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Examining Pre-Service Elementary Teacher Self-Efficacy for Engineering Education

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ABSTRACT

Engineering education is receiving increased attention, although teacher preparation for engineering in the elementary grades is not well understood. This study investigated the influences of an elementary science teaching methods course, focused specifically on elementary engineering, on teacher candidates' self-efficacy for teaching engineering in elementary classrooms. The study builds on prior research with the Teaching Engineering Self-Efficacy Scale (Yoon et al., 2014) and offers insight about the tool's use with teacher candidates. These findings are accompanied by qualitative analysis of participants' responses to course assignments and semi-structured interviews to further explore connections between efficacy and understanding. Strong gains are reported in participant self-efficacy, even as some misunderstandings remain about engineering and the relationship of engineering, science, and technology. Overall, the study reveals the power of a focused methods course that includes field experiences in an elementary school with an expert teacher. Implications for teacher educators and researchers are discussed.

Keywords: elementary engineering, self-efficacy, pre-service teachers

Introduction

Arguing for the introduction of engineering in Massachusetts' school curriculum, Ioannis Miaoulis (2010) referred to engineering as "the missing core discipline" (p. 37). That is, while elementary and secondary education in the United States has concerned itself with learning about the natural and social worlds we inhabit, it has not sufficiently prepared students to understand the engineered, designed world that influences our daily lives. However, with the publication of *A Framework for K-12 Science Education* (National Research Council [NRC], 2012) and the associated Next Generation Science Standards (NGSS, NGSS Lead States, 2013), there is increasing attention paid to engineering education in kindergarten through grade 12 (K-12) settings. The NRC (2012) explained in these reform documents that

> engineering and technology are featured alongside the natural sciences (physical sciences, life sciences, and earth and space sciences) for two critical reasons: (1) to reflect the importance of understanding the human-built world and (2) to recognize the value of better integrating the teaching and learning of science, engineering, and technology. (p. 2)

As engineering finds its home within the core curriculum, science teachers are expected to engage students in authentic engineering learning experiences that promote understanding and use of engineering practices, habits of mind, and design processes (National Academy of Engineering [NAE], 2009; Sneider, 2016). Teachers are further challenged to harness the potential of engineering design to better connect learners to concepts in science, math and other disciplines (Kim et al., 2019; Reimers et al., 2015; Wendell, 2014). The integration of engineering into the science curriculum leads us as teacher educators to ask, how are we preparing our teacher candidates to support student learning of engineering and its relationship to science and other subject areas?

Research suggests that supporting elementary teachers' preparation for engineering education is an area of need (Antink-Meyer & Meyer, 2016; Banilower et al., 2018; Capobianco & Radloff, 2021; Cunningham & Carlsen, 2014; Douglas et al., 2016; Pleasants et al., 2020; Pleasants et al., 2021; Yoon, et al., 2013). The nature of engineering has not been well defined for teachers (Pleasants & Olson, 2019), and engineering education may feel different from teaching other subject areas. For instance, without clear-cut or singular solutions, engineering design challenges can promote a level of unpredictability that requires teachers to act as a fellow participant in the learning process (Capobianco, 2011). Thus, teachers may need to shift their mindsets to embrace uncertainties in the classroom and do more to help students persist through frustrations and failures (Dickerson et al., 2016; Lottero-Perdue, 2017). In sum, teachers need to be prepared to not only understand this new content area, but also new pedagogical approaches.

Beginning teachers need opportunities to refine their understandings of both scientific inquiry and engineering design (Kaya et al., 2017; Kim et al., 2019) and gain confidence in their abilities to engage youth in authentic engineering learning (Yaşar et al., 2006; Yoon et al., 2014). Cunningham and Carlsen (2014) summarize guiding principles for professional development of both pre- and in-service teachers, including to a) engage teachers in engineering practices, b) model pedagogies that support engagement in these practices, c) provide experience as both learners and teachers, d) develop teachers' understanding of the fundamentals of and interconnections between science and engineering, and e) promote teachers' understanding of engineering as a social practice. Teacher candidates also need opportunities for authentic practice with young learners, such as through robust field experiences in schools (Park & Oliver, 2008), and reflection around these experiences.

Teacher preparation programs play an important role in promoting engineering in the elementary grades especially. While there are a multitude of complex factors that influence teachers' practice, research suggests that teachers who experience success in their preparation are more likely to make the commitment and build the understanding and confidence they need to be successful in their own future classrooms (Tschannen-Moran et al., 1998). The purpose of this research is to examine the influences of a science methods course that included a specific focus on engineering in grades 1-5 on teacher candidates' self-efficacy for teaching engineering in elementary grades.

Engineering and Science

The inclusion of engineering in *The Framework for K-12 Science Education* (NRC, 2012) marks a shift from previous science education policy documents. The *Framework* argues that "engagement in the practices of engineering design is as much a part of learning science as engagement in the practices of science" (p. 11). Here, science refers to the study of the natural and physical world, while engineering is broadly defined as "any engagement in a systematic practice of design to achieve solutions to particular human problems" and technology as "all types of human-made systems and processes" (NRC, 2012, p. 11).

Certainly, the two disciplines are related and mutually supportive. For instance, engineers often apply scientific principles in the design of solutions, tools, and products. In the K-12 context, engineering design has often been promoted as a means of enhancing and providing relevance for science education (Apedoe et al., 2008; NRC, 2012), serving as much as a pedagogical approach for science teaching as a unique discipline (Pleasants et al., 2021; Purzer & Quintana-Cifuentes, 2019). Yet, when engineering design is presented as an application of science concepts, it is important that educators be able to help students appreciate *how* the science ideas are relevant to the engineering context (Chao et al., 2017).

Engineering and science also engage in several related practices or behaviors, which are highlighted in the NGSS. Both use and develop models, plan, and carry out investigations, analyze and interpret data, use mathematical and computational thinking, rely on data and evidence to make decisions, and communicate information and ideas (NGSS, 2013). Collaboration, creativity, and innovation are also central to both science and engineering. Productive responses to failure are arguably essential to any learner of any discipline, but especially within the field of engineering given that failure is an important element of the engineering design process (Lottero-Perdue, 2017; Petroski, 2006). Additionally, both disciplines have an influence upon, and are influenced by, society. Outcomes influence the way that people interact and the environments people inhabit. Society also influences science and engineering, as they are both human and social endeavors.

