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Teaching engineering to enhance beginning elementary preservice teachers' engineering-related knowledge and beliefs

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Abstract

Background Teacher educators have begun exploring the most effective ways to prepare preservice teachers (PSTs) to engage elementary students in engineering design. However, this remains challenging as PSTs continue to report a lack of exposure to engineering during their *K*-12 school experiences. This study investigates the engineering-related knowledge and beliefs of PSTs in their first education course, collaborating in small teams to lead elementary students in engineering design challenges. We explored two different iterations to understand how the structure of the teaching experiences contributed to PST outcomes as a first step in identifying helpful approaches. In spring 2022, PSTs collaborated with undergraduate engineering students to develop and teach a carnival-themed design challenge lesson, while PSTs from fall 2022 collaborated with education classmates to teach a premade engineering lesson focused on designing plastic filters. We used quantitative and qualitative measures to analyze PSTs knowledge of engineering, knowledge of engineering pedagogy, beliefs about the importance of elementary engineering instruction, self-efficacy for teaching engineering, and intention to integrate engineering in their future instruction.

Results Teaching engineering had a positive influence on PSTs' engineering-related knowledge and beliefs. PSTs began to understand engineering as a process and see the ubiquity of engineered products in everyday life. They recognized their teaching role as guiding students through the design process and practices. PSTs noted how elementary students found engineering fun and engaging and were able to develop successful solutions with minimal assistance and even persevered through failure. These observations contributed to the development of their engineering-pedagogical knowledge and helped cultivate positive engineering-related beliefs. Following their teaching experiences, most PSTs gained self-efficacy for teaching engineering, believed engineering should be taught in elementary schools, and had an intention to integrate engineering into their future instruction.

Conclusions Our findings suggest teaching engineering to elementary students is an effective approach to enhancing beginning PSTs' engineering-related knowledge and beliefs. Recommendations are made for structuring teaching opportunities early in preparation programs, including: teaching elementary students, practicing teaching, and engaging as students in meaningful design challenges. Questions remain regarding how best to structure teaching experiences for early PSTs, such as ideal team composition and placement in elementary teacher education programs.

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Introduction

"I would have never thought I would be able to teach engineering concepts to kids" (first-year elementary education student).

The Next Generation Science Standards (NGSS) began calling for the inclusion of engineering design as a core feature of K-12 science more than 10 years ago (NGSS Lead States, 2013), and 80% of state standards include some sort of reference to engineering (Lopez & Goodridge, 2018). However, preparing preservice teachers (PSTs) for the task of teaching engineering is challenging for several reasons. Historically, preservice teachers (PSTs) have had limited exposure to engineering, both during their K-12 schooling and in their professional teacher preparation programs (Banilower et al., 2018; Miaoulis, 2010; O'Brien et al., 2015; Sneider & Purzer, 2014). Despite the new engineering standards, the K-12 trend appears to persist, as PSTs continue to report a lack of prior exposure to engineering (Kidd et al., 2023; Kim et al., 2019; Lux et al., 2022; Mumba et al., 2024; Smetana & Nelson, 2023). General education course requirements within elementary teacher preparation programs often focus on math and science content (e.g., Biology, Chemistry, College Algebra, and Geometry) and fail to address engineering (DiFrancesca et al., 2014). In response, teacher educators within elementary education preparation programs must help PSTs develop basic knowledge of engineering practices and pedagogy, as well as positive beliefs about engineering education, so they have the expertise, confidence, and will to integrate engineering into their future instruction. Yet, the question of how to design preparation experiences that best support PSTs' engineering-related knowledge and beliefs remains unresolved.

To provide insight into approaches teacher educators can use to prepare PSTs to integrate engineering into elementary education, we investigated the experiences of PSTs who taught an engineering lesson to elementary students as part of a course project in their first education course. The goal was to explore PSTs' knowledge and beliefs related to teaching engineering to examine how the experience may have contributed to PST development at the start of their teacher preparation program. The study builds on work by other scholars and teacher educators who have integrated engineering instruction into elementary teacher preparation programs, either via a content course (e.g., DiFrancesca et al., 2014), science methods courses (e.g., Capobianco & Radloff, 2022; Kaya et al., 2017; Perkins Coppola, 2019; Yesilyurt et al., 2021), or programmatically (e.g., Antink-Meyer & Parker, 2021; DiFrancesca et al., 2014; Ozkizilcik & Cebesoy, 2023). To our knowledge, our project is the first to examine the effects of exposing elementary PSTs to engineering in their first teacher preparation course—one not focused on pedagogy. Drawing on prior research on teacher practices (e.g., Jacobs et al., 2010; Johnson et al., 2017), we chose to focus on PSTs' perceptions of their knowledge and beliefs related to teaching engineering, specifically what aspects of their practice they attended to, interpreted, or noticed during their reflections. These "noticings" shed light on what the PSTs derived meaning from, the experiences that triggered their sensemaking. This study is unusual among studies introducing PSTs to engineering, because it focused on PSTs at the start of their teacher preparation program. While research suggests benefits for early field experiences (e.g., Coffey, 2010; Ferguson & Sutphin, 2024; Maheady et al., 2007; Wallace & Brooks, 2015) and some teacher preparation programs are moving toward early field placement models, early field experience opportunities have traditionally been limited in scope (e.g., observations, tutoring) with opportunities to lead students through extensive lessons reserved for later stages of preparation programs, such as practicum or student internship experiences (Kwok & Bartanen, 2022). We introduce the idea that PSTs can benefit from an earlier introduction to teaching and teaching engineering specifically.

Since formal preparation in engineering is still relatively new in teacher education—and embedding such experiences at the very start of a preparation program is even more novel—we examined two iterations of our teaching engineering project to explore what PSTs could learn from teaching engineering to elementary students during the early stages of their professional training, when they are just beginning to engage with teaching as their chosen profession. In spring 2022, PSTs collaborated with undergraduate engineering students to develop and teach carnival-themed design challenge lessons to fourth graders in an introductory engineering course. In the fall of 2022, PSTs partnered with their education peers to teach a pre-designed engineering lesson, challenging fourth graders to design a filter for removing plastic pollution from a waterway. We examined PST outcomes over both iterations, looking at PSTs' perceptions of their engineering-related knowledge and engineering-related beliefs following lesson preparation and implementation with elementary students. We were interested in identifying both commonalities and differences in PST outcomes across the two iterations to understand how the project design might shape PST experiences. Specifically, we explored:

> *When teaching an engineering lesson to elementary students as part of their first education course, what did PSTs notice related to:*

1. *Knowledge of engineering and engineering practices?*
2. *Knowledge of engineering pedagogy?*
3. *Beliefs about the importance of engineering in elementary education?*
4. *Self-efficacy for teaching engineering?*
5. *Intention to integrate engineering into their future instruction?*

These research questions aim to identify effective strategies for elementary teacher educators to enhance PSTs' engineering-related knowledge and beliefs. This study is unique in that it engages PSTs enrolled in their *first education course*, prior to any methods coursework, in teaching engineering lessons to upper elementary students. Engineering, as a multidisciplinary hub within STEM, offers a valuable context for PSTs to develop not only knowledge about engineering but also conceptual understanding across science, mathematics, and technology. Research emphasizes the importance of multiple opportunities for PSTs to practice teaching novel content and pedagogical approaches (Grossman et al., 2000; Munter & Correnti, 2017), particularly in subjects, such as engineering and computer science, where PSTs often have limited or no prior exposure. Cunningham and Carlsen (2014) suggest it can take three to 6 years before in-service teachers are comfortable leading engineering lessons. By introducing engineering instruction before a science methods course, this study examines a novel entry point for building PSTs' confidence and capacity to teach engineering.

