature of engineering instruction, and integration of literacy, science, and mathematics with engineering as effective instructional models. For example, after the PSTs went through the engineering design process, the phases of the design process were introduced and connected to their design experiences. Relatedly, one of the PSTs touched upon this strategy as follows:

> What stands out the most to me is *how the professor really connected the steps of the design process with the processes we have already gone through*. Also, *the discussions on how to teach the nature of engineering after the design challenge* help me build my confidence in teaching engineering.

During the first week, the instructor had a discussion on an article that integrates the engineering design challenges with literacy. The PSTs seemed to find this lesson idea useful to target more than one standard. One participant, for example, stated:

> I love the article on the soda can crusher challenge and agree with the idea that you can always *teach an engineering or science-based lesson with support from reading, writing, and math allowing the teacher to hit several standards* at once.

In a similar way, the instructor also integrated reading activities and made math and science connections during the engineering design activities. In that respect, one participant PST shared her observation as follows: "The coaster car handout I thought was very interesting. I liked this activity because *it can be cross-curricular*. With this activity, *you can have writing standards, reading standards, science and math standards*".

It appears that several PSTs recognized the value of engineering education in K-12 settings after the instructions. One of the participants, for example, underlined the importance of making real-life connections by integrating engineering: "I think that allowing the students some freedom as well as *having structured engineering activities that showcase how what they are learning can be translated into the real world makes their learning meaningful*". In another example, one participant stressed the value of engineering in science lessons due to its interdisciplinary nature as follows: "*Engineering introduces social studies into the science classroom*, helping us teachers make the interdisciplinary connections." Besides, another participant underlined the context that engineering provides for promoting science learning: "Engineering is the application of scientific knowledge; it is not merely enough that students are taught about scientific topics, but they need the space and opportunity *to apply that knowledge.*"

Another factor influencing the PSTs' self-efficacy was the connections made between the activities and the current science education standards. During the instruction, the standards including mainly engineering and science as well as literacy and mathematics were also addressed. For instance, one participant mentioned: "This lesson has helped me grow my confidence in *connecting meaningful activities to the standards that are associated* and helping to grow the students' love of the STEM subjects." Another participant PST pointed out that after the engineering instructions, she started to examine more closely how the lessons taught in the practicum addressed the standards: "After last week's class, I was able *to look more critically at how the engineering and science standards were being covered* by the teachers and whether the students really engaged in the NGSS as we have been discussing and practicing."

The participants also highlighted the important skills that students can acquire by engaging in engineering design activities. Consider the following statement: "I believe with the incorporation of activities, such as the EV3 robots, it will help bring support for teachers who try to *relate real-world benefits and skills that students may acquire, such as critical thinking and problem-solving skills*". By the same token, another PST specified that "by allowing students to engage in the engineering design process, we are allowing them *to develop and hone their skills of critical thinking, reasoning, exploration, and problem-solving.*"

Several participants mentioned the limited time that they would have for teaching science in elementary classrooms. In light of this, they recognized the value of engineering as a context to teach and make connections to other subject areas. One participant discussed the need for cross-curricular activities for elementary education as follows:

> It is *difficult in terms of time constraints* to be able to easily incorporate ample opportunity for engineering practices. However, by using and directly engaging in the coaster car activity, I have found that *allowing students to participate in the hands-on activities will significantly improve their ability to think critically and process the other content area information*.

Of the vicarious experiences, cognitive self-modeling ($n$ = 71) and simulated modeling ($n$ = 27) were the two major sources of engineering teaching efficacy. Cognitive self-modeling is defined as visualization of oneself performing instructional practices and thus, the responses were coded as cognitive self-modeling if they mentioned the future plans to use ideas and resources presented during the engineering unit. The participant teachers discussed the potential use of effective instructional models (e.g., hands-on engineering design activities) and lesson ideas that integrate engineering across subjects. Consider the following example related to the future use of resources (cognitive self-modeling): "I think *YouTube* *channel videos* seem really helpful... *I will most definitely use these activities (teachers' activities in videos) in my future class.*" In another statement, one participant pointed out the potential benefits of using the picture books about engineering that were provided at the end of the engineering instructions:

> I was given a booklist to incorporate into my future lessons. *This booklist was very helpful because they (the books) not only discussed the process and phases, but it also gave an explanation of the connection to the nature of engineering.*

During one of the engineering challenges, we read a book that addresses several science concepts including gravity, force, momentum, and the relationship between them. The PSTs were required to apply their knowledge that they acquired from the book to design their products. In this regard, one of the PSTs stated:

> My idea of teaching engineering has changed. *I saw the connection with other subjects, so I can see in my mind how to create cross-curriculum lessons in my future classes* that can tackle several standards including math, science, engineering, writing, reading, and more.

