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Partnering for Engineering Teacher Education

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Partnering for Engineering Teacher Education

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Citation
Smetana, L.K., Nelson, C., Whitehouse, P., & Koin, K. (2019). Partnering for engineering teacher education. *Innovations in Science Teacher Education, 4*(2). Retrieved from https://innovations.theaste.org/partnering-for-engineering-teacher-education/

by Lara K. Smetana, Loyola University Chicago; Cynthia Nelson, Loyola University Chicago; Patricia Whitehouse, William C. Goudy Technology Academy; & Kim Koin, Chicago Children's Museum

Abstract

The aim of this article is to describe a specific approach to preparing elementary teacher candidates to teach engineering through a field-based undergraduate course that incorporates various engineering experiences. First, candidates visit a children's museum to engage in engineering challenges and reflect on their experiences as learners as well as teachers. The majority of course sessions occur on-site in a neighborhood elementary school with a dedicated engineering lab space and teacher, where candidates help facilitate small group work to develop their own understandings about engineering and instructional practices specific to science and engineering. Candidates also have the option to attend the elementary school's Family STEM Night which serves as another example of how informal engineering experiences can complement formal school-day experiences as well as how teachers and schools work with families to support children's learning. Overall, candidates have shown increased confidence in engineering education as demonstrated by quantitative data collected through a survey instrument measuring teacher beliefs regarding teaching engineering self-efficacy. The survey data was complemented by qualitative data collected through candidates' written reflections and interviews. This approach to introducing elementary teacher candidates to engineering highlights the value of a) capitalizing on partnerships, b) immersing candidates as learners in various educational settings with expert educators, c) providing opportunities to observe, enact, and analyze the enactment of high-leverage instructional practices, and d) incorporating opportunities for independent and collaborative reflection.

Introduction

It is not uncommon for elementary teacher candidates to arrive to the first day of the science methods course a bit anxious about the subject matter. They might not consider themselves scientists, or might be bringing what we refer to as school science baggage (Smetana, Birmingham, Rouleau, Carlson, & Phillips, 2017; Birmingham, Smetana, & Coleman, 2017) – an accumulation of negative and/or passive science learning experiences that can restrict one's vision for what science teaching and learning can be. When they learn that not only will the course be focused on teaching science but also on teaching engineering in elementary grades, eyes grow even wider. "I was very overwhelmed by the thought of teaching engineering to such young students", wrote one elementary teacher candidate reflecting on the beginning of the Teaching Science in the Elementary Classroom course. By the end of the course, our experience over the past few years is that candidates are not only more comfortable with, but genuinely enthusiastic about teaching engineering. "Now, I love it!" is a reflection typical of what we've heard candidates share at the end of the semester.

In this article, we describe our approach to moving elementary teacher candidates from a place of nervousness to one of excitement about teaching engineering through a field-based undergraduate course that incorporates in- and out-of-school science and engineering experiences. We begin with an overview of how we understand engineering in the context of elementary education. Then, we describe the various learning experiences of the course that take place across a variety of settings – the university classroom, a public elementary school classroom, a children's museum, and a family night. We offer a summary of findings related to teacher candidates' outcomes – specifically, teaching engineering self-efficacy – and discuss implications for our program and for other science and engineering teacher educators. The first author is the university-based instructor for the course; the second author is a graduate research assistant; the third author is a classroom-based co-teacher educator for the course; the fourth author is the museum-based co-teacher educator for the course.

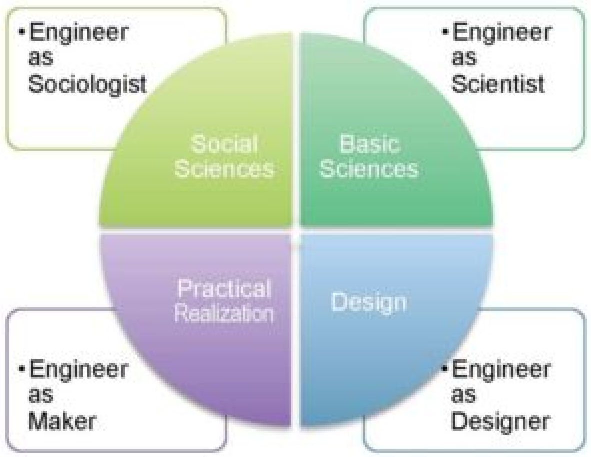
Defining Engineering in the Context of Elementary Education