Moreover, this study compares two distinct instructional models, helping to isolate features of the experience that most meaningfully support PST learning. The models vary in key design elements, including whether PSTs work in single-disciplinary vs. cross-disciplinary teams and whether they design their own engineering lessons or implement pre-developed ones. In their recent meta-synthesis on science and engineering teaching self-efficacy, Menon et al. (2024) highlight the need for studies that offer detailed contextual reporting to better understand how teaching self-efficacy is developed. Few studies have examined the effects of having PSTs teach engineering lessons to elementary students, and to our knowledge, none have compared different instructional models or directly explored how such early experiences shape PSTs' intentions to integrate engineering into their future instruction. By addressing these gaps, this study contributes vital evidence to guide the design of effective engineering experiences in teacher preparation.

Conceptual framework

Our conceptual framework, modeled in Fig. 1, visualizes the essential components used to assess elementary PSTs' readiness to teach engineering. It includes two core constructs: **engineering-related knowledge** and **engineering-related beliefs**. Engineering-related knowledge includes PSTs' *engineering content knowledge* and *engineering-pedagogical knowledge.* Engineering-related beliefs include their *beliefs about the importance of engineering in elementary education*, their *self-efficacy for*

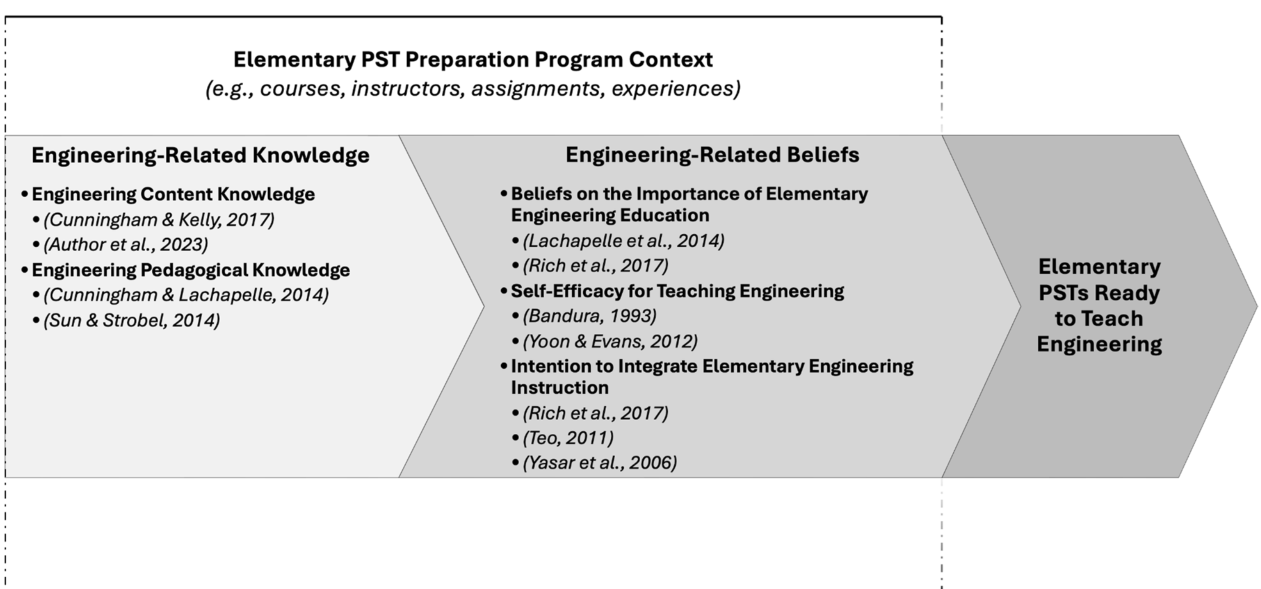

Fig. 1 Conceptual framework outlining the essential components for assessing PSTs' readiness to teach engineering in elementary classrooms

teaching engineering, and their *intention to integrate engineering into future instruction*.

While engineering-related knowledge is foundational, it is just one piece of the puzzle. Understanding PSTs' engineering-related beliefs—such as their confidence in their ability to teach engineering and their value for including it in elementary instruction—is equally critical. Together, these dynamic and interdependent constructs evolve over time as PSTs move through their preparation programs and into their future classrooms. Figure 1 illustrates this developmental arc. Prior to entering the teacher preparation program, PSTs possess varying degrees of engineering knowledge and related beliefs, represented by the dotted line on the left. Their experiences teaching engineering to elementary students during coursework deepen both their knowledge and beliefs. These constructs continue to evolve throughout their preparation and into their professional practice, as depicted by the dotted line on the right side of the figure.

Engineering-related knowledge

Engineering has emerged as a new and essential content area for elementary teachers (Banilower et al., 2018; Pleasants, 2023). However, a persistent question in engineering education is: *what exactly constitutes engineering content knowledge?*

Engineering content knowledge

Consistent with our prior work, we define **engineering content knowledge** as encompassing both knowledge of engineering practices and a general understanding of engineering as a profession and discipline (Pazos et al., 2023a). This includes knowledge of how engineers design solutions to problems (i.e., the engineering design process) and the epistemic practices common across engineering fields, as described by Cunningham and Kelly (2017). It also includes awareness of what engineers do, how they work, and their role in society.

While some definitions of content knowledge limit this construct to disciplinary core ideas, we intentionally adopt a broader definition aligned with the goals and design of our instructional intervention. Our survey instrument, for example, includes items addressing both practical engagement with engineering design and conceptual understanding of the field (e.g., "I am familiar with what engineers do as part of their jobs") in the Knowledge of Engineering Practices (KEP) subscale. We acknowledge that this broader framing diverges from the *Framework for P12 Engineering Learning* (ASEE, 2020), which treats "engineering practices" and "engineering knowledge" as distinct constructs. Our definition intentionally integrates these elements under the umbrella of "content knowledge" to reflect the overlapping ways engineering is experienced and conceptualized in *K*-12 teaching and learning contexts, particularly at the elementary level. As a foundational element of our framework, engineering content knowledge is essential for understanding how PSTs begin to develop confidence and competence to engage students in engineering practices and conversations.

We draw heavily on Cunningham and Kelly's (2017) framework of epistemic practices of engineering, which outlines both general processes and context-specific actions engineers use to solve problems (see Table 1). Cunningham and Kelly (2017) identified four categories of epistemic practices, including: "engineering in social contexts, uses of data and evidence to make decisions, tools and strategies for problem-solving, and finding solutions through creativity and innovation" (p. 491). They further identify 16 specific engineering practices but caution against placing any one practice into any one of the four categories, because "the practices themselves and the categories of practices overlap and are not mutually exclusive" (p. 497). We selected this framework, because it emphasizes what engineers *do* across contexts and identifies many more specific actions than the four practices enumerated in the *Framework for P12 Engineering Learning* (ASEE, 2020), making it particularly useful for determining what elementary PSTs noticed about facilitating engineering learning experiences. However, we pair this with a more general understanding of the field, including basic awareness of engineers' societal roles and examples of engineering applications in the world around them.

Table 1 Epistemic practices of engineers (Cunningham & Kelly 2017)

Epistemic practices of engineers
1. Developing processes to solve problems
2. Considering problems in context
3. Envisioning multiple solutions
4. Innovating processes, methods, and designs
5. Making trade-offs between criteria and constraints
6. Using systems thinking
7. Applying math knowledge to problem-solving
8. Applying science knowledge to problem-solving
9. Investigating properties and uses of materials
10. Constructing models and prototypes
11. Making evidence-based decisions
12. Persisting and learning from failure
13. Assessing implications of solutions
14. Working effectively in teams
15. Communicating effectively
16. Seeing themselves as engineers

Engineering-pedagogical knowledge

Preparing educators to incorporate engineering into their teaching requires cultivating an understanding of the design process and these engineering practices, developing pertinent pedagogical understanding, and integrating content and pedagogical knowledge, commonly called pedagogical content knowledge (Brophy et al., 2008; Shulman, 1986). Pedagogical content knowledge entails the fusion of a teacher's cognitive grasp of the subject matter with the know-how to teach the subject matter effectively (Shulman, 1986). Engineering-pedagogical content knowledge thus encompasses familiarity with pedagogical strategies to facilitate students' involvement in the engineering design process and practices, including methods, such as eliciting brainstorming during solution development, encouraging multiple solutions and pathways, embracing failure as part of the design process, and focusing student attention on design requirements and constraints (Lachapelle & Cunningham, 2014). It also involves understanding how to connect engineering to students' interests and prior knowledge. In addition, Sun and Strobel (2014) assert that educators must consider both the learners and the context (i.e., classroom and school) in conjunction with engineering instruction to fully develop engineering-pedagogical knowledge. Thus, providing PSTs with opportunities for engineering teaching experiences in a real classroom context with actual learners is vital to cultivating engineering-pedagogical knowledge (Sun & Strobel, 2014).