Yet, there are also important distinctions between science and engineering. It must be noted that critiques of the *Framework* offer a limited perspective on these unique differences (see Cunningham & Kelly, 2017). Scientists seek to explain the natural and physical world, generating new, verifiable knowledge by asking questions that are answered through rigorous investigations. Engineers consider criteria and constraints as they design solutions to address specific problems, needs and desires that will improve lives and the environment (Major, 2018). In science the audience is typically other scientists, while in engineering, the audience is often a specific client (Pleasants & Olson, 2019). Engineering problems are often ill-structured, with constraints that limit potential solutions and even eliminate the ideal solution. Thus, engineers must consider multiple solutions and optimize based on what resources (materials, knowledge, tools) are available (Cunningham & Kelly, 2017; Pleasants & Olson, 2019). It is critical that teacher educators and teachers have a strong grasp of both science and engineering, and the relationships and distinctions between science and engineering, if they are to support youth in also developing engineering knowledge and understanding and skill.

Engineering in K-12 Education

While the United States has articulated *A Framework for K-12 Science Education* (NRC, 2012) and the related NGSS (NGSS Lead States, 2013), which point to how engineering can serve as a route to enhancing students' science learning, there still lacks agreed upon guidance for pre-college engineering education. Most frequently, engineering is incorporated into science through involving students in engineering design challenges, where they develop technological solutions to context-specific problems (NAE, 2009; Pleasants et al., 2021). One of the best-known curricula is Engineering is Elementary (EiE, see Cunningham, 2009), which was also utilized by participants in this study.

In 2014, Moore and colleagues put forth *A Framework for Quality K-12 Engineering Education* which could serve as a guide for structuring future standards and initiatives. After several iterations, these authors put forth key indicators for quality pre-college engineering curricula. This include opportunities to: Apply science, engineering and mathematical knowledge; Engage in processes of design; Develop conceptions about the nature of engineering and the job of engineers; Engage in engineering habits of mind; Gain experience with the techniques, skills, processes, and tools engineers use; Grapple with current local and global issues and the potential impacts that engineering solutions have on these, as well as the ethical considerations inherent to engineering work; and Communicate ideas in both technical and common language.

In 2019, Pleasants and Olsen put forth a framework on the nature of engineering that could support K-12 students, learning, and teacher practice. They identify and elaborate upon nine features of engineering: Design in engineering; Specifications, constraints, and goals; Sources of engineering knowledge; Knowledge production in engineering; The scope of engineering; Models of design processes; Cultural embeddedness of engineering; The internal culture of engineering; and the Relationships between engineering and science.

These frameworks will continue to inform the curriculum development within the field of engineering education as well as pre- and in-service teacher education.

Teaching Engineering Self-efficacy

The literature consistently demonstrates that teachers' classroom actions are linked to their belief systems (Luft & Roehrig, 2007). This is of interest to teacher educators since, although experienced teachers' beliefs are consistently shown to be tenacious (Luft, 2001), there are encouraging examples of beginning teachers' beliefs about teaching and learning science being positively influenced by the support they receive early on, including from a preparation, induction, or mentoring program (Osisioma & Moscovici, 2008). Thus, part of preparing teachers to meet new expectations around science and engineering education is promoting what Yoon et al. (2014) have termed *teaching engineering self-efficacy*, or "a teachers' personal belief in their ability to positively affect students' learning of engineering that reflects the multifaceted nature of self-efficacy of teaching engineering" (p. 479).

The attention to self-efficacy as it relates specifically to teaching engineering stems from the understanding that self-efficacy is situation specific. According to Bandura's (1977) social learning theory, self-efficacy beliefs are perceptions about one's capabilities to successfully perform a task or behavior within a given context. Building off this idea, Tschannen-Moran et al. (1998) put forth a model of the relationship between a teacher's judgment of their personal capabilities and competencies and their analysis of a particular future task and situation. This model also describes the cyclical nature of teacher self-efficacy. That is, a teacher's self-efficacy beliefs can influence their instructional practice in each situation, as well as students' psychological and academic outcomes. Subsequently, a teacher's perception of the degree of successful performance in that past situation can contribute to raising or lowering their self-efficacy beliefs going forward. Complementary to self-efficacy is outcome expectancy, or an individual's assessment of the outcomes resulting from their performance of a task (Bandura, 1977). While the nature of the relationship between self-efficacy and outcome expectancy is debated (Tschannen-Moran & Woolfolk-Hoy, 2001; Williams, 2010), the two constructs are typically measured together.

With a goal to understand teacher efficacy within the specific context of K-12 engineering, Yoon et al. (2014) developed and validated the *Teaching Engineering Self-efficacy Scale* (TESS), a 23-item instrument which measures teacher beliefs across four sub-scales: engineering pedagogical content knowledge self-efficacy, engineering engagement self-efficacy, engineering disciplinary self-efficacy, and outcome expectancy. See Table 1 for TESS constructs. The TESS instrument was developed through a process of exploratory and confirmatory factor analyses using structural equation modeling and exhibited high internal consistency reliability coefficients (Cronbach's α ranging from 0.89 to 0.96).

Methods

This study took place in conjunction with an elementary science methods course that was designed with a focus on engineering in grades 1-5. We sought to better understand how well the course was influencing candidates' self-efficacy for teaching engineering in elementary classrooms. Thus, we collected, analyzed, and integrated quantitative and qualitative data over two iterations of the course, following an explanatory sequential design. In this design, an initial quantitative phase is followed by a subsequent qualitative phase intended to help to explain the quantitative results

(Creswell & Clark, 2017). This mixed methods approach was selected to increase the breadth and depth of understanding and corroborate findings. It is appropriate for this study given the known complexity of measuring self-efficacy (Morrell & Carroll, 2010; Thomson et al., 2022; Wheatley, 2000).