The Framework for K-12 Science defines engineering "in a very broad sense to mean any engagement in a systematic practice of design to achieve solutions to particular human problems" (NRC, 2012, p.11). In order to prepare teacher candidates for teaching engineering in their future elementary [Grade 1-5] classrooms, we follow recommendations of the Framework, the Engineering in K-12 Education report (NAE & NRC, 2009) and the Framework for Quality K-12 Engineering Education (Moore, et al., 2014) including that pre-college engineering education should: 1) emphasize iterative processes of design; 2) incorporate important and developmentally appropriate science, math and technology concepts and practices; and 3) promote habits of thinking, working and communicating.

First, learners should be actively engaged in engineering design which involves processes and practices such as defining problems to situations that could be improved, researching the problem and specifying criteria and constraints for acceptable solutions, brainstorming multiple solutions, creating and testing prototypes, and optimizing a solution through analyzing results and considering improvements (Lottero-Perdue, 2017; NGSS Lead States, 2013).

Second, engineering – including its processes and practices, purposes and products – should be introduced in relation to the related but distinct disciplines of science, technology and math, as well as in relation to social studies, reading and language arts. Here, deFigueiredo's (2008) model of engineering as comprised of four related dimensions is useful in illustrating how incorporating engineering challenges in the classroom can promote transdisciplinary teaching and learning (Figure 1).

Figure 1 (Click on image to enlarge). Engineering dimensions, adapted from deFigueiredo (2008).



Third, learners should be apprenticed into the norms for how engineers go about their work. The sorts of habits of mind relevant to engineers, teacher candidates and elementary-aged learners include – among others – a desire to solve problems, creativity, persistence and a resilient response to failure (Lottero-Perdue, 2017; NAE & NRC, 2009). Similarly important are the development of collaborative teamwork skills, and the use of multiple means and modes of communication and representation (Moore, et al., 2014). The following sections illustrate how these recommendations have influenced our course, and some of the impacts the course has had on the teacher candidates we work with.

Developing Working Definitions

Before sharing the Framework's definition of engineering with teacher candidates, the course begins by deconstructing ideas about technology, engineering, what engineers do, and how engineering relates to technology and the other S-T-E-M disciplines. Candidates select items around the classroom that they consider to be examples and non-examples of technology and then share their lists as they collaboratively develop a working definition of 'technology'. Then, tasked with drawing an engineer, they are challenged to think about how the work of an engineer relates to these technologies (For more on this activity, see Lottero-Perdue, 2017, p. 208). After sharing their drawings and ideas, we arrive at a working definition for 'engineering' that will be further refined throughout the course. Candidates discuss how the examples of technology they identified solve a problem or meet a need, as well as how and why the design of that technology may have changed over time. The class enjoys watching and discussing videos from the Museum of Science, Boston's Engineering is Elementary (https://www.eie.org) collection depicting elementary-aged children grappling with similar questions.

Field-based Experiences

The course begins in the university classroom but soon transitions to other settings that are designed to allow candidates to (a) experience engineering as learners themselves, (b) work with expert instructors who provide a vision for what best practices look like as well as the realistic challenges, and (c) have authentic, low-risk teaching opportunities and interactions with youth.

We believe that the combination of course experiences – in the museum, elementary engineering lab, and traditional university classroom – work together to develop candidates' engineering self-efficacy better than any one experience in isolation. Table 1 summarizes how the course experiences relate to the Teaching Engineering Self-efficacy dimensions (Yoon, Evans, & Strobel, 2014) of engineering pedagogical content knowledge self-efficacy (KS), engineering engagement self-efficacy (ES), and engineering disciplinary self-efficacy (DS).