As elementary students engage in the engineering design process and practices, the teacher's role is to encourage students to develop ideas, assist them in negotiating team dynamics, and help them to see failure as an opportunity to improve, all of which require that teachers are responsive to what students are noticing and wrestling with (Watkins et al., 2018; Wendell et al., 2019). To make this a reality, teachers must elicit their students' resources, or questions, ideas, beliefs, and lived experiences (Richards & Robertson, 2015). This focus on student resources is critical in engineering, where students must engage in the engineering practice of weighing the tradeoffs of their different ideas and deciding how to progress through a design challenge (Dalvi & Wendell, 2017). When teachers support students to use their prior knowledge and unique ideas, students are more likely to engineer solutions independently (Preminger et al., 2024). Thus, students must feel empowered to develop and evaluate their own solutions to a problem for which no single 'correct' answer exists (Dalvi & Wendell, 2017). In line with the research on responsive teaching, we believe that it is important that PSTs gain discipline-specific (i.e., engineering) pedagogical content knowledge, because the ways that teachers respond to students' thinking differ from discipline to discipline (e.g., supporting students to develop a novel design in engineering rather than make sense of a natural phenomenon in science) (Coffey & Edwards, 2015; Watkins et al., 2021).

Engineering-related beliefs

Due to the inclusion of engineering in the NGSS (2013) and many state standards (e.g., VSOL for Science, 2018) as well as the release of the Standards for Technological and Engineering Literacy (ITEEA, 2020), teacher education programs are increasingly responsible for fostering positive beliefs to help PSTs embrace engineering and its practices (Kazempour & Sadler, 2015). Beliefs reflect an individual's perception of their capacity to complete tasks and apply skills, as well as the values and outcome expectations one has for those tasks and skills (Bandura, 1997). In other words, beliefs are the lens people use to inform their behaviors. Beliefs are especially important for elementary teachers because of their effect on teachers' choices in the classroom, in other words, how they enact lessons. For this study, we explore three beliefs related to teaching engineering: (1) beliefs about the importance of engineering in elementary education; (2) self-efficacy for teaching engineering in elementary education; and (3) intention to integrate engineering into future instruction.

PSTs' beliefs about the importance of engineering in elementary education

PST beliefs about the importance of engineering in elementary education capture perspectives about the benefits of integrating engineering in elementary classrooms. We characterize this belief as PSTs' perception of the overarching value of incorporating engineering into elementary instruction, rather than their own instruction specifically. We draw on the work of Lachapelle et al. (2014), who outline eight benefits of early exposure to engineering. Some of these include elementary students' capability to develop skills and engineering understanding at an early age, inclination to tinker and to problem-solve, development of technological literacy, science and math achievement, and increased engagement. Assessing PSTs' beliefs about the importance of engineering education for elementary children provides a measure of what the PST values for their elementary student experience. In an instrument designed by Rich et al. (2017) teachers' engineering belief statements were expanded to include items that assessed how educators value engineering in their classroom, including items about the importance of student understanding of the engineering design process, and the value placed on providing their students with engineering design problems reflecting those in the "real world."

PSTs' self-efficacy for teaching engineering in an elementary classroom

Self-efficacy can be described as a person's belief about their abilities to perform a specific task (Bandura, 1993). In the field of education, teacher self-efficacy is used to describe a teacher's belief that they can complete a particular teaching task (Tschannen-Moran et al., 1998). Bandura (1993) described four sources that influence teacher self-efficacy: (1) mastery experiences (e.g., a successful teaching experience); (2) vicarious experiences (e.g., witnessing another's successful teaching experience); (3) social persuasion (e.g., encouragement from others about one's teaching capabilities); and (4) affect (e.g., a relaxed and joyful physiological state signaling confidence in one's capabilities). Mastery experiences are regarded as the most potent source of self-efficacy (Bandura, 1997), so an authentic teaching experience has the potential to profoundly influence a PST's assessment of their teaching capabilities. Teacher self-efficacy has garnered interest among educational researchers given its connection to other positive outcomes (Zee & Koomen, 2016). For example, teachers with a strong sense of efficacy tend to be more receptive to new ideas and innovative teaching methods (Nie et al., 2013; Tschannen-Moran & McMaster, 2009; Tschannen-Moran et al., 1998), suggesting that teachers with higher self-efficacy might be more receptive to teaching engineering. This study focuses on PST *self-efficacy for teaching engineering;* in other words, whether elementary PSTs believe they can successfully incorporate engineering-based instruction into their future teaching (Yoon et al., 2012). This specific focus on engineering is important, because teaching self-efficacy is tied to the discipline teachers are being asked to teach (Tschannen-Moran et al., 1998). In other words, teachers' feelings of efficacy depend on the particular context of their teaching. While teachers with high general teaching self-efficacy may be more open to trying to teach engineering, this measure would not indicate the teacher's confidence in teaching engineering. We assess self-efficacy for teaching engineering to understand how confident PSTs are in their ability to engage elementary students in engineering activities and how PSTs' participation in engineering instruction can influence their confidence.

PSTs' intention to integrate engineering into their future instruction

Borrowing from related work on teachers' intention to use technology (Teo, 2011), the third assessed belief is PSTs' intention to integrate engineering into their future instruction. To bring engineering into elementary classrooms, future teachers must see themselves teaching engineering. It is not sufficient for PSTs to believe that engineering should be included in elementary instruction and to believe they can teach engineering; they must be committed to teaching engineering in their future classroom. However, research surrounding elementary PSTs' intention to integrate engineering is limited. In this study, we drew on work by Yaşar et al. (2006), who developed an instrument to assess *K*-12 teachers' perceptions of design, engineering, and technology (DET) instruction. These authors explored responses to statements regarding *K*-12 teachers' interest in learning more about engineering, motivations for teaching engineering, familiarity with engineering knowledge, and barriers to teaching engineering. While not explicit in their intention to integrate engineering into their future instruction, this instrument helped frame items within our quantitative and qualitative instruments that addressed reasons for PSTs' willingness and intention to integrate engineering into their future classrooms. The statements in Rich et al.'s (2017) instrument to assess "engineering beliefs" overlap with the construct of engineering integration in PSTs' future classrooms. The authors were interested in learning more about teachers' willingness to invest additional planning time to develop engineering lessons. Taken together, the work by Yasar et al. (2006) and Rich et al. (2017), and the history of assessing behavioral intention as a means to predict actual use (e.g., the theory of planned behavior (Ajzen, 1991) help to provide a theoretical foundation to help frame PSTs' intention to integrate engineering into their future instruction.

Understanding teachers' knowledge and beliefs about elementary engineering and their ability to teach engineering is vital for understanding how we should prepare PSTs to implement engineering instruction in their future classrooms. If teacher educators can design instruction that increases engineering-related knowledge and positively influences PSTs' beliefs about the importance of having elementary students engage in engineering and their perceived effectiveness for doing so, they may be able to enhance the PSTs' willingness to engage students in engineering in the future.