Table 1

Constructs Around Self-Efficacy for Teaching Engineering

Construct	Definition *(adapted from Yoon et al., 2014)*	Example TESS Item	Example Statement
Engineering pedagogical content knowledge self-efficacy (KS)	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	I can discuss how given criteria affect the outcome of an engineering project.	"I now understand what engineers exactly do, the products they create, and the process that they use to arrive at these solutions." [Year 1, Essay]
Engineering engagement self-efficacy (ES)	Teachers' personal belief in their ability to engage students, while teaching engineering	I can encourage my students to think creatively during engineering activities and lessons.	"It important to "talk about students' lives and what they're interested in. I think that's a big part of it too because if you're doing a project where the students aren't interested then it's going to take longer and if they're interested then they get going and they want to get to the design phase and they want to get to the build phase and they want to get to the improve phase." [Year 1, Interview]
Engineering disciplinary self-efficacy (DS)	Teachers' personal belief in their ability to cope with a wide range of student behaviors during engineering activities	I can establish a classroom management system for engineering activities.	"It's a rowdy atmosphere. And not rowdy in a bad way but the kids are excited, and they want to socialize about the project." "They were so involved and had so many ideas and just loved to share what they were thinking." [Year 1, Interview]
Outcome expectancy (OE)	Teacher's personal belief in the effect of teaching on students' learning of engineering	I am generally responsible for my students' achievements in engineering.	"It's hard ...thinking about questions that will spark their interests and then also phrasing questions in a way that gets them thinking." [Year 1, Interview]

The study took place over two consecutive years. Given the small sample size of Year 1, additional data were collected and analyzed in Year 2 to increase the participant pool and look for trends across both years. One of the researchers was the primary instructor for the course in Years 1 and 2; the other researcher was familiar, but not affiliated, with the course and was not involved with the candidates outside of the research. Both researchers have experience with engineering education and initial teacher preparation, one specializing in science and the other in math teacher education.

Context and Participants

Participants included undergraduate teacher candidates enrolled in a semester-long elementary science methods course at a university in the central United States. The course is a requirement for candidates in the Elementary, Special Education and Bilingual/Bicultural Education programs, and all participants were pursuing one of these three programs. Eight of ten candidates enrolled during Year 1 and all 12 candidates enrolled during Year 2 of the class agreed to participate in the study.

The course was influenced by Cunningham and Carlsen's (2014) guiding principles for professional development summarized previously. See Table 2 for course component alignment with the guiding principles for teacher education.

Table 2

Alignment of Course Components and Design Criteria for Engineering Teacher Education

	Guiding Principles for Teacher Education (adapted from Cunningham & Carlson, 2014)				
	Engage candidates in engineering practices	Model pedagogies that support engineering practices	Provide opportunities to experience engineering as both learners and teachers	Develop understandings about interconnections between science and engineering	Promote understanding of engineering as a social practice
Course Component					
Course readings, discussions & written reflections				x	x
Engage in example science & engineering 5E lesson	x	x	x	x	x
Review EiE videos		x	x		x
Visit museum engineering exhibit	x		x		x
Observe & participate in elementary engineering lab	x	x	x	x	x
Conduct Engineering Talk with youth			x		
Develop lesson plans				x	

The course introduced candidates to *A Framework for K-12 Science Education* (NRC, 2012) and the NGSS (NGSS Lead States, 2013), including the presentation of engineering alongside science. Since the type of teaching and learning promoted in these reform documents was different than what most candidates had experienced in their own elementary education, it was particularly important that they had opportunities to engage in experiences that modeled strong examples of phenomena-based learning, and science and engineering integration, and to reflect upon these experiences. Candidates engaged in a sample 5E lesson as learners, in which they developed explanations for how a light bulb connected to a single battery lights up and then used that scientific understanding in the design of a hands-free, battery-powered reading lamp (see Jackson et al., 2011.) Candidates' engagement in engineering as learners continued during a visit to a local museum's engineering-focused exhibitions.

Then, as will be detailed further, candidates had the opportunity to observe and assist an expert veteran teacher to facilitate engineering learning for elementary aged youth. Weekly written assignments and class discussions allowed for candidates to reflect on these experiences from the perspectives of both learner and teacher.

A local partner school with a culturally and linguistically diverse, low-income population has a dedicated engineering lab space in which grade K-5 classes visit approximately once every seven days, following a rotating schedule. The engineering lab teacher and the methods course instructor had a strong working relationship from prior collaborations that allowed for alignment of course goals for both the university and elementary students and co-teaching. The Partner Teacher utilized the EiE curriculum (Cunningham, 2009) in conjunction with other teacher-developed engineering and science lessons. Candidates were introduced to the EiE curriculum guides and encouraged to go to the EiE website to explore videos of other classrooms and units.

Teacher candidates spent approximately one hour per week for eight weeks in the engineering lab working with the various Grade 2 through Grade 4 classes that visited the lab. Pairs of candidates typically worked with small groups of students during the class sessions and each week they were able to speak informally with the Partner Teacher, learn about her instructional decision-making, and ask questions, such as about the lessons, students, the school's approach to engineering and science education, etc. Candidates also had an opportunity to plan and conduct "engineering talks" with students to learn more about their perspectives on the lessons they were participating in and uncover their understandings about engineering.

Data Sources

Both quantitative and qualitative data were collected. The TESS served as a quantitative measure of candidates' self-efficacy beliefs toward teaching engineering (Yoon et al., 2014). The TESS was administered as a pre-test at the beginning of the course, prior to exposure to the engineering classroom or curriculum, and as a post-test upon completion of the course.

A subsequent qualitative phase allowed for additional and complementary insight into candidates' understandings of and beliefs about teaching engineering. The qualitative data were deemed important since high self-efficacy can at times negatively correspond with depth of understanding, such as when individuals are overconfident because they are unaware of what they do not know (Wheatley, 2000). Qualitative data also provided insight into participants' thoughts about specific aspects of the methods course and fieldwork, including any influence on their knowledge, understandings, and beliefs.