Table 1 (Click on image to enlarge)

Key Course Experiences Mapped to Engineering Efficacy Dimensions

Teaching Engineering Self-efficacy Dimension	Working Definition	Course Mapping
Engineering pedagogical content knowledge self-efficacy (KS)	Personal belief in one's ability to teach engineering to facilitate student learning, based on knowledge of engineering that will be useful in a teaching content	• Visit museum exhibitions that emphasize design thinking processes, engineering habits of mind, collaboration and communication, candidates' free exploration in exhibition areas • Review engineering curricular materials from various sources • Observe engineering and science model lessons in elementary classroom; teacher shares her thinking, decision-making, advice • Plan units and lessons that integrate science and engineering • Implement and reflect upon small-group science and engineering talks in elementary classroom
Engineering engagement self-efficacy (ES)	Personal belief in one's ability to engage students while teaching engineering	• Engage as a learner in museum space that promotes interest, cooperation, creative thinking • Observe in elementary engineering lab; teacher shares her thinking, decision-making, advice • Facilitate and reflect upon small-group activities in elementary engineering lab
Engineering disciplinary self-efficacy (DS)	Personal belief in one's ability to cope with a wide range of student behaviors during engineering activities	• Observe in elementary engineering lab; teacher shares her thinking, decision-making, advice • Facilitate and reflect upon small-group activities in elementary engineering lab

Children's Museum

The first field experience is a visit to a local children's museum and affords an opportunity for candidates to think about how museums and out-of-school learning opportunities support and complement classroom-based engineering education. The visit combines: discussion with museum staff around two specific exhibition spaces that emphasize design thinking processes, engineering habits of mind, collaboration and communication, candidates' free exploration in exhibition areas, and reflection on the kinds of instruction candidates could design around or draw inspiration from the exhibitions. The museum-based class session follows a collaborative teaching model that we've developed in which museum staff serve as co-teacher educators (Smetana, Bedford, Carlson, Clark, Cook, Incandela, Moisan, Rouleau, & Stecz, 2018) and share in the planning and facilitation of the session.

The first stop is to Chicago Children's Museum's Tinkering Lab, which invites young visitors to participate in creative, playful problem-solving with a delightful assortment of materials and tools available in the space – from hammers and saws to fabric and feathers. Tinkering, as explained by Bevan, Gutwill, Petrich & Wilkinson (2015), is a "generative process of developing a personally meaningful idea, becoming stuck in some aspects of physically realizing the idea, persisting through the process, and experiencing breakthroughs as one finds solutions to problems" (p. 99). Or, as one young visitor puts it, "Tinkering is playing around and eventually making something amazing." (Slivovsky, Koin & Bortoli, 2017).

Teacher candidates, like any visitor to the space, are given a short, open-ended design challenge here, such as "connect two things together" or "make something that rolls" that can be approached from a multitude of ways. Museum educators explain how these sorts of short, specific prompts are excellent for school groups who have limited time in the lab and museum. For candidates, this is an opportunity to experience what it feels like to be given some structure (in the form of an open-ended prompt framing the challenge) as well as the invitation to experiment, negotiate ideas, goals and constraints, take risks and persist through frustration. Afterwards, candidates reflect on their experience in the space as learners as well as teachers. Educators explain their mantra of "wait, watch, follow". That is, staff in the space step back and allow visitors to explore the space and materials and think about the challenge, watch for where visitors may need help, and then follow with a question or prompt that encourages visitors to figure out their own solutions.

Several candidates wrote in an exit slip how the Tinkering Lab was a defining moment for them in terms of thinking about balancing engagement, structure, choice and autonomy within the learning process. For instance, responding the question "What was a defining moment for your today in the exhibit – as a learner and/or as an educator?" one candidate wrote "When [the museum educator] was talking about the instructions and how they should be open-ended, it really gave us so much freedom to really think for ourselves and go for it, which is something kids should be given the opportunity to do." Another candidate shared, "I really liked the Tinkering Lab and seeing how each person interpreted the directions differently and expressed themselves. I learned how important tinkering is for all ages and why it is important. Not only does it build cognitive/social emotional learning, but also builds confidence." Here, we see evidence that candidates are beginning to identify aspects of their own Tinkering Lab experience that could be transferred to their future elementary engineering classrooms.