Literature review

The literature review describes the current state of engineering education in elementary PST preparation programs and what is known about supporting PSTs' preparation for teaching elementary-level engineering. This section also explores the research gaps related to engineering-related knowledge (i.e., engineering content knowledge and engineering-pedagogical knowledge) and engineering beliefs (i.e., beliefs about the importance of engineering in elementary education, self-efficacy to teach engineering, intention to integrate engineering).

Preparing PSTs to teach engineering

Despite the addition of engineering to national and state standards over 10 years ago, PSTs continue to report a lack of prior exposure to engineering (Kidd et al., 2023; Kim et al., 2019; Lux et al., 2022; Mumba et al., 2024; Smetana & Nelson, 2023). In a study of US teacher preparation programs (Rose et al., 2017), less than one-third offered their students experiences intended to prepare them to teach engineering at the elementary level, and none of the elementary programs offered a course focused on engineering content. It is unsurprising, then, that only 3% of elementary teachers felt well-prepared to teach engineering (Banilower et al., 2018). With the infusion of engineering knowledge and practices within state and national standards (e.g., NGSS, VDOE SOLs for Science, ITEEA, etc.), teachers must be better prepared to engage their students in engineering (Lux et al., 2022). Teacher educators face an uphill challenge, however, as science methods courses tend to focus on teaching pedagogical strategies with less emphasis on developing related content knowledge (Litowitz, 2014; van Driel et al., 1998). This presents a problem, since PSTs are unlikely to begin their preparation programs with sufficient engineering content knowledge. In addition, pedagogical content knowledge has been identified as a focal point in engineering education research (Martin & Ritz, 2014; Pazos et al., 2023a), because related studies indicate a significant link between educators' preparation experiences and their pedagogical content knowledge (Love & Hughes, 2022). Research suggests teacher preparation programs should infuse engineering content with practical engineering-pedagogical strategies within their programs to have the most significant influence on the quality and frequency of engineering lessons in classrooms (Love & Hughes, 2022; Love & Wells, 2018; Love et al., 2017). In response, teacher preparation programs nationwide have begun to move toward a more systematic approach to engineering education.

To date, many programs have chosen to infuse engineering education in science methods courses (typically an upper-level course) (e.g., Capobianco & Radloff, 2021; Hammack et al., 2024; Kaya et al., 2017; Perkins Coppola, 2019; Smetana & Nelson, 2023; Yesilyurt et al., 2021) and most studies of engineering instruction in elementary preservice teacher preparation have focused on these interventions. Meanwhile, fewer studies (e.g., Antink-Meyer & Parker, 2021; DiFrancesca et al., 2014; Gutierrez et al., 2023; Ozkizilcik & Cebesoy, 2023) have examined engineering instruction in other contexts or a programmatic approach. The programmatic approaches include the provision of opportunities for PSTs to experience engineering through both formal (e.g., additional required STEM content courses, specific content and methods courses, student teaching internships, and classroom experiences) (Hammack & Vo, 2022) and informal (e.g., mentoring opportunities, professional conferences, and professional development) experiences (Love & Wells, 2018; Yoon et al., 2018). These experiential teaching and learning environments can help PSTs transform knowledge about engineering into knowledge about teaching engineering. Based on their research with elementary teachers who engaged in elementary engineering professional development, Sun and Strobel (2014) argue that opportunities for teachers to engage in engineering teaching in school settings are "essential for elementary teachers' construction of engineering-pedagogical content knowledge" (p. 56). Learning about engineering teaching in professional development, without actually teaching it, was not enough.

Engineering "as students" and "with students": two contexts to support PST learning

Cunningham and Carlsen (2014) assert that for teachers to understand engineering, they need to engineer. Likewise, Hammack and Vo (2022) found that reading and discussing engineering concepts and pedagogy were inadequate to support elementary PSTs in conceptualizing teaching engineering and suggested that engaging them in engineering may be vital. One strategy to engage PSTs with engineering practices is to have them complete well-designed engineering design challenges *as students*, preferably at the grade level they intend to teach (Cunningham & Kelly, 2017). Engaging as students helps the PSTs gain familiarity with engineering practices, such as collaborating with peers, persevering through failure, and experiencing the iterative nature of the EDP. Lin et al. (2021) further support this approach, showing that participating in engineering design challenges can strengthen PSTs' design thinking and problem-solving abilities and prepare them to create instruction that engages *K*-12 students in solving authentic, real-world problems.

Such engagement can enhance engineering content knowledge, and this content mastery can contribute to teaching self-efficacy (Palmer, 2006). For example, Kaya et al. (2019) observed an increase in PSTs' engineering teaching self-efficacy beliefs after having them engage in an engineering design challenge during elementary science teaching methods courses. This suggests that engaging PSTs as students in engineering lessons supports their knowledge of engineering practices and enhances their self-efficacy in teaching engineering. Several researchers (e.g., Hammack et al., 2024; Nesmith & Cooper, 2021; Smetana & Nelson, 2023) have reported positive effects on PSTs' beliefs about engineering and engineering teaching in the elementary classroom after engaging in engineering activities during a science method course, suggesting PSTs' beliefs are malleable. These authors also described connections between PSTs' beliefs about engineering and their self-efficacy.

Engaging in engineering design challenges as students can also help PSTs develop pedagogical content knowledge. When PSTs engage in engineering lessons as students, they can pretend to have the knowledge and understanding of a student they plan to teach, and, as such, gain insight into what could be new for their students and identify places, where their students might need support (Cunningham & Kelly, 2017). Some scholars describe this as the moment teachers put on their "student hat" (Lowell, 2024). Often, after initially being positioned as students, teachers are asked to put on their "teacher hat" and reflect on the content and pedagogy that was a part of the lesson (Klein & Riordan, 2011). This reflection helps PSTs identify instructional moves that facilitate student learning and consider what instructional supports they may need to guide students through the lesson.

Another strategy to engage PSTs with engineering practices is to have them teach engineering design challenges to students. When PSTs engage in engineering lessons *with students*, they are positioned as the teacher working with students to complete the lesson. Asking PSTs to engage elementary students in engineering challenges and use engineering practices may initially make them uncomfortable (Gutierrez et al., 2023), but risk-taking in the controlled environment of their teacher preparation program can help PSTs develop positive beliefs about teaching engineering with their future students (Nilsson & Loughran, 2012) while developing critical pedagogical content knowledge (Sun & Strobel, 2014). Moreover, numerous studies (e.g., Cima et al., 2021; Fogg-Rogers et al., 2017; Gutierrez et al., 2022; Kaya et al., 2019; Lewis et al., 2021; Perkins Coppola, 2019) have demonstrated that the development and implementation of design-based engineering lessons as a part of a teaching experience enhance PSTs' engineering-related knowledge and engineering-related beliefs. However, what aspects of the teaching experience best support their learning is unknown.

One structural aspect that has received some attention is team composition, or partnering PSTs with others. During engineering teaching opportunities, PSTs are often placed in teams to teach the lesson alongside fellow PSTs. Team teaching allows PSTs to engage in professional dialog with their partners, which enriches their experience by providing additional resources from which they can pull (Buckley, 1999). Teaching teams do not always consist exclusively of PSTs; research has also investigated team teaching between engineering students and teachers (both preservice and in-service) and demonstrated positive outcomes for both parties (Bers & Portsmore, 2005; Cima et al., 2021; Fogg-Rodgers et al., 2017; Gutierrez et al., 2022), including increased self-efficacy among PSTs for teaching engineering (Kidd et al., 2023; Lewis et al., 2021; Pazos et al., 2023b).