Multiple sources of data were collected for this qualitative phase: written reflections about the TESS, interviews, and various written course reflections and assignments, as will be discussed. After completing the TESS post-tests, candidates were given the results from their pre- and post-tests. They then wrote a reflection explaining why they chose the responses they did and any changes they noticed between the TESS pre- and post-tests. See Appendix A for this information.

Six candidates in Year 1 and 12 candidates in Year 2 also agreed to participate in semi-structured, in-person interviews at the end of the semester. Interviews (see Appendix B) probed candidates' thinking about their own prior experiences with engineering, how their understandings of engineering and teaching engineering had shifted throughout the semester, and implications of their semester experiences for future teaching. Each interview lasted about 25 minutes and was conducted and transcribed by a graduate assistant not affiliated with the course. Candidates who did not wish to participate in an interview were invited to complete and submit an essay addressing the same questions as the interview; three participants took this option.

Additional qualitative data came from course assignments that candidates provided access to for the study. Names and other personal identifiers were replaced with codes. These data sources included weekly open-ended reflections in the form of "exit slips" and written responses to a summative assessment. See Figure 1 for example prompts. Overall, the multiple data sources allowed for triangulation to support the validity of the qualitative conclusions (Creswell & Clark, 2017).

Figure 1

Example Written Assignment Prompt

Exit Slips

- What can you take away from how setbacks are addressed in the Partner School Engineering Class? How might you support your students when they encounter frustrations and challenges with their assignments?
- How did today's visit help you to think about supporting elementary-aged students' engineering habits of mind and practices. Please include specific examples.
- What was a defining moment for you this semester working in the 4th grade engineering class?

Summative Assessment

Analyze how the academic disciplines of science & engineering, social studies & history complement one another, but also uniquely generate and shape knowledge. Discuss the opportunities and challenges you see for teaching these disciplines in your future classroom. What resources might you draw upon to make use of the opportunities and overcome the challenges?

Data Analysis

Analysis of quantitative data began by following the guidelines outlined by Yoon et al. (2014) for calculating raw and mean scores of the four TESS constructs described above, as well as an overall raw score of teaching engineering self-efficacy. Descriptive statistics were calculated for each test administration and for each dimension of the TESS, as were changes in candidates' scores from pre- to post-test. Changes in candidates' teaching engineering self-efficacy beliefs across the course were determined through comparison of pre- and post-test scores on the TESS. The percent difference from pre- to post-test is reported (See Figure 2 and Tables 3 and 4).

Since the goal was to use the qualitative phase to bring nuance and context to results of the quantitative phase, we began with a general coding scheme related to the three themes of interest: engineering teaching self-efficacy, knowledge and understandings of engineering and engineering education, and influences on candidates' knowledge, understandings, and efficacy. For the first coding category, an a priori coding scheme corresponding to the efficacy constructs measured by the TESS instrument was outlined (see Table 3). We also applied conceptually derived ratings of high or low to indicate whether data were exemplary of high or low efficacy beliefs. The second coding category targeted candidates' knowledge and understandings of engineering and teaching engineering. These codes were derived from an interaction between the data and the literature (Bingham & Witkowsky, 2021. See Table 3 for these constructs. For instance, the code *knowledge for managing engineering learning* *environments* was not initially one we anticipated but it emerged from the data. Given that novice teachers often are concerned about but feel unprepared for the challenges of managing a classroom (Flower et al., 2017), it is not surprising that most participants brought up this topic in their interviews and assignments in both Year 1 and Year 2. Again, we applied conceptually ratings of high or low to indicate whether data were exemplary of deep or shallow levels of knowledge and understanding.

Table 3

Constructs for Knowledge about Engineering and Engineering Education

Knowledge Construct	Definition	Related literature
Engineering	Evidence of understanding about engineering as a practice and a profession	Engineering is concerned with the design of technologies (broadly defined), systems and processes (Pleasants & Olson, 2021)
Relationship between engineering and science	Evidence of understanding about how engineering and science are mutually beneficial, and how the disciplines compare	Engineering shares characteristics with the natural sciences but has unique goals and utilizes different approaches (Pleasants & Olson, 2021)
Engineering process of design	Evidence of understanding about the engineering design processes	Design processes involves iterations of defining and delimiting problems; developing potential solutions; evaluating pros and cons in light of constraints and trade-offs; testing and evaluating and optimizing solutions (Moore et al., 2014; NAE, 2009)
Engineering habits of mind	Evidence of understanding about engineering habits of mind	Engineering habits of mind include collaboration, ability to communicate with varied audiences, attention to ethical considerations, systems thinking, creativity, reflective thinking, productive responses to failure (Moore et al., 2014; NAE, 2009)
Pedagogical content knowledge related to engineering in elementary grades	Evidence of understanding about how to apply engineering design processes to classroom situations, how engineering can be integrated into science curricula, classroom management strategies for teaching engineering	Engineering design activities involve students in designing technological solutions to context-specific problems (NAE, 2009). Activities highlight how the science ideas are relevant to the engineering context (Chao et al., 2017)
Pedagogical content knowledge related to managing engineering learning environments	Evidence of knowledge about managing learning environments for elementary engineering	Elementary engineering activities often necessitate hands-on materials, cooperative group work, a variety of workspaces, and making mistakes (Petrich et al, 2013)

A third major coding category – influences on knowledge, understandings, and efficacy – served to identify those elements of the course experience that participants indicated were impactful on their knowledge and understandings and/or self-efficacy beliefs. Codes for this category emerged from the data in Year 1 and included prior personal experiences, field experience, and course readings and assignments. We utilized these same codes with the Year 2 data.

To check for inter-coder reliability, the two researchers each used Dedoose (2018) software to review the same Year 1 data source in search of meaningful segments – sentences or groups of sentences constituting a complete thought – related to the themes of interest: engineering teaching self-efficacy, knowledge and understandings of engineering, and influences on knowledge, understanding, and efficacy. The software enabled the researchers to check for areas of consistency and inconsistency. The researchers discussed any discrepancies and refined the coding scheme to increase clarity. One such point of discussion was around what terms might be included in the coding category Engineering Habits of Mind and how many different examples of habits of mind would indicate a weak versus strong understanding.