Next, candidates explore the Skyline exhibition space, in which they participate in small group teams in a challenge to brainstorm, design, and create a skyscraper structure under constraints of time and materials, and then reflect upon the process. This experience highlights the interdisciplinary connections with mathematics, science and language arts, but perhaps more prominently the importance of teamwork and communication – which groups often forget about in their rush to just start building but later come to recognize the value of as they progress in their creation. Candidates complete their towers and then step back to compare their design choices with their peers as well as with the designs of other structures previous visitors have left on display.

Finally, candidates use the exhibit's recording studio feature to create a narrative reflection on their process, including design choices as well as challenges encountered and how they overcame them. Afterwards, the reflection discussion focuses on their process and how it helps them to understand what they've read about the engineering design process. Typically, the importance of planning, testing, failing and improving emerge in these reflections. As one candidate shared, "A defining moment for me today was building the skyscraper even though it ended up falling down. This visit helped me realize how important failure is and how learning from that is so beneficial." Candidates also reflect on the opportunity for incorporating writing or other communication formats into learning experiences to allow for reflection on the learning process – whether it is for themselves or for their future students. These themes are picked up in the engineering lab classroom.

Engineering Lab Classroom

The majority of course sessions take place on-site at a partner elementary school, which is fortunate to have an elementary engineering lab space and dedicated engineering lab teacher. The neighborhood school is a high achieving, culturally and linguistically diverse, low socio-economic urban school within close proximity to the university. The class meets in a classroom made available by the school for the first two hours of class, and then transitions together with the university professor to the engineering lab to work with the elementary class that is scheduled to be there for that one hour class period. Engineering is built into the school schedule as an enrichment class with each grade level visiting the engineering lab twice in every six-day cycle. Since the teacher preparation course meets once per week on the same day of the week, candidates see different classes from the same grade level in the engineering lab. The large lab space has an open gathering rug space in the front of the room for class meetings and eight large tables. Students are organized into table teams of 4-6 students for each engineering design challenge; one to two teacher candidates are assigned to work with each table. The university class (teacher candidates and professor) arrives to the lab 10-15 minutes ahead of the elementary class to check in with the engineering lab teacher about the lesson for the day. This is also a good time to assist with any preparations for the activity. On any given class session, the teacher candidates assist with whatever portion of the design challenge students happen to be working on.

The engineering lab teacher and the university professor meet prior to the start of the semester to discuss both logistics and content. This is a chance for the engineering lab teacher to share specifics about the classroom context, including the specific curriculum content, background about the students and classes, as well as how the candidates can be of most help in the classroom. This meeting is also a chance for the university professor to discuss assignments and other course goals. Together, they also discuss how to manage the number of added people in the room, how to match candidates with students, and work out schedules for completing university course assignments that involve students (see below).

The engineering lab teacher has adapted the Engineering is Elementary (EiE) curriculum (Engineering is Elementary, 2011) to fit the particular needs and interests of her classroom. For instance, the Lighten Up: Designing Lighting Systems unit, which introduces the field of optical engineering and invites youth to design a lighting system for the interior of a model ancient Egyptian tomb, integrates well with the fourth grade focus on energy and matter (NGSS PS3.A-C). At the point of the semester when the university class joined the elementary classes this past semester, the 4th grade had just concluded their exploration of light properties and were excited to share their learning with the teacher candidates. Youth referenced the consensus charts around the room, which summarized their learning about light, how it travels in straight lines, reflects in a particular way, and interacts with different materials; these charts then became useful references for the teacher candidates as well as they practiced asking probing questions – rather than providing answers – and reviewed key vocabulary while assisting the teams of young engineers. When asked about what they were learning from the teacher and the students in the partner classroom, candidates remarked at how it was beneficial to see the strategies that they were reading and discussing about exemplified in the elementary classroom. “The entire experience of being in the [engineering] lab really stuck with me because everything we have been learning directly applied to what we observed,” one candidate shared in an exit slip.