What we still need to learn to best prepare elementary PSTs to teach engineering

Research indicates that engaging PSTs in experiences that include engineering content—such as professional development or coursework—is associated with enhanced engineering-related knowledge and beliefs. Opportunities that go further by involving PSTs in actually teaching engineering to students appear especially impactful, as they provide authentic mastery experiences that build instructional confidence. Emerging studies support this, showing increases in elementary PSTs' engineering-related beliefs and self-efficacy following such experiences (Kidd et al., 2023, 2025; Pazos et al., 2023b; Perkins Coppola, 2019). These findings highlight the powerful role of teaching engineering in shaping PSTs' developing instructional identities and confidence (Webb & LoFaro, 2020) while also addressing key gaps in our understanding of how PSTs become ready to teach engineering. There is some evidence that PSTs' beliefs about engineering, along with their teaching self-efficacy, are key predictors of their intention to integrate engineering into future instruction. Research has found that teachers' beliefs about the importance of engineering in elementary education mediated their intention to teach it (Christian et al., 2021; Pazos et al., 2023b). Similarly, PSTs who participated in experiences that enhanced their self-efficacy for teaching engineering expressed significantly greater intention to integrate it than those who did not (Kidd et al., 2023; Pazos et al., 2023b).

Yet, important questions remain about which specific features of an engineering teaching experience—such as the lesson audience, team composition, placement within the teacher preparation program, or degree of involvement in lesson development—most effectively support PSTs' developing knowledge and beliefs. Further research is needed to understand how these instructional conditions shape PSTs' perceived competence, confidence, and intention to integrate engineering into elementary teaching.

Methods

Data for this study was collected as part of the NSF-funded project, *Ed + engineering: An Interdisciplinary Partnership Integrating Engineering into Elementary Teacher Preparation Programs*, a partnership between education and engineering faculty and students aimed at improving the capacity and intention of PSTs to incorporate engineering into their teaching practices and developing and accessing a model for integrating engineering into the academic preparation of PSTs. The model consisted of three interventions integrated into required teacher preparation courses, where preservice teachers collaborated with engineering students to teach engineering lessons to elementary school students. This study focuses on the first intervention which occurred in *Foundations and Assessment of Education*, the first course taken by students in the elementary education program. The course provides a broad introduction to the American educational system, the sociological forces that shape it, and assessment practices standard in preK-12 schools. At this point in their program, the preservice teachers are typically sophomores and have taken some, but not all, of their general education courses. We wanted to gain insights into PSTs' initial knowledge and noticings before they engaged with coursework related to teaching science and engineering to determine whether exposure to these topics could be beneficial, shaping their thinking and potentially priming them for subsequent courses focused on pedagogy. We chose to explore iterations in spring 2022 and fall 2022, because critical changes were made to the engineering project between the two semesters based on formative feedback and ongoing research within the project. Furthermore, the semesters were taught in the same year by the same professor and provided a realistic example of variation between semesters of teaching the same course with the same focus, goals, and large project assignments. In the following sections, we describe the project in general and then detail the differences between the two iterations.

Project overview

The project included multiple phases (see Table 2) to build PSTs' familiarity with engineering and prepare them to teach an engineering lesson to elementary students. PSTs were first introduced to engineering and the justifications for teaching engineering in elementary school. The preservice teachers were grouped by schedule congruency, GPA, and heterogeneity in race/ethnicity and gender. These teams then formed a charter to establish team norms. Next, since the engineering design challenge was novel for all participating undergraduates, the teams moved together through the challenge they would teach. This allowed them to experience the engineering design process and practices as students and anticipate the difficulties the fourth graders might experience. Next, the teams planned the specifics of their lessons, including developing content (e.g., goals, a quiz), teaching strategies (e.g., activities to learn their students' names), and making logistical decisions, such as dividing the teaching responsibilities among their team members. Finally, teams practiced their lessons with peers and instructors role-playing the part of fourth graders. The rehearsals simulated a classroom experience without the high stakes of a roomful of students, creating the opportunity for verbal and written feedback. Teams then finalized plans for their lesson delivery and subsequently taught their lessons to fourth-grade students. The project assignments were designed to help PSTs feel capable of executing the lesson successfully in front of students and build confidence to participate in what was, for many, their first teaching experience.

Differences between iterations

In spring 2022, the project utilized cross-disciplinary teams consisting of two elementary PSTs and two to three first-year engineering students that led fourth graders through carnival-themed engineering design challenges. The carnival theme was selected, because pandemic restrictions were still in place, and the lessons would be taught outdoors. Teams had the option to choose from three engineering design challenges, each simulating a carnival attraction: a claw, a paddle-powered boat, or a kicking machine (see Fig. 2). The instructors drew from existing instructional materials to create one-page teaching guides for each challenge, including suggested supplies, vocabulary, and teaching tips. To develop their engineering skills, the engineering students on each team designed and constructed a "testing station" for their team's chosen carnival-themed challenge. The testing stations were intended to add a carnival-like experience to the lessons, wherein the means through which the elementary students tested their designs simulated a game commonly found at a carnival. The teams piloted their testing station while engaging in their design challenge "as students". Afterward, the teams collaboratively drafted a detailed lesson plan, including probing questions to guide a group of fourth graders through their chosen engineering challenge. After incorporating rehearsal feedback and making final revisions to their lesson plans and testing stations, the cross-disciplinary teams delivered their 75-min carnival-themed lessons at two participating schools.

In fall 2022, the project team designed and implemented a variation of the model, where PSTs worked with their classmates to deliver a predesigned lesson to the elementary students. The decision to form teams exclusively of elementary PSTs was made to prevent the PSTs from deferring teaching responsibilities to the engineering students and to assess the viability of the PST-only teaching model. The project team observed that many PSTs tended to play supportive, rather than lead roles when teaching with engineering students and

Table 2 Project description

Spring 2022	Fall 2022
Lesson focus/engineering design challenge	
"Carnival Games" Teams chose from one of the three carnival game-focused engineering design challenges: a claw, kicking machine, or paddle boat	"Filters" After learning about the problem of pollution in Mobile Bay and the concerns of stakeholders, students designed a filter to catch plastic pollutants
Preservice teacher demographics	
Race/ethnicity: ● Black: 13% ● White: 62% ● Other: 25% Gender: ● Female: 94% ● Male: 6% ● Other: 0%	Race/ethnicity: ● Black: 44.5% ● White: 44.5% ● Other: 11% Gender: ● Female: 100% ● Male: 0% ● Other: 0%
Teams/teamwork	
2 education students + 2 first-year engineering students = 14 teams total	3 education students (no first-year engineering students) = 6 teams total
Each team produced a charter to establish roles and norms	
Practice with the EDP ("as students")	
Teams completed an unrelated challenge and their selected carnival challenge	Teams designed plastic filters
Engineering students designed (with PST feedback) a testing station to simulate a carnival game	
Preparation for teaching	
Teams (education and engineering students) developed a detailed lesson plan with probing questions to guide the students through their selected design challenge	Teams (education students only) added details (e.g., class rules, review quiz) to an instructor-developed slideshow
Dress rehearsal: teams practiced and received feedback on their lesson with peers and faculty role-playing 4th graders	
Teams revised their lesson plans and testing stations based on peer and instructor feedback	Teams revised their approach for teaching the premade filter lesson based on peer and instructor feedback
Teaching context	
Teams taught their lessons to a group of approximately 10 fourth graders	
Carnival-themed lessons (~ 75 min) were taught outside two elementary school using testing stations developed by the engineering students	Filter lessons (~ 105 min) were taught inside university classrooms utilizing an instructor-created slideshow