Once a consistent level of agreement (over 90%) was reached, coding of the remainder of the Year 1 data continued independently, with the researchers meeting throughout to discuss the coding, emerging patterns, and resolve any subsequent discrepancies. Verification occurred continuously throughout the entire analysis process by checking for inter-coder reliability and returning to the data corpus in search of emerging patterns as well as disconfirming evidence for each conclusion set forth. Analysis of Year 2 data followed a similar process, using the refined coding scheme from the Year 1 analysis. Overall findings were revised to account for the patterns identified across both years of data.

Results

Teaching Engineering Self-efficacy

Qualitative and quantitative data assignments revealed that at the beginning of the course candidates lacked confidence in their own understanding and in their beliefs about being able to facilitate engineering experiences for youth in the classroom. However, participants made strong gains by the end of the course. These goals align with the key objectives of the course, which included "developing specific skills, competencies, and points of view needed by teaching professionals."

Results of the quantitative analysis indicate that candidates made gains in their self-efficacy during the course, as would be expected. See Figure 2 and Tables 4 and 5 for information on TESS scores for study participants. Overall, TESS scores improved by 21% in the Year 1 cohort and by 31% in the Year 2 cohort, with scores near the maximum score possible. There was also strong growth across each of the various dimensions of engineering self-efficacy. By the end of the course, candidates demonstrated strong personal beliefs in their abilities to engage students while teaching engineering (ES) and to cope with a wide range of student behaviors during engineering activities (DS). Candidates' personal belief in their abilities to teach engineering (KS) increased by 43% (Year 1) and by 65% (Year 2) from the beginning of the course to the end of the course.

Despite the strong improvement on KS items from pre- to post-test, we note that high pre-test scores for ES and DS items in Year 2 left little room for growth. Again, this suggests that candidates may have held inflated views about their abilities initially, given their lack of experience in an elementary engineering classroom. We also caution that despite the valuable time spent in an elementary engineering lab as part of the course, candidates lacked experience leading engineering learning activities and so the applicability of the OE section of the TESS remains questionable for this group of participants.

Figure 2

Mean Pre- and Post-Test TESS Scores Across Four Dimensions for Years 1 and 2

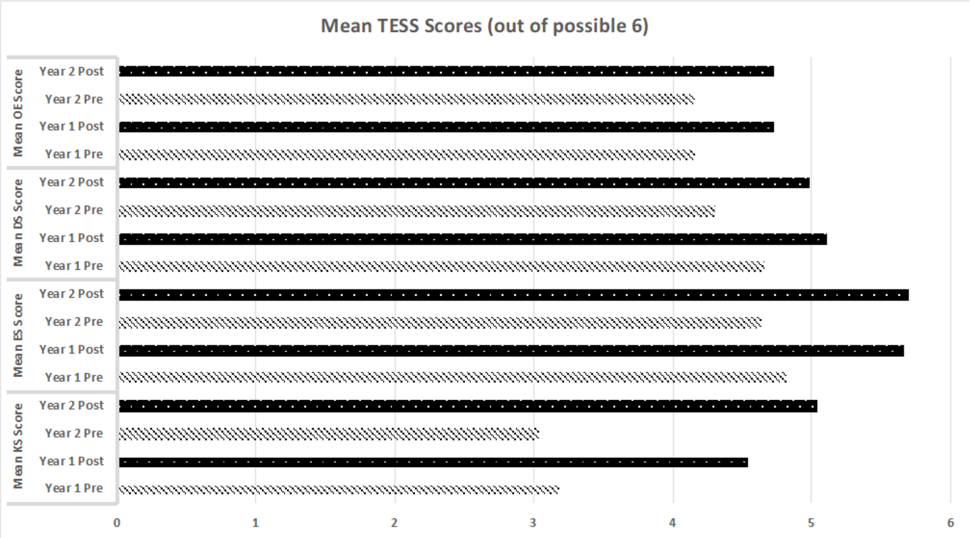

Table 4

Teaching Engineering Self-Efficacy Scale (TESS) Pre-Test and Post-Test Scores Year 1

	Mean KS Score		Mean ES Score		Mean DS Score		Mean OE Score		Overall TESS Score	
	Pre-Test	*Post-Test*	*Pre-Test*	*Post-Test*	*Pre-Test*	*Post-Test*	*Pre-Test*	*Post-Test*	*Pre-Test*	*Post-Test*
Minimum	1.33	3.44	4.00	4.75	3.80	4.00	3.00	3.40	13.33	16.62
Maximum	4.11	5.22	5.50	6.00	5.20	6.00	4.80	6.00	19.36	23.22
Mean	3.17	4.53	4.81	5.66	4.65	5.10	4.15	4.73	16.78	20.01
Max possible	*6*	*6*	*6*	*6*	*6*	*6*	*6*	*6*	*24*	*24*
Percent change	43%		18%		10%		14%		19%	

Table 5

Teaching Engineering Self-Efficacy Scale (TESS) Pre-test and Post-Test Scores Year 2

	Mean KS Score		Mean ES Score		Mean DS Score		Mean OE Score		Overall TESS Score	
	Pre-Test	*Post-Test*	*Pre-Test*	*Post-Test*	*Pre-Test*	*Post-Test*	*Pre-Test*	*Post-Test*	*Pre-Test*	*Post-Test*
Minimum	1.78	3.33	2.00	4.75	3.20	4.00	3.20	3.00	13.02	16.78
Maximum	4.89	6.00	6.00	6.00	6.00	6.00	5.80	6.00	21.49	23.58
Mean	3.04	5.03	4.63	5.69	4.30	4.98	4.31	4.98	16.27	20.68
Max possible	*6*	*6*	*6*	*6*	*6*	*6*	*6*	*6*	*24*	*24*
Percent change	65%		23%		16%		16%		27%	

Analysis of qualitative data reinforced findings in the quantitative phase. The following statement is representative of participants' written reflections about the shifts in their scores on the TESS overall.