The engineering classes monitor their progress through a modified engineering design process (EDP) using a large chart at the front of the room that displays the various stages of the EiE model – Ask, Imagine, Plan, Create, Improve – with a space for each group to mark “GTG”, short for “Good to Go”, once that phase has been approved by the lab teacher or one of the teacher candidates. The GTG is a coveted mark in team members’ journals and on the classroom chart because it signifies that the group can move onto the next phase of their design process. The EDP/GTG chart also serves as a space for the engineering lab teacher to make notes about where a group leaves off or what needs to be checked the next time they are in the lab. And, it is a useful resource for teacher candidates who may not be working with the same group of students from one week to the next. Further, in terms of modeling best practices, the journals are an example for candidates of ways to make student thinking visible and public, and empower youth to monitor their own learning. “I like the strategy because it encourages students to share their thoughts and ideas and also gives them a chance to show their thoughts to the other students, even in the other classes,” shared one candidate. Candidates also identified how the GTG chart functions as both a form of assessment and classroom management, since many students were eager to stay on task, progress through their design project and be rewarded with a GTG on the chart. “I saw how excited the students were to be able to be a part of a class that encouraged and explored a variety of different Engineering practices,” shared another candidate.

As candidates help facilitate small group work they are developing their own understandings about engineering as well as instructional practices consistent with the Framework for Quality K-12 Engineering Education and the Framework for K-12 Science Education. For instance, candidates learn about "talk moves" designed to support academically productive conversations (Michaels & O'Connor, 2012) in their course readings and then observe and try out these practices during their time in the elementary engineering lab, with the support of the lab teacher and university professor. Reflecting in an interview about the model lessons she observed, one candidate shared "seeing the class having a discussion about science is not something I was familiar with at all. So that was a really cool experience to see the students so engaged. No textbook at all. [Students] just taking initiative over their learning… It was a really cool experience to witness their energy and excitement about that."

Candidates also learn from listening to the students since, by the spring semester, students are quite familiar with these talk moves and are adept at using them in their teams and in whole-class discussions. The lab teacher demonstrates appropriate questioning techniques using talk moves as she circulates to each table group to support students and candidates as they think through their design decisions as a team – brainstorming, creating and testing ideas, analyzing results and considering improvements. Rather than giving away answers or determining the course of action for students, candidates also practice implementing the "wait, watch, follow" approach introduced at the museum's Tinkering Lab and demonstrated by the partner school teacher. Candidates follow the lead of the elementary engineering lab teacher as they practice and reflect on the experience of encouraging students to share their ideas with the team, listen to one another and think collectively through challenges, and deepen their reasoning using evidence.

Candidates also develop and carry out a "science and engineering talk" (Rosebery & Ballenger, 2008) with students. This past term, the talk took place at the start of a new unit mid-way through the semester and focused on Earth's Systems (NGSS ESS.2A&C) and designing solutions for erosion (NGSS 4-ESS3-2 & ETS1.B). Candidates used a combination of questions suggested by the lab teacher as well as questions they wrote to lead their table teams in elicitation conversations about photographs depicting puzzling phenomena – landforms that had somehow been altered by erosion, weathering and deposition. Goals of the science talk include uncovering students' initial ideas about the landforms and how they came to be, and identifying the sorts of prior knowledge and experiences students draw upon to make sense of the phenomenon. They also reflected on the implications of the talk for the unit and upcoming design challenge, focused on designing a solution to stop water erosion – a problem of particular interest since their school is a short distance from a lakefront and riverfront facing similar issues. Reflection prompts included "In what ways did conducting the science talk and observing the new 4th grade unit being introduced help you to think about the lesson and unit plans you're developing?" As exemplified in the quote below, candidates remarked at how much they learned about the students through the talk, and how interested and engaged the class was in the phenomenon:

> “The really interesting part of this assignment is how unique each student’s experience was with water, and how that affected their responses to my questions…As a future science teacher, I will begin my lessons with a particular Phenomena or big question! This will not only get my students eager to learn more, but it will cause them to draw upon their own personal experiences and perceptions of the world. By conducting this Science talk, I learned so much about my students, about the way students think and make connections, and about how I can guide them without giving away the answer.
> These and other authentic teaching opportunities in the partner classroom help move candidates to develop confidence and understandings about the engineering and design processes, its connection to science and other content areas, its relevance to their own and their students’ lives and experiences, as well as in pedagogical strategies for teaching science and engineering at the elementary level.”