Also, experiences with respect to engaging in class activities as a student which is defined as simulated modeling were observed in the PSTs' responses. In that sense, the responses that indicated increased confidence due to having an opportunity to learn as a student were coded as simulated modeling. The participant teachers talked about the benefits of engaging in engineering lessons as a student helped them understand what students may gain from a particular experience. For instance, one participant said:

> Yes, this lesson has helped me grow my confidence because I had the opportunity to do an activity and *put myself in the student's perspective*. As a teacher, I need to know what students will be thinking while they are designing.

One participant discussed engaging in hands-on activities as students helped him understand what difficulties students may have during an engineering lesson: "I enjoy being able to *engage in these activities from the student perspective* as a teacher so that I might better understand the struggles my students might be going through as I teach them science and engineering concepts." Another stated engaging in the design process facilitated his understanding of how to transfer the particular experience to their future classes: "I think *doing the hands-on activities are helpful for us* as future educators. *This helps us remember the activity*. This also makes us think about how we would use the activity in our classroom."

It is important to note that many students' responses indicated more than one source of efficacy in their statement which demonstrates how the sources are connected to each other. The PSTs mentioned how they visualize themselves teaching engineering after indicating how pedagogical approaches to teaching engineering, resources, and engaging in the engineering design activities help them increase their confidence. One participant, in this respect, stated "*showing the engineering lesson how it would be taught for a student* is helpful (cognitive pedagogical mastery). This *gave me an idea of how I would deliver it to my students* (cognitive self-modeling)." In another example, the participant teacher noted how increased content knowledge could help him structure his future engineering instructions. In this example, he underlined the importance of the process rather than end-products as follows:

> I am very glad that *I've learned the process* (cognitive content mastery) because before I would have just asked students to create anything and then I would have graded them based on what they gave me. This is clearly ignoring two out of three components of the engineering design process. I would have had them ignore the "define" and "optimize" components of the process and that would have been unacceptable. I am really happy that *I now know the three components of the engineering design process so that my students could take part in the engineering design process* (cognitive self-modeling).

In a similar way, another participant teacher noted that engaging in the design process as a student encouraged her to integrate the design process into her future classrooms as indicated in the following expression: "It was really cool to *see what the models of robots can do in person*... (simulated modeling). *It gave me a good idea of what kinds of engineering projects my future students can make* (cognitive self-modeling)."

Also, it was indicated that engaging in hands-on engineering activities increased PSTs pedagogical knowledge regarding how to teach engineering. One of the participants illustrated this point in the following observation:

> *Engineering is building and designing solutions to human problems* (cognitive content mastery). Prior to this week's lessons, I would tell my students the desired outcome of a design I wanted them to create and would provide little guidance for the

> project, letting them build their designs and explore on their own. I did not mention engineering as a discipline or guide them through the steps they should take to design, build, and improve their models. *The engineering design process will help me plan engineering lessons with more focus and clarity* (cognitive pedagogical mastery).

Several students indicated fruitful learning experiences, but they did not specify the learned material (content or pedagogy). These responses were classified as unspecified cognitive mastery or pedagogy mastery (*n* = 10). Only a few students indicated that watching other teachers' instructional performances encouraged them to teach engineering (symbolic modeling) (*n*=4). For instance, one participant PSTs said: "seeing other teachers integrating it [engineering] and students' engagements were very helpful" (Table 3).

Few students mentioned their anxiety and stress about teaching engineering before the engineering unit (emotional states) (*n*=5). For instance, one of the participants stated: "I was very nervous to teach a lesson on engineering because I didn't even know what engineering design process is." However, most of these participants indicated a decrease in their anxiety after the engineering unit: "I really was *worried* when this whole topic of engineering came up and did not think I would be good at it… Now I feel really confident and *excited to do* some hands-on engineering activities with my students." The engineering unit did not include any experiences in teaching engineering (enactive mastery), teaching it in real class (effective actual modeling), and watching videotaped PSTs' teaching performances (self-modeling). Therefore, these categories were not included in this study.