> When I took the TESS survey at the beginning of the year, it was obvious that I was not as confident in explaining what engineering actually is and ways that I could incorporate this into classroom teaching. I believe that I was not as sure of myself because I wasn't sure about the significance of engineering before I took this class and how it actually related to science. After going through the unit and seeing the different examples that the classroom teacher we observed presented, I can say that I walked away more confident than before and that I can teach and incorporate significant engineering topics to my students [Year 1, TESS Reflection].

Here, we see evidence that candidates like the participant quoted felt that their overall understandings about engineering and teaching engineering, as well as their efficacy for teaching engineering, improved over the semester. Other candidates also reflected on growth in their efficacy for themselves and their students engaging in engineering. "I never would have considered myself an engineer before. But I can do the stuff that [the students in the engineering lab] are doing. I [too] can be an engineer" [Year 1, Interview].

These statements are consistent with literature concluding that vicarious experiences and achieving successes in conjunction with mastery experiences promote self-efficacy (Bandura, 1995). However, as we report on in the next section, not all of those who scored high on the TESS necessarily demonstrated fully informed understandings about engineering in their written assignments and interview responses. Thus, we are also reminded that self-efficacy goals and assessments need to be complemented with content-oriented goals and assessments.

Knowledge and Understandings About Engineering

In addition to revealing shifts in candidates' self-efficacy for teaching engineering, evidence emerged of how candidate understandings developed over the semester. Overall, while there is evidence that all candidates were more knowledgeable about the field of engineering and about current visions for engineering education following the course, findings also indicated that there was still significant room for improvement in several areas.

Engineering and Engineers

At the start of the course, candidates struggled to be able to provide a concise working definition of what engineering is and were surprised to learn that they would be responsible for teaching engineering, since none had K-12 classroom experiences with engineering themselves. "I think this semester studying this engineering, I mean, it's the first time I've studied it or even really heard about it, so it's all really new to me" (Year 1, Interview), reflected one candidate. Findings suggested this statement was typical of candidates in both Years 1 and Year 2 overall. When candidates were asked to explain how their understandings had shifted over the semester, they unanimously expressed initial confusion at the start of the semester about engineering and how to teach engineering, particularly with young students.

Reflecting on the full semester, candidates were enthusiastic about their progress. Indeed, most candidates across both cohorts demonstrated basic understandings. Yet, only seven candidates across the two cohorts (two in Year 1 and five in Year 2) demonstrated what could be considered a strong understanding in their interviews or written essay responses about the field of engineering – including the work of professional engineers, the kinds of problems engineering addresses, the iterative design process that is unique to engineering, and technology as the product of engineering design. An example of what was deemed a strong understanding was the following response: "I like to think of engineering as something that like if you're looking at a problem and trying to design a solution to that problem" [Year 2, Interview]. Reflecting on her shifts in understanding, this candidate shared that she came to understand that "it [engineering] encompasses so much more than just building a bridge".

Analysis of qualitative data indicated that most candidates, however, still held an incomplete or shallow understanding of the types of problems that engineering entails at the end of the course. For instance, these candidates may have been able to list different types of engineers if pressed, but only offered up examples of civil engineering, as in those fields that related to building and constructing physical creations. And, while they were aware of the centrality of design processes to engineering, they offered a generic explanation or only described a part of the process. The following are examples of incomplete understandings:

> I feel like engineers have a lot to do with constructing, building, modeling, like 3-D models and everything like that [Year 2, Interview].
>
> Students are engaging in engineering when they are "creating a bridge in a classroom. That makes them an engineer [Year 1, Interview].

These two examples illustrate an emphasis on civil engineering, a common misconception cited in the literature (Yaşar et al., 2006). Their misconceptions may also have been influenced by the particular EiE units that candidates experienced in the class – Designing Bridges – as well as the exhibits they explored during a visit to the local children's museum, which focused on designing and constructing skyscrapers. The use of the generic term "creating" and the example of the end product (a bridge) emphasize the construction aspect of the work without referencing the problem that the design solved, specific features of the design, etc. Both statements are exemplary of the kinds of data that suggested a limited understanding of engineering and what engineers do.

Relationship Between Engineering and Science

Candidates varied in their ability to describe the relationship between engineering and science at the end of the course. The seven candidates who demonstrated strong understandings about engineering were also the ones who demonstrated strong understandings about how the two disciplines connect and interact. The following were coded as strong explanations.

> Although these disciplines are different from each other, they are all used within one another. For example, engineers design technology and use science in order to do so. These three must be intertwined when they are taught in the classroom. [Year 1, Engineering Essay].
>
> You can use what you know about science to help find solutions to problems that you're trying to solve for engineering [Year 2, Interview].

More common, however, were candidates that held an understanding of a hierarchical relationship between the two disciplines, such as "Science is the big umbrella. Engineering and technology are kind of a branch out of it. Engineers have to use technology to solve a problem or meet a need that science finds out." [Year 2, Summative Assessment]. And, the following response puts forth an oppositional view of the two disciplines, as well as misconceptions about science.

> In a general science lesson, students will gain understanding and will most likely ask questions to confirm their understanding. In a technology lesson, students can think more critically about the topic and ask questions that may relate more to their lives, since technology is a growing area [Year 1, Summative Assessment].

This response suggests that engineering problems have more relevance than those in science, and that there is little to no connection between the two disciplines.

There is more encouraging news when comparing the two cohorts. Findings indicate improvement in candidates' understanding of the relationship between science and engineering in Year 2, with approximately twice as many candidates demonstrating more robust understandings. This is likely due to additional emphasis put on this topic in the Year 2 course, following a review of Year 1 findings. Still, the results of Year 2 suggest additional emphasis is warranted in the future.