An ongoing challenge we’ve found is how to help candidates understand the relationship and interaction between science and engineering. Research suggests that explicit attention to this integration is necessary (Reimers et al., 2015). This year, we placed more emphasis on reflecting upon the interaction of science and engineering and on encouraging candidates to think about how to leverage students’ engineering experiences to develop understanding of science concepts. For instance, during the lighting system unit described above, we discussed how the engineering design challenge followed the class’s study of light and thus served as a context for students to transfer and further develop their understandings. Then, for their own 5E lesson and unit planning, we encouraged candidates to take a similar approach and integrate engineering challenges within the Extend/Elaborate phase. In another class activity, groups worked together to respond to the prompt: “Explain (through words, diagrams, etc.) your understanding of what the disciplines of science, technology and engineering are. How are these fields related? How are they distinct? What will you want to emphasize for your students about these fields separately, and as they relate to one another?”

An important conclusion of each class session is taking time with the engineering lab teacher after students have left to debrief. While there would ideally be more time for a discussion (typically there are only a few minutes before other classes arrive), this time together affords the lab teacher an opportunity to make some of her thinking explicit to candidates. The university professor continues the debrief and also picks up on topics brought up by the lab teacher in exit slip reflection assignments and future class discussions. Together, these debriefings help candidates to develop their own professional vision. Conversations have, for example, helped to highlight the importance of setting aside time for team-building and encouraging productive responses to failure. Questions posed to candidates included: “Why do you think the class takes so much time for team-building? What did you notice about how the new groups worked together on their team folders? What did you notice about how project setbacks are addressed in the engineering lab? How might you support your students when they encounter frustrations and challenges with their assignments?”

In discussing the significance of giving time for students to get to know other members of their team by decorating team folders at the start of each new unit, one candidate shared, "I like that [the engineering lab teacher] switches up the groups after each project so that students have a chance to work with new classmates. I think it is great that she does 'get to know you activities' when the students get new groups so that they get to know one another better." Sharing takeaways from another class period where the young engineering class took time to talk through setbacks they encountered in their design process, one candidate was pleasantly surprised by how "setbacks are looked at in a positive way in the Engineering Class…I need to realize that setbacks are okay [in my own work, too]". Agreeing, another shared "failure and frustrations are places where students including myself can learn and come up with new ideas…I can work with them individually to come up with new ideas or new ways of looking at a problem." These examples further illustrate how candidates are simultaneously deepening their understanding of engineering and engineering education, as learners themselves and as novice teachers.

Family STEM Night

A final, optional field experience takes place at the partner school's annual Family STEM Night, where Kindergarten through Grade 4 students and their families attend a series of different interactive science, technology, engineering, and math focused sessions. Candidates are invited to help facilitate a session; due to time constraints, the university instructor selects the activity, gathers materials and provides a brief orientation before the event begins. Building on the museum-based experience at the start of the semester, the Family Night serves as another example for candidates of how informal engineering experiences can complement formal school-day experiences, promoting more connected learning and overall academic success (Fenichel & Schweingruber, 2010). The event allows for another touch-point with engineering for the teacher candidates and for the youth who visit the engineering lab with their classes. Held in late spring, elementary students and teacher candidates engage confidently in the engineering design challenges. Candidates have developed the vocabulary around the engineering design process, practices and habits of mind and are eager to assist youth and their families in thinking through the challenge, working on their designs and considering improvements or extensions to make at home.