## Discussion

The NGSS put equal emphasis on science and engineering education in K-12 settings. In that sense, the standard documents call for teachers to integrate engineering as a separate disciplinary topic and as a context to teach scientific knowledge in their programs (NRC 2012). This new approach to science education requires teacher educators to upgrade their existing science methods courses by integrating engineering units in existing courses or offer engineering content and methods courses (Murphy and Mancini-Samuelson 2012; Ortiz et al. 2015). However, many departments have a lack of resources and

**Table 3** The sources of engineering teaching self-efficacy indicated by the participant PSTs

| Sources of self-efficacy | | Examples |
|---|---|---|
| Mastery experiences | Cognitive content mastery (*n* = 64) | "Another tool that made me more confident in teaching this topic was *learning the engineering design process*. Learning about the process will help me ensure not all prototypes will be a success. Having the students understand the process may have to be repeated several times to receive positive results will help eliminate discouragement" |
| | Cognitive pedagogical mastery (*n* = 62) | "*Learning about connecting this topic to other subjects (i.e., reading)* has helped me become more confident in teaching this topic. This part of the lesson introduced me to ways I can incorporate engineering successfully in many different content areas that I am more comfortable in teaching". |
| | Unspecified cognitive mastery or pedagogy mastery (*n* = 10) | "Teaching engineering was not something I was comfortable with. As a student, I did not have opportunities to do it myself, therefore I was unsure of how to approach it. This lecture helped me become more confident and well-rounded in teaching engineering. *It gave me a better understanding of how I should be setting forth my expectations and how to provide appropriate support while still ensuring there is rigor*". |
| Vicarious experiences | Cognitive self-modeling (*n* = 71) | "I think the most helpful things I learned during this week's lectures were all the creative activities that you can do with your students, such as the building of the car model activity and soda can crusher. I think that would be great to do with grades 4-5$^{th}$. *At first, I was not as confident in teaching engineering but then I realized that there are so many creative activities that I can do and introduce to students*". |
| | Simulated modeling (*n* = 27) | "*Being able to engage in the process as a student* allowed me to understand that I was eager to jump into the building and testing phases, and I began to think about how I might get my students to slow down enough to do background research and brainstorming solutions before jumping into building". |
| | Symbolic modeling (*n* = 4) | "Something else I find good is that students can learn how to collect data, which is the empirical aspect of engineering. *I liked the fact that the teacher (in the video)* helped the students gather data and had the students analyze the data and chart it to come up with a pattern or any other things they noticed". |
| Physiological and emotional states (*n* = 5) | | "I feel that this week has gotten me more confident to teach engineering. *I initially was nervous* and thought that engineering was some complex subject that required years of studying and experience to even fathom, but it turned out that the design process was feasible and easier to understand than I expected. I especially loved the presentation we were able to see. It was fun, easy to relate to, and I found myself learning about all sorts of technologies that I could possibly begin to use in my class in the future". |

funding to offer new courses. From this perspective, this study could be exemplary for integrating engineering in methods courses among the others to provide instruction on engineering as well as an interdisciplinary approach to teaching science. In this study, we developed an engineering unit that addressed both content and pedagogy. We presented the engineering design activities along with the epistemological aspects of engineering through the explicit-reflective nature of engineering instruction in an elementary science teaching methods course. In addition, we integrated engineering with other subjects such as science, mathematics, and literacy.