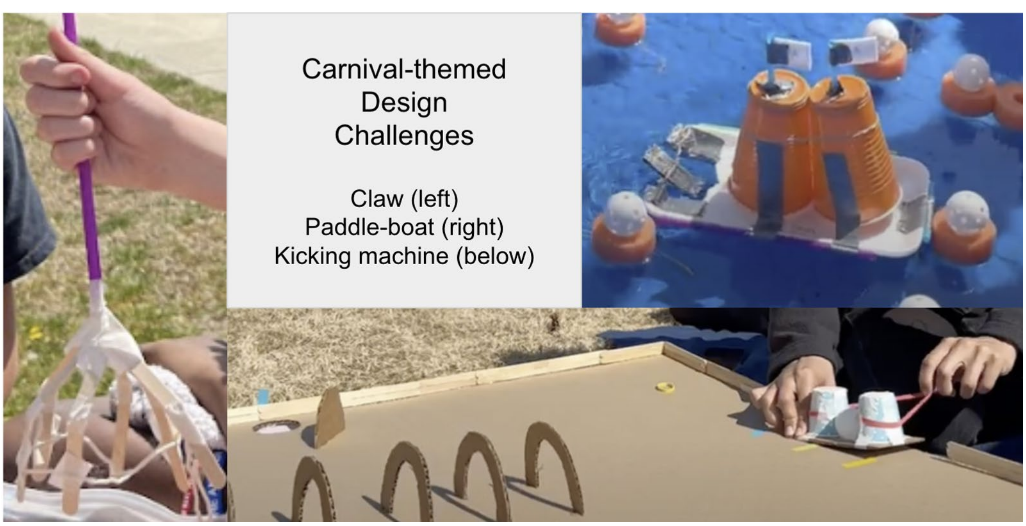

Fig. 2 Prototype testing during the carnival lessons. The figure illustrates students evaluating their prototypes for a claw (left), paddle boat (top right), and kicking machine (below) using testing stations designed by engineering students in Spring 2022

were concerned that this tendency was hampering the development of the PSTs' skills and confidence. Based on work done in science education (e.g., Beyer & Davis, 2009; Forbes, 2011), PSTs were given a predesigned lesson, because it was assumed that PSTs unfamiliar with engineering and teaching, and working without engineering student collaborators, would be more receptive to teaching a predesigned engineering lesson rather than trying to develop their own lesson. The fall lesson was adapted from a Youth Engineering Solutions (YES) unit, where "students consider the effects of plastics on the marine ecosystem and community as they engineer filters to reduce plastic waste entering the ocean" (YES, 2023). It was selected because of its close alignment with the fourth-grade Virginia Standards of Learning for Science (Virginia Department of Education, 2018). The YES unit was adapted to have students design, build, and test a filter to catch plastic pollutants as they exited a model river and flowed into a model bay (see Fig. 3) within a 105-min time frame. The instructor created the lesson slideshow, including all the instructional elements to guide the fourth graders through the engineering design process and practices. The PSTs had to make logistical decisions, such as establishing team member roles, determining who would present which slides, and deciding when and how materials would be distributed. Accordingly, the PSTs' lesson preparation activities focused mainly on how they would distribute the work of teaching the lesson rather than on developing the content they would teach. After making final adjustments based on feedback from the rehearsal, the PST teams taught the filter lesson to fourth graders visiting the university campus.

To summarize the differences between the two iterations, there were three critical distinctions: team composition, lesson focus, and lesson preparation. Regarding team composition, the carnival lesson PSTs collaborated with engineering students, while the filter lesson PSTs worked only with their education student classmates. Related to lesson focus, the carnival lesson teams had the option to choose one of the three carnival-themed design challenges on which to base their lesson. In contrast, the filter PSTs' lesson focused on plastic pollution and the design of a filter to trap pollutants before entering a waterway. Regarding lesson preparation, the carnival lesson PSTs designed their lessons alongside engineering students, while the filter lesson PSTs utilized professionally developed instructional materials curated in a slideshow prepared by their instructor.

Data sources and analysis

This mixed-methods study uses quantitative and qualitative approaches to analyze data from two iterations of an engineering project to examine PSTs' perceptions of their engineering-related knowledge and engineering-related beliefs. More specifically, we examined PSTs' knowledge of engineering and knowledge of engineering pedagogy, PST beliefs about the importance of including engineering in elementary instruction, PST self-efficacy

Fig. 3 PSTs and fourth-graders engaging in the filter lesson. The figure illustrates events from the filter lessons in Fall 2022: a 4th grader pours a cup of plastic pollutants down the model river and into the model bay to test the effectiveness of his filter (left); a PST explains the role of engineers in society (right)

for teaching engineering, and PST intention to integrate engineering into their future instruction. We used a concurrent mixed methods design (Creswell & Creswell, 2018) to gain both quantitative and qualitative perspectives on the influences of the intervention on the PSTs and provide a comprehensive view of their experiences. The study participants were elementary preservice teachers in their first education course at a public university in the mid-Atlantic region. The study was approved by the Institutional Review Board (IRB) of the hosting institution, and media permissions were obtained for all those pictured, including the participating PSTs and the elementary students who attended the lessons. All undergraduates (education and engineering) who enrolled in the course sections participating in this study were part of the project, but the PSTs are the focus of this study, and only the data for those who consented were included in the analysis.

We used quantitative surveys and open-ended reflections to understand the participating PSTs' knowledge and beliefs. Two quantitative online surveys were administered at the beginning and end of each course. Three subscales from the *Engineering Integration Pedagogical Content Knowledge* survey, assessed PSTs' perceptions of their pedagogical content knowledge (PCK) (7 items, $\alpha=0.86$), engineering-pedagogical content knowledge (EPCK) (7 items, $\alpha=0.95$), and knowledge of engineering practices (KEP) (9 items, $\alpha=0.92$). Building on the technology integration framework TPACK, this instrument was developed through an iterative process that involved item development, item revision, expert validation, and two rounds of factor analysis and reliability analysis using data collected from a sample of 450 PSTs from a minority-serving university (Pazos et al., 2023a). The factor structure and internal consistency of the instrument's subscales were supported. The scale items use a five-point Likert scale (1 = strongly disagree, 5 = strongly agree). A second survey, the *Engineering Beliefs Survey*, was used to assess PSTs' beliefs about the importance of integrating engineering into elementary instruction (BEI) (5 items, $\alpha=0.93$), self-efficacy for engineering integration (SEI) (6 items, $\alpha=0.88$), and intention to integrate engineering (ITI) (5 items, $\alpha=0.95$) into their future instruction, also using a five-point Likert scale (1 = strongly disagree, 5 = strongly agree). The *Engineering Beliefs Survey* is a researcher-developed and pilot-tested measure (Pazos et al., 2023b) that uses items adapted from existing instruments assessing elementary teachers' attitudes toward elementary engineering (Lachapelle et al., 2014; Rich et al., 2017; Yaşar et al., 2006) and teaching engineering self-efficacy (Rich et al., 2017; Yoon et al., 2014). The scale development followed a similar approach to the previous instrument, with engineering education and pre-college education faculty involved in constructing and refining items, combined with factorability and reliability evaluations. Preliminary results provided evidence of internal consistency of the subscales.

Two inferential statistical analyses were conducted, the first looking at changes over time within each of the two iterations and the second comparing the two groups of PSTs across all measures. The first analysis addresses whether changes were observed in the variables of interest within each iteration. A Wilcoxon signed-rank test was used for each measure to determine whether the means of the pre-test and post-test scores were statistically different for each group of PSTs. The Wilcoxon signed-rank test is a non-parametric alternative to the paired samples *t* test. It compares two data groups from the same sample when the assumptions of parametric tests are unmet. Differences were determined based on a significance level of <0.05. The second analysis utilized Kruskal–Wallis to look for differences between the fall and spring iterations across each measure. No repeated students were represented in the data in the fall and spring iterations. The Kruskal–Wallis test is a non-parametric alternative to one-way ANOVA. It tests differences between iterations by rank when the ANOVA assumptions are unmet.

PSTs in both iterations were assigned to complete an open-ended reflection at the project culmination. This 42-item assigned questionnaire asked PSTs to reflect on their experience with the course, the project, teammates, and teaching. A sample question related to PSTs' engineering content knowledge was, "What did you learn about engineering?" In the same vein, the questionnaire assessed PSTs' engineering-pedagogical knowledge through questions, such as "What did you learn about teaching engineering?" and "What design decisions did the elementary students have to make (e.g., what material to use, etc.)? How did you help them make these decisions?" PSTs' beliefs regarding engineering integration and self-efficacy were analyzed through questions, such as "Should engineering be included in Pre-*K*-6 instruction? How so? Why?" and "Do you see yourself teaching engineering lessons to students in the future? Why or why not?" Overall, when PSTs completed the questionnaire, they reflected on their teaching and "noticed" aspects of their practice. We define PSTs' noticing in line with others in the field (e.g., Estapa & Tank, 2017; Jacobs et al., 2010) who describe it as how teachers attend to, interpret, and decide how to respond to students' actions and thinking.