Learning how teachers and schools work with families to support their children's learning is another critical skill set for teacher candidates. Those who participate in the Family STEM Night witness firsthand how the event provides families another window into their children's school experience as well as into the world of engineering, which may or may not be familiar. The positive energy of the evening, along with the collaboration between teachers, administrators, staff and volunteers that ensure its success, also illustrates for candidates the value of bringing families together for community-building events at the school that are both educational and social (Smetana, Chadde, Goldfien, & Nelson, C., 2012), making it more likely that they will participate in similar events in the future.

Candidate Outcomes

We began with the claim that the course shifted elementary teacher candidates' perceptions about teaching engineering. In addition to the anecdotal evidence provided throughout the article as a way of illustrating what the field-based experience entailed, this section summarizes overall findings, reported in greater detail and expanded upon elsewhere (Smetana & Nelson, 2018), about candidate efficacy beliefs. Beliefs are of interest to us since teachers' classroom actions are linked to their belief systems (Jones & Carter, 2007) and beginning teachers' beliefs about teaching and learning science are shown to be positively influenced by the support they receive early on (Cantrell, Young & Moore, 2003; Osisioma & Moscovici, 2008).

Overall, candidates over multiple semesters have shown increased confidence on a number of quantitative and qualitative scales. Quantitative data was collected through the Teaching Engineering Self-efficacy Scale (TESS), a 23-item instrument that measures teacher beliefs across multiple sub-scales including: engineering pedagogical content knowledge self-efficacy (KS), engineering engagement self-efficacy (ES), engineering disciplinary self-efficacy (DS) and outcome expectancy (OE) (Yoon, Evans, & Strobel, 2014). While outcome expectancy is a construct of interest, we found that the five TESS items corresponding with outcome expectancy were geared toward teachers who have the primary responsibility for their students' engineering assessment and evaluation. Since our teacher candidates are only supporting classroom teachers at this stage of the program and not responsible for documenting students' progress, they expressed uncertainty about how to answer most of the OE questions. For instance, while Item #23 (My effectiveness in engineering teaching can influence the achievement of students with low motivation) was something our teacher candidates felt comfortable answering, Item #19 (When a student gets a better grade in engineering than he/she usually gets, it is often because I found better ways of teaching that student) was confusing to our teacher candidates who do not assign grades to the elementary students they worked with, or know students' overall course grades. Given this confusion, we did not want the OE scores to skew the overall TESS scores. In the future, we may re-word these five questions to be more applicable to the 2nd year teacher candidates' experience or provide additional explanation for how to answer the items. For instance, Item #19 could be reworded for teacher candidates to state, "When a student performs better academically in engineering than he/she usually does, it is often because I found better ways of teaching that student".

In order to measure the candidates' self-efficacy towards teaching engineering, each candidate completed the TESS twice: once at the beginning of the course, prior to exposure to the engineering classroom or curriculum, and again, upon completion of the course. Data were collected from nine candidates in year 1 and twenty candidates in year 2. We calculated descriptive statistics to measure the change in the candidates' self-efficacy towards teaching engineering (See Table 2).

Table 2 (Click on image to enlarge)

Teaching Engineering Self-efficacy Scale (TESS) Pre-test and Post-test Scores Over Two Years

	Mean KS Score		Mean ES Score		Mean DS Score		Overall TESS Score	
	Pre-Test	*Post-Test*	*Pre-Test*	*Post-Test*	*Pre-Test*	*Post-Test*	*Pre-Test*	*Post-Test*
Minimum	1.33	3.33	2.00	4.75	2.80	4.00	**8.78**	**12.59**
Maximum	4.89	6.00	6.00	6.00	6.00	6.00	**15.69**	**17.58**
Mean	3.00	4.89	4.54	5.68	4.13	5.01	**11.67**	**15.58**
Max. possible	*6*	*6*	*6*	*6*	*6*	*6*	*18*	*18*
Percent change	**63%**		**25%**		**21%**		**34%**	

In order to expand on the survey data, qualitative data were collected through an ungraded writing reflection at the end of the course that asks the teacher candidates to reflect back on the beginning of the semester and how their TESS responses and ideas have changed – such as new understandings or realizations about engineering and engineering education – if at all. The assignment also asked them to consider what has most contributed to the changes. Additionally, the second author conducted semi-structured interviews with candidates after the end of the course each year to further probe candidates' ideas, understandings and beliefs. The following response is typical of what we found in written reflections and interviews over the past two years:

> "I do notice many significant changes. Before this class, I was not one hundred percent certain on what engineering was. I knew it was a very diverse career field, but I did not know how to bring that into an elementary setting. I was not confident in the beginning of the semester on going into an engineering classroom, and was very nervous. Coming out at the end of the semester, I feel very confident in my ability to conduct an engineering activity with students and help them through the engineering design process."