Even though efforts have been made to incorporate engineering/STEM in methods courses to develop PSTs content and pedagogical knowledge (Bartels et al. 2019; Kaya et al. 2017; Ortiz et al. 2015; Perkins Coppola 2019), little was known about what particular sources of efficacy information support the development of PSTs' engineering teaching efficacy. From this perspective, this study examined the sources of engineering teaching self-efficacy within the engineering education intervention to inform the decisions that teacher educators make concerning their instructional practices as well as related research. The findings of this study indicated that cognitive content mastery, cognitive pedagogical mastery, and cognitive self-modeling were the most important engineering teaching efficacy sources for the PSTs. Many PSTs stated that engaging in hands-on activities (engineering challenges), instruction on the engineering design process, and nature of engineering, and pedagogical discussions on how to teach engineering concepts helped them improve their engineering teaching efficacy. Also, the PSTs expressed a willingness to use ideas and resources in their future teaching. In terms of relative importance, in the current study, cognitive content mastery was found to be the strongest source of engineering teaching self-efficacy among the master experiences. It appears that most PSTs benefitted from the instruction on the engineering content knowledge (e.g., the phases of the engineering design process, the nature of engineering ideas, common misconceptions with regard to engineering work, and the interrelationships between engineering, science, and technology). In this respect, previous studies investigating the sources of teaching efficacy in the subject areas of general teacher education, science, and childhood education produced inconsistent results. Bandura (1997) contended that enactive mastery experiences are the most important source of self-efficacy since they indicate direct evidence as to their capabilities to succeed. Several studies provided empirical support for Bandura's claim by illustrating that enactive mastery experiences were the most important sources of self-efficacy strengthening teachers' teaching efficacy (Bautista 2011; Morris and Usher 2011; Tschannen-Moran and McMaster 2009). On the other hand, other studies found that social persuasion, vicarious experiences, and other mastery experiences (e.g., cognitive content and cognitive pedagogical mastery) could be the most effective sources (e.g., Menon and Sadler 2016; Palmer 2006; Phan and Locke 2015). For instance, Palmer's study indicated that cognitive pedagogical mastery and vicarious experiences were the most effective sources that significantly improved the PSTs' self-efficacy beliefs even when enactive mastery experiences were included in the course. Unlike most previous studies on the sources of teaching efficacy (Bandura 1997; Bautista 2011; Palmer 2006), the greatest emphasis was given to the cognitive content mastery experiences in the current study. The reason for this may be that many PSTs did not have any background knowledge about engineering concepts (e.g., nature of engineering, engineering design process, etc.) despite having some background knowledge about science throughout their education. Besides, most PSTs discussed the benefits of engaging in the engineering design process for their teaching confidence. This may be attributable to little or no exposure to engineering design activities throughout their education. Similar to Banilower et al.'s (2018) report, many PSTs stated they had no or little experience in engineering prior to the engineering education intervention. Further, several PSTs underlined that they had held misconceptions concerning engineering and engineering work prior to the intervention. Likewise, past research revealed the misconceptions that teachers often have (Cunningham et al. 2006; Hsu et al. 2011). In this regard, the PSTs recognized that the intervention helped them eliminate or minimize their misconceived views concerning engineering.

Besides, cognitive pedagogical mastery experiences were found to be important for the PSTs' teaching efficacy. The PSTs emphasized that they appreciated the value of engineering education in K-5 settings after the intervention due to its potential to be used as a context to make connections to other subjects such as mathematics, science, and literacy. Considering the limited instructional time available for science in elementary education settings, several participant PSTs voiced that one of the instructional components influencing their confidence was the use of cross-curricular activities in engineering lessons. In addition, of the vicarious experiences, cognitive self-modeling was the most powerful source in this study. This finding further supported the significant impact of the intervention on the participant PSTs' teaching self-efficacy since they indicated that they were willing to use the hands-on activities, diagrams, and other engineering content as well as pedagogical techniques that they experienced for their future instructions. Also, it was shown that it was necessary to provide multiple resources and ways to teach engineering including sample lesson plans, videos, children's engineering books in order to improve PSTs' engineering teaching self-efficacy beliefs.

We recommend caution in interpreting our findings due to the fact that the engineering unit did not include enactive mastery, effective actual modeling, and self-modeling experiences. This was maybe the reason why we did not find a large effect on the PSTs' ETOE beliefs. Similarly, most studies on science and engineering teaching self-efficacy illustrated that PSTs' personal teaching efficacy indicated more growth than their outcome expectancy beliefs (e.g., Deehan 2016; Perkins Coppola 2019). From this perspective, several scholars argued that outcome expectancy has been reported to be a difficult construct to measure because various variables could have an impact on teachers' outcome expectancy beliefs (Morrell and Carroll 2003; Riggs and Enochs 1990). Others claimed that PSTs lack the necessary understanding of the teaching profession due to the limited classroom teaching experiences and lacking real-life teaching context to base their judgments about the outcome expectancies upon (Hechter 2011; Tosun 2000). That is why the scholars argued that PSTs don't have the conceptualizations required to respond to the outcome expectancy questions appropriately. This emphasizes the need for an engineering teaching context for PSTs such as field and clinical experiences and internships. By the same token, after engaging in the engineering unit, the participant PSTs still indicated some doubts with respect to their ability to transfer their understanding to the classroom context. It is, therefore, necessary to integrate a variety of mastery and vicarious experiences regarding engineering teaching into elementary teacher education programs.