Six authors participated in the coding process, which began by defining and identifying examples of the a priori themes: engineering content knowledge, engineering-pedagogical knowledge, beliefs about engineering education, self-efficacy, and intention to integrate (Strauss, 1987). Working in pairs, the coders used these categories to code all the PST reflections, highlighting responses that touched on any category. The first and second authors then used a constructivist grounded approach (Charmaz, 2017) to complete a thematic analysis of the identified responses to determine what PSTs noticed regarding their engineering-related knowledge and beliefs after engaging in the project. All noticings were then discussed by the first and second authors and collaboratively grouped into themes. Exemplary quotes that best articulated the most common themes were then chosen by the first and second authors and confirmed by the third author. We unpack these PST noticings in our presentation of the findings alongside our own observations of PSTs' knowledge and beliefs within their reflections.

Findings

Our examination of two iterations of an engineering education intervention revealed trends in PSTs' knowledge about engineering, knowledge about teaching engineering, beliefs about the importance of including engineering in elementary instruction, self-efficacy for teaching engineering, and intention to integrate engineering into their future instruction. We discuss each outcome variable first by describing the quantitative findings and then by presenting overall trends in the qualitative data described as PST noticings.

Engineering-related knowledge

Engineering content knowledge

Beginning with the quantitative data, PSTs' perceptions of their knowledge of engineering practices (KEP) showed statistically significant growth in both iterations after participating in the project, with each PST gaining an average of 1.3 points on a five-point scale (see Table 3). At the start of each semester, PSTs reported feeling neutral about their knowledge of engineering, while at the end of the semesters, PSTs were more likely to agree or strongly agree that they possessed basic knowledge about engineering (e.g., *I am familiar with some of the activities engineers engage in as part of their jobs.*). None of the PSTs reported a lower level of engineering content knowledge at the post-test. The Kruskal–Wallis test showed that the PSTs' assessment of their engineering content knowledge was not significantly different between the two iterations, $H(1) = 0.006$, $p = 0.936$.

PSTs noticed that engineering is everywhere. Qualitative data revealed that PSTs developed a broader view of engineering as something relevant to their daily lives. Carnival-lesson PSTs and filter-lesson PSTs emphasized this theme differently. Carnival-lesson PSTs, who were required to generate real-world examples to support their instruction, focused on the ubiquity of engineered products. One shared, "I now recognize how many things in my day-to-day life actually relate to engineering concepts." In contrast, filter-lesson PSTs highlighted how engineering-related thinking could support everyday problem-solving. As one noted, "[Engineering] is valuable because it teaches skills to students that they could use in their everyday lives." These reflections suggest that both types of teaching experiences helped PSTs recognize the relevance of engineering beyond the classroom.

PSTs noticed that engineering is a process. Another key takeaway for many PSTs was that engineering is a process—one that is iterative, involves multiple steps, and requires learning from failure. When PSTs described engineering in this way, they demonstrated understanding of the engineering practices of *developing processes to solve problems* and *innovating processes, methods, and designs*. As one carnival-lesson PST explained, "I learned the specifics of the engineering process and gained a better understanding of how engineers revise their creations over and over before arriving at a final product." PSTs also came to appreciate the engineering practice of *persisting*

Table 3 Wilcoxon signed-rank test results for PSTs' perceived knowledge

		Spring 2022 (carnival lesson)					Fall 2022 (filter lesson)				
		N			Wilcoxon test		*n*	Wilcoxon test			
			M	*SD*	*V*	*p*		*M*	*SD*	*V*	*p*
KEP	pre-test	16	3.15	1.11	0	0.00*	10	3.16	0.80	0	0.00*
	post-test		4.47	0.48				4.46	0.47		
PCK	pre-test	16	3.55	0.79	3	0.00*	10	3.70	0.43	2	0.02*
	post-test		4.42	0.55				4.40	0.59		
EPCK	pre-test	16	2.74	1.10	0	0.00*	10	2.30	0.93	0	0.00*
	post-test		4.46	0.60				4.42	0.55		

*p value < 0.05. KEP = knowledge of engineering practices; PCK = pedagogical content knowledge; EPCK = engineering-pedagogical content knowledge

and learning from failure. A filter-lesson PST emphasized that "a good engineer must…be willing to learn from failure," reflecting a deeper understanding of the mindset and habits of effective engineering.

Engineering-pedagogical knowledge

The quantitative data revealed gains in PSTs' perceptions of their pedagogical knowledge due to participating in the project. Both iterations showed a significant increase in pedagogical knowledge (PCK) and engineering-pedagogical knowledge (EPCK) (see Table 2) between the pre- and post-test values. Twenty-three of the 26 PSTs rated their knowledge higher at the post-test. Gains in pedagogical knowledge were more modest (0.80 points), while gains in engineering-pedagogical knowledge were more substantial (1.82 points). This suggests that PSTs believed they learned about teaching generally (e.g., *I know how to prompt students to ask questions*) but learned more about teaching engineering specifically (e.g., *I know how to prompt students to come up with solutions to an engineering design problem*). Mean post-test scores (~4.4) were similar between both pedagogy scales and across iterations, indicating that PSTs felt equally knowledgeable in general pedagogy and engineering pedagogy at the end of the semester, and the two groups of PSTs rated themselves similarly on both scales. There were no significant differences between the two iterations in the PSTs' pedagogical knowledge, $H(1)=0$, $p=1$, and engineering-pedagogical knowledge, $H(1)=0.006$, $p=0.935$.

The qualitative data likewise suggest PSTs gained pedagogical and engineering-pedagogical knowledge. Because PSTs' pedagogical noticings focused on their experiences teaching engineering, we grouped pedagogical knowledge and engineering-pedagogical knowledge in our presentation of the results. PSTs primarily noticed what students were doing and how they were responding to the lesson, and less often analyzed how their own instructional decisions or the lesson's structure promoted student learning and engagement. This was not surprising as PSTs had no prior instruction in pedagogy, and pedagogy was not the focus of the course. However, some PSTs were beginning to make connections between their instructional choices and/or the lesson structure and student responses, and we recognized this as growth in their pedagogical understanding, even if they did not yet have the language to describe it as such.

PSTs noticed that students find engineering fun and engaging. To begin discussing PSTs' pedagogical learning, we start with the most common noticing: elementary students found engineering fun and engaging. The carnival-lessons PSTs in particular used the word "fun" to describe students' experience, for example, one said: "Students had so much fun I don't think they realized they were learning." Many PSTs expressed surprise at how excited and involved students were during the lessons. A filter-lesson PST remarked, "it really kept students' attention and I did not know it would." While this recognition may initially appear observational, PSTs often reflected on what that engagement meant for student learning. These noticings suggest that PSTs began to recognize the pedagogical value of engineering instruction—particularly it is potential to motivate students and immerse them in core engineering practices, such as *envisioning multiple solutions*, *constructing models and prototype*s, *assessing implications of solutions*, and *considering problems in context.* PSTs from both iterations noted how unusually high the engagement levels were. Another characterized the students' response in terms of interest and engagement:

I was surprised by the amount of questions and engagement I got from our students! I figured I would have a couple students that could care less about what we were teaching… but not one student was like that. They were all so interested in the lesson and asked questions about everything.