The overwhelming majority remark on how they were unsure of their understandings and nervous about the prospects of teaching engineering to begin with, but emerge with great – perhaps even inflated – confidence at the end of the semester. Inflated perhaps since our research suggests that candidates still hold some misunderstandings and misconceptions about engineering and its interaction with science at the end of the course (Smetana & Nelson, 2018), a challenge that we continue to explore and attend to in the design and implementation of each subsequent course.

Conclusion

Our approach to introducing elementary teacher candidates to engineering and promoting their comfort with and efficacy for teaching engineering in the elementary grades highlights the value of a) capitalizing on partnerships, b) immersing candidates as learners who, like their students, benefit from teaching and learning experiences across different educational settings and with expert educators, c) providing opportunities to observe, enact and analyze the enactment of high-leverage instructional practices and d) incorporating opportunities for independent and collaborative reflection. These elements resonate with those emerging from other studies that describe characteristics of practice-based and participatory approaches to teacher preparation (Forzani, 2014; Grossman et al., 2009; Lampert et al., 2013) as well as initiatives that successfully introduce educators to engineering education and pedagogies (Goldman & Zielezinski, 2016). When asked about their course experiences, candidates consistently rank the time in the elementary engineering lab as most influential on their ideas and beliefs about engineering and engineering education at the end of the semester. This is not unexpected given the amount of time spent in the classroom and the timing of the question, which comes at the end of the semester when candidates have just completed the school-based experience and said their farewells to the elementary classes. However, these findings reinforce the value of the field-based experiences and the collaborations between the university instructor and engineering lab teacher whose educational practices are consistent with current science/engineering standards and align with the rest of the course content and strategies. As Zeichner (2012) argues, it is not just being in a P-12 classroom that makes for a meaningful teacher preparation learning experience. Rather, a coherent and participatory learning experience focuses on the work of teaching and involves observing and participating in practice, as well as acquiring ones' own skills in specific core practices through enactment and reflection (Forzani, 2014).

Although fewer candidates cite the influence of the museum in the end of semester essays and interviews, their early semester reflections illustrate how impactful the visit is on candidates' understanding of engineering practices and habits of mind, but also structured yet flexible and self-directed learning environments, and strategies for scaffolding intellectual risk-taking. These findings suggest that the museum-based session laid the groundwork for the elementary engineering lab experience. That is, the visits provided an introduction to focused inquiry, through examining influences on the processes and conditions for learning that exist within the informal setting and that also have relevance for the classroom setting. Additionally, our experience and findings suggest that the museum session, with its behind the scenes look at the exhibition spaces and programing as well as the chance to personally experience them, helps candidates attend to both the learner and educator perspectives (Grossman et al., 2009).

Critical to the success of the course and partnerships with the museum and engineering lab is the museum educators, engineering lab teacher and the university professor all being positioned as co-teacher educators who share in the responsibility of preparing the teacher candidates. Each brings a unique set of experience and expertise, and each guides candidate learning in complementary ways. These collaborations and professional relationships have developed over several years, during which time tremendous energy and time have gone into meeting, planning and reflecting upon course sessions and activities. Along the way, we have all learned from one another, adding to our own professional repertoires.

Going forward, we are eager to continue to innovate in our practice, reviewing candidate outcomes and further improving upon the learning experiences we provide. Future longitudinal research in this area needs to consider how candidates progress into student teaching and beyond, and the extent to which the interest and efficacy demonstrated at the end of the course is indeed associated with high quality engineering instruction in their own elementary classrooms.

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