## Conclusion

As a powerful construct, teaching self-efficacy has been indicated to be related to teachers' instructional practices (e.g., Morris et al. 2017; Tschannen-Moran et al. 1998). Since Bandura (1997) introduced the sources of self-efficacy information that support the formation of self-efficacy beliefs, the necessity to identify such sources was underlined by many scholars to inform instructional practices in teacher education programs (e.g., Morris et al. 2017; Poulou, 2007; Tschannen-Moran et al. 1998). Since the advent of the NGSS, there has been an increasing push to prepare PSTs for engineering teaching starting from the elementary school level to meet the demands of the standards; however, there is a paucity of research on the sources of PSTs' engineering teaching efficacy beliefs. Therefore, we aimed to investigate the sources of engineering teaching self-efficacy for PSTs and examine whether the engineering education intervention providing various sources of teaching efficacy information had a significant impact on their engineering teaching efficacy beliefs. The analysis indicated that cognitive content and cognitive pedagogical mastery were highly effective sources of engineering teaching efficacy among the PSTs. Specifically, the data revealed that engineering design activities and explicit emphasis on the nature of engineering concepts were regarded as the most influential components of the intervention by the PSTs. Also, the PSTs in this study underscored the value of integrating engineering with other subjects due to the limited time devoted to teaching science and engineering in elementary education. From this perspective, the study suggested that future engineering education interventions be designed in a way that allows teachers to engage in design activities along with explicit and reflective instructions on the nature of engineering ideas. Also, it would be wise to model the integration of other subjects including science, mathematics, and literacy in engineering instruction.

Hence, the current study provided insight into the sources of engineering teaching self-efficacy beliefs for PSTs and the ways of integrating the NGSS aligned engineering unit into a teaching methods course. In that respect, our study will be beneficial for educators who seek ways to develop engineering units for their methods courses. Also, those interested in exploring factors influencing PSTs' engineering teaching self-efficacy beliefs would benefit from our findings.

The current study also indicated the engineering education intervention consisting of various sources of engineering teaching efficacy information significantly improved the PSTs' personal engineering teaching efficacy. Although statistically significant, we found a relatively small impact of the intervention on the PSTs' engineering teaching outcome expectancy. In this sense, this study suggested providing teaching contexts for engineering teaching experiences for PSTs. Although science teaching methods courses could provide an ideal context for the integration of engineering concepts, these courses are limited in scope and time since the courses are specifically designed to teach science teaching methods. One practical solution could be designing integrated courses that provide teaching contexts for PSTs. PSTs could be given the opportunity to practice engineering teaching along with science teaching. Hence, there is a need for additional studies in order to examine the effectiveness of integrated courses which allow PSTs to gain experiences in teaching engineering to elementary students (enactive mastery experiences) and receive feedback from instructors, mentor teachers, and their peers about their teaching performances (social persuasion). Such studies will have the potential to inform engineering/STEM teacher educators in terms of the effective integration of engineering in elementary teacher education programs. Besides, it would be useful to investigate experienced teachers' engineering teaching outcome expectancies to determine if the small effect size found for the outcome expectancy in this study is related to the lack of teaching context or the particular sources of efficacy information.

It should also be noted that the findings of this study may not be applicable to other populations such as secondary pre-service teachers and in-service teachers because they might prioritize different components of the engineering instruction and different combinations of sources of self-efficacy in justifying their improved engineering teaching efficacy beliefs. In addition, the sources of self-efficacy reported in this study were specific to a relatively short engineering instruction provided to PSTs within the constraints of an elementary science methods course. Therefore, we think that it would be fruitful if future research includes longer engineering education interventions using various mastery and vicarious experiences with different populations such as pre-service secondary teachers and in-service teachers.

### Abbreviations
PST: Pre-service teachers; ETEBI: Engineering Teaching Efficacy Belief Instrument; STEBI-B: Science Teaching Efficacy Belief Instrument Version B; PETE: Personal engineering teaching efficacy; ETOE: Engineering teaching outcome expectancy; NGSS: Next Generation Science Standards; EFL: English as a Foreign Language

## Supplementary Information
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**Additional file 1.** Appendix A. Nature of Engineering Framework (Deniz et al. 2020). Appendix B. Engineering Teaching Self-Efficacy Instrument (ETEBI).

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### Authors' contributions
EY designed the research study, implemented the engineering unit, and drafted the manuscript. All authors together developed the engineering unit for the science methods course. HD developed the ETEBI measurement tool. All authors together analyzed the reliability of the ETEBI. HD and EK contributed to the data collection, analysis of the data, and revising the manuscript. All authors read and approved the final manuscript.

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## Declarations

### Competing interests
The authors declare that they have no competing interests.

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