Teaching Engineering in Elementary Grades

Candidates all discussed an interest in incorporating engineering experiences in their future classrooms. "I feel like I'll definitely be incorporating it [engineering] a lot more than I thought I would" [Year 2, Interview]. They expressed this commitment even if their plans for doing so remained rather vague. For instance, when asked about her future plans a Year 1 candidate said, "I think it's important that my learners get to explore and just immerse themselves in the doing part of engineering instead of just like me giving them all the information they need." She articulates here a student-centered approach but not what "immersing themselves" entails other than citing the Engineering Design Process.

Thinking about their orientations to teaching engineering and instructional strategies that aligned with those beliefs, candidates frequently referenced engineering habits of mind that they wished to promote, including independent, reflective, and metacognitive thinking.

> The teacher would ask questions in between and for [the students] to think about, to stop building and just reflect and think about. And so there would be these questions that would go on and on and add on to the previous question and the kids were excited to make these new creations and also think about new information based on what they're building and the science behind it as well [Year 2, Interview].

Or, as another candidate shared,

> You can't give students the answers. It's their time to explore and figure it out. She never said no, that's wrong…Because if you gave them the answers, they'd just stop thinking. So it encourages them to think more [Year 2, Interview].

Multiple candidates across Years 1 and 2 also highlighted the need for building a classroom climate that supports collaboration.

> [the elementary students] are teaching each other about what they learned and their building off of each others' ideas and that's what I want to see in my classroom [Year 2, Interview].

However, most reflections, like those noted above, spoke more toward candidates' beliefs about engaging students in engineering and managing an engineering classroom space. There were less data that pointed toward candidate understanding of engineering curricula and knowledge of assessing students' progress in engineering. This may be due, in part, to the course focus on instructional strategies and orientations to teaching, whereas subsequent courses in candidates' preparation focus more specifically on designing and implementing lessons and assessments across the curriculum. Future courses would benefit from a more balanced approach to teaching about instruction and assessment.

Influences on Knowledge, Understandings, and Efficacy

Since none of the teacher candidates were exposed to specific engineering classes in their own K-5 education, they unanimously shared how it was an invaluable experience to be able to observe the Partner Teacher's instruction and then also personally engage with small groups of elementary students as they worked on hands-on projects. As one candidate said, "the idea of teaching engineering in elementary schools was very foreign to me as this is not something that I was able to experience in my own schooling" [Year 1, TESS Reflection].

> The observations in [Partner Teacher's] classroom helped me truly understand what engineering looks like in an elementary classroom. This helped me to experience what I had been reading about first-hand which helped me to understand how to properly implement engineering. Also, these experiences helped me to understand how students viewed engineering [Year 1, Essay].

These statements illustrate how candidates valued the opportunity to be immersed in an engineering classroom and experience for themselves the types of learning they were reading about in their coursework.

Discussion

This study investigated the influences of an elementary science teaching methods course on teacher candidates' self-efficacy for teaching engineering in elementary classrooms, as well as their understandings about engineering and engineering education. With the introduction of engineering into national standards for science teaching and learning, it is important for teacher educators to assess the conceptions elementary teacher candidates hold about engineering and about supporting young students' engineering learning. It is also important to critically investigate how teacher preparation programs are influencing candidates' understandings to ascertain what is working well and what could be improved. While a handful of other studies report on teaching engineering self-efficacy results with in-service teachers (Van Haneghan et al., 2015; Yoon et al., 2014), the current study offers insight into measuring and developing the engineering self-efficacy beliefs of elementary teacher candidates. In this section, we discuss results and implications for research and teaching.

Measuring Teaching Engineering Self-Efficacy

While the TESS is a relatively new instrument designed for a target audience of K-12 teachers (Yoon et al., 2014), this study provides insight about its use within teacher preparation courses and research. As teacher educators, we found the TESS to be an effective tool for measuring growth across specific dimensions of teaching engineering self-efficacy, and across cohorts. Yet, findings also suggest that the TESS could benefit from revisions and formal validation testing for the audience of teacher candidates. This population has limited experiences to inform responses to some prompts, especially at the time of the pre-test and to those items measuring outcome expectancy (OE).

To address existing gaps in the literature, such as those outlined in *A Synthesis of Research on and Measurement of STEM Teacher Preparation* (Bell et al., 2019), future research into preservice teacher self-efficacy for engineering should continue to utilize common, validated instruments such as the TESS. This will allow for examination of similar constructs across preparation programs and more coordinated programs of research (Zeichner, 2013) that contribute to "broader and shared understandings of [pre-service teacher learning] in STEM teacher preparation" (Bell et al., 2019, p.30).

The qualitative component of this study provided an additional complementary lens into teacher candidates' thinking and understanding about facets of engineering and pedagogical content knowledge specific to engineering. Other teacher educators and researchers may find benefit from coupling the TESS with a self-reflection assignment and semi-structured interviews such as those described here. This approach has potential benefits for teacher candidates; participants in this study found the TESS to be a useful tool to prompt personal reflection on their learning at the end of the semester, particularly when coupled with an assignment to review and reflect upon their pre-and post-test scores. The opportunity to spend time and participate in a partner school engineering lab during the course also meant their reflections could be linked to a specific classroom context. Research indicates this is an important component to candidates developing "a sense of belonging and competence" (Ditchburn, 2015, p. 30) within the profession.

While results indicate that the teacher candidates in this study held high efficacy beliefs and felt increased confidence in their knowledge and understandings following the course, qualitative results also demonstrated that gaps in understanding and naïve conceptions remained. These findings are a reminder that self-efficacy is associated with perceived ability which may differ from actual ability (Bandura, 1977). Thus, this study reinforces the importance of complimenting any inquiry into teacher efficacy with explorations of teacher knowledge, understanding, and practice to investigate how candidates' perceptions of their efficacy match their actual instructional practice. Future research should analyze practice data, such as teacher candidates' lesson plans and teaching observations. Longitudinal studies can also follow teacher candidates into their induction years to investigate lasting impacts on their beliefs and practice.

Course Experiences and Revisions

We are encouraged by the growth seen in teacher candidates engineering self-efficacy during this course, and in the improvements from Year 1 to 2 in some of the knowledge constructs. While the literature has reported teachers feeling hesitant and intimidated about teaching engineering (Capobianco, 2011; Douglas et al., 2016; Yaşar et al., 2006) and conflicted about the importance of doing so (Douglas et al., 2016; Lachapelle et al., 2014), findings from this study provide evidence that even a single course with an emphasis on engineering education in elementary grades can make a strong initial impact. The significance of the opportunity to be involved in an actual elementary engineering classroom with an expert mentor teacher, not solely as observers but as active participants, cannot be dismissed. Enactive, mastery experiences and the psychological arousal that accompanies these experiences are powerful influences on self-perception (Bandura, 1995; Tschannen-Moran et al., 1998). If efficacy is understood to be situated within a feedback loop (Tschannen-Moran et al., 1998), we can predict that the candidates in this study are likely to want to continue to learn more about engineering following this course and were left feeling confident and energized about teaching engineering. This prediction aligns with Bandura's (1977) argument that "efficacy expectations are a major determinant of people's choice of activities, how much effort they will expend, and of how long they will sustain effort in dealing with stressful situations" (p. 194).

Several other concerning findings warrant further attention and discussion. Misconceptions persisted about what makes science and engineering unique. These findings support other arguments that the NGSS does not adequately present engineering knowledge and practices (Cunningham & Carlsen, 2014; Cunningham & Kelly, 2017). Findings of the qualitative analysis also indicated that the excitement that some candidates felt for engineering might have come at the expense of that for teaching science. Findings revealed that some candidates expressed the idea that, in comparison to engineering, science lacks creativity and real-world relevance. Interestingly, these findings echo those reported by Sengupta-Irving and Mercado (2017), who also found that participants thought of science as procedural and prescriptive. Overall, these findings suggest that more resources are needed on both the nature of engineering and the nature of science to help teachers and teacher educators alike understand what science and engineering share as well as how they differ (NRC, 2012, see p. 46). Cunningham and Kelly's (2017) proposed set of epistemic practices of engineering makes a first step in this direction. *A Framework for Quality K-12 Engineering Education* (Moore et al., 2014) is also useful for guiding the design of course experiences and teacher candidate reflection assignments.

In our own practice, the results of this and other studies have prompted us to provide more learning experiences in our courses that aim to clarify what distinguishes science from engineering, what they share, and the relationships between engineering and other non-engineering subjects. Engineering design challenges can serve as a context for students to manipulate and transfer their understandings of varied content areas while also developing skills such as creativity, communication, critical thinking, and collaboration that are shared across academic disciplines and beyond, but explicit attention to this integration is necessary (Reimers et al., 2015).

Course adaptations include additional design challenges for candidates to participate in and reflect upon, with themselves as learners, with attention to core epistemic practices and indicators within *A Framework for Quality K-12 Engineering Education.* Other assignments include using the EiE assessments geared at uncovering student misconceptions about engineering as small group discussion prompts within class sessions. Further emphasis on the inherent interdisciplinary connections may also help to bring to light the significance of engineering to their own lives and communities, something that the participants in this study valued and wanted to further in their own practice.

Other amendments to the methods course include providing a more substantial orientation to the EiE curriculum before joining the partner classroom. In future iterations of this course, candidates chose units and accompanying professional development videos on the EIE website to review and report on. The focus here is on candidate understanding of the engineering design process, and alignment between science, engineering, literacy and equity goals. All candidates also develop (and ideally implement) lesson plans that include engineering design elements. And, while our teacher candidates are often most excited about thinking about planning and implementing curricular activities, we must continue to support their understandings of engineering and engineering education and of the theoretical perspectives that influence their instructional decision-making.

Conclusion

This study contributes to the small body of literature investigating pre-service elementary teacher self-efficacy for teaching engineering. Findings open the door for future research into supporting the development of this specific teacher population. As engineering education becomes more embedded in elementary classrooms across the United States, teacher educators are adjusting their science methods courses to include an emphasis on engineering. The idea of teaching engineering to young children can feel daunting to teacher candidates and teacher educators alike, given that this subject area was likely not a prominent part of either group's own grade school experience. There is a need for continued research describing and investigating efforts to promote candidates' knowledge, understanding, and efficacy for teaching engineering in elementary classrooms.

Getting candidates more excited about teaching engineering may be the first step, and then the second step is to ensure that they hold strong understandings themselves. Findings from this study indicate that attention is needed to achieve both goals. Findings also remind that purposeful collection and analysis of course data from year to year following the model of pedagogical action research (Norton, 2019) is central to informing iterative course improvements. Future studies should continue to utilize mixed methods and robust instruments to examine course influences on elementary teachers' preparation for teaching engineering.

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Appendix A

TESS Reflection Prompts

Now that you have completed the End of Semester TESS survey, please collect a copy of your survey responses from the beginning of the course from your Instructor.
Review your responses to the TESS survey at the beginning of the semester and at the end of the semester. Then, respond to the following questions.

1. What changes do you notice, if any?
2. How might you explain these changes, or what do you feel has contributed to the changes in your responses?
    a. You might consider new understandings or realizations you have had about engineering and engineering education, as well as new questions that arose for you over the semester.

Appendix B

Interview Protocol

- Could you start by sharing a particular experience around engineering education that stands out for you this semester?
- Thinking about the lessons you observed and helped with at [the Partner School], which were more exemplary of science and which were more exemplary of engineering? Explain.
- How would you explain what engineering is, or what engineers do?
- How would you explain what science is, or what scientists do?
- How do you see science and engineering relating to one another?
- Have your ideas and understandings about science and engineering changed since the beginning of this course? (Ex. Any new realizations? Has anything been clarified or reinforced? Anything you still feel uncertain about?)
- From your time at [the Partner School], I'm interested in what you feel you learned about teaching engineering with elementary aged students. What did you learn from the teacher? And what did you learn from the students?
- How do you see yourself approaching engineering education in the elementary classroom? How would you incorporate engineering into your science classes, even if there were not a separate engineering lab course like at [the Partner School]?
- Were there any other course experiences or assignments that you feel especially contributed to your learning about engineering and engineering education?