Some PSTs linked that engagement directly to features of the lesson design. A filter-lesson PST reflected: "The best part of my lesson was the part, where the plastic filters were being tested. I got to see the excitement on the students' faces when they saw the trash being picked up by their creations." These comments demonstrate how PSTs observed not just enjoyment, but student engagement in engineering practices—and began to interpret that engagement as a meaningful instructional outcome. For many, this appeared to shift their thinking about engineering from something complex and intimidating to something capable of fostering excitement and deep involvement in learning.

One filter-lesson PST noticed that the topic of their design challenge sparked student engagement: "They were really engaged when we were explaining the problem of pollution in the Bay." In the fall, the lesson focused on water pollution—an environmental issue with local relevance. The fourth-grade students portrayed community members affected by water pollution—such as fishermen and marina owners—articulating stakeholder perspectives and weighing the implications of various design solutions. This aligns with the engineering practice of *considering problems in context* and points to the PST's emerging recognition of how situating engineering tasks in meaningful scenarios can foster engagement.

PSTs noticed that students can make design decisions independently. Building on the engagement, they noted that when the students could develop and test their ideas, PSTs described how students worked independently in their teams to complete the Engineering

Design Process (EDP). They observed students imagining solutions, making design decisions, and negotiating with teammates to finalize a prototype plan. These noticings align with several engineering practices, including *working effectively in teams*, *communicating effectively*, *envisioning multiple solution*s, and *making evidence-based decisions*:

> *For example, one carnival-lesson PST shared,*
> *I believe that the students followed the EDP... they made sure they understood the problem first, and they brainstormed lots of ideas before choosing one. They asked each other what would work best and communicated their ideas to each other. They tested their [kicking] machine while making it to see what needed to be changed.*

Many PSTs were surprised by students' ability to work independently, designing and revising their prototypes without direct teacher assistance. As one carnival-lesson PST explained, "The students had to figure out what material to use for each part of the kicking machine, which they did very well on their own…they did way more on their own than I expected." Another carnival-lesson PST described how it was "really surprising" when her 4th graders determined that they needed to "add more force to their [kicking machine]… without any guidance."

PSTs often attributed this independence to the structured nature of the EDP. As one filter-lesson PST reflected, "Because they understood the design criteria and constraints, they were able to evaluate if they had made an effective filter." This comment illustrates PSTs' observations of the students engaged in *making evidence-based decisions* and suggests an emerging understanding that lesson structure and design processes can support students in taking initiative and making informed decisions. These noticings indicate that PSTs began to reconsider their assumptions about what elementary students can accomplish when given the opportunity to lead aspects of their learning.

PSTs noticed that there is a balance between guiding and telling. Another theme in the pedagogical noticings focused on the approaches PSTs used to instruct the students. PSTs often begin their professional development with the notion that teaching primarily involves telling students information (Davis, 2006). Teaching engineering helped reframe teaching as a process that facilitates learning. When the PSTs taught their engineering lessons, they understood that they should not tell the students what to do; rather, they should support their students' autonomy and guide them through the design process. They discussed the ways in which they guided students in engineering practices, such as *applying science knowledge to problem-solving*, *investigating the properties and uses of materials*, and *making trade-offs between criteria and constraints*. Some of the PSTs' reflections captured their internal struggles as they wrestled with the best ways to be responsive to students' questions and ideas, without providing too much direction.

As one filter-lesson PST recounted, "I learned a bit of patience with the students I worked one-on-one with… I couldn't outright tell them what to do, I had to redirect them and patiently see what they'd do with the information I gave them." This example illustrates how this PST is beginning to embrace the role of facilitator and provide space for students to determine their own solutions based on their *investigation of the properties and uses of materials*.

A carnival PST described the difficulty she and her team encountered trying to find the right balance between letting students struggle to *apply math and science knowledge* on their own and providing guidance that would lead them to a successful solution:

> *We were told in our dress rehearsal that we provided too many hints, so we did not provide any hints for how to design the paddle. We did talk about transferring potential energy to kinetic energy and what supply would do that the best. They definitely got the idea that the rubber band would do it, but they kept going to the idea of a slingshot. We were running out of time, so we had to show them an example.*

This quote illustrates the challenge some PSTs experienced in providing students with the time and space to develop their own solutions while still wanting them to finish the lesson with a successful design in the allotted time period.

PSTs from both iterations described guiding students through the lesson, particularly in *investigating potential materials* and *making trade-offs between criteria and constraints*. These moments often emerged as students evaluated the results of earlier testing and considered which materials best met the design goals within specified limits, such as the allowable cost. For example, a filter-lesson PST explained:

> *I helped the students in their design by bringing their attention back to the material testing stage. I wanted them to remember how each material responded to water and use that information to decide if it would help or hurt their filter design.*

Carnival-lesson PSTs often referred to using open-ended questioning to guide students' design thinking while encouraging ownership. One PST described how she prompted her fourth graders to *apply science knowledge* in their design: "I asked questions like… 'Where does your machine display potential and kinetic energy?' allowing them to make the decisions but asking a question that will lead them to think about what to do." Across both groups, PSTs demonstrated emerging pedagogical strategies aligned with responsive teaching, including helping learners activate their resources when formulating solutions and responding to students' sensemaking. They also began to notice the value of leveraging students' interests—such as arcade games or sailing—to support conceptual understanding and engagement. These instructional moves reflect not only their growing comfort with teaching engineering content but also their ability to adapt teaching practices to student needs and contexts.

PSTs noticed that students can persist through failure. PSTs also discussed how failure focused the students' learning and engagement. A carnival-lesson PST explained that failing on their first try acted as motivation rather than a deterrent for her group of 4th graders, "Their first design turned over. They got more excited when it fell over…each immediately brainstormed some ways to fix it. I definitely think they enjoyed the failure because it meant they could try out another idea they had." PSTs described how the students embraced failure as part of the engineering process, with one filter lesson PST explaining, "I also think they learned that failure is okay…and that it is part of the process…because the students…were constantly saying that it was okay if the filter failed the first time because they had more opportunities to improve it." These comments suggest that PSTs noticed how participating in the engineering design process helped students develop the engineering practices of *envisioning multiple solutions* and *persisting and learning from failure*.

Engineering-related beliefs

Beliefs about engineering in elementary education

There were increases in the PSTs' belief scores (average increase = 0.46 points) throughout the project, and 15/25 PSTs reported higher beliefs about the importance of including engineering in elementary education at the post-test; however, these differences did not reach significance. The quantitative analysis revealed no significant pre–post-difference in PSTs' beliefs about engineering integration at the elementary school level (see Table 4) and no significant difference between iterations, $H(1) = 0.082$, $p = 0.773$. PSTs' post-test means in both iterations were high (above 4.3) and correspond with the qualitative data that suggest PSTs believed elementary-aged learners should be exposed to engineering as part of their classroom instruction.

PSTs believed that engineering should be taught in elementary schools. With few exceptions, PSTs in both course iterations expressed strong support for introducing engineering in elementary classrooms. They identified a range of benefits, including opportunities for students to practice creativity, develop problem-solving skills, learn to collaborate, and consider engineering as a potential career path. PSTs noted that engineering design projects provide engaging contexts for students to *apply math and science knowledge* in other disciplines, *work effectively in teams*, and *see themselves as engineers*. One carnival-lesson PST reflected, "If students were taught STEM concepts that they would use in engineering… they would be more engaged in paying attention and learning…[and] would have a use for those concepts." She went on to explain that the EDP could serve as a transferable "framework for learning," helping students plan "a paper, project, or even studying." A filter-lesson PST echoed this idea, emphasizing the long-term cognitive benefits of early exposure: "By introducing the EDP to students early, that way of thinking and problem-solving

Table 4 Wilcoxon signed-rank test results for PSTs' beliefs

		Spring 2022 (carnival lesson)					Fall 2022 (filters lesson)				
		n			Wilcoxon test		*n*			Wilcoxon test	
			M	*SD*	*V*	*p*		*M*	*SD*	*V*	*p*
BEI	pre-test	16	3.89	1.26	23	ns (0.12)	9	4.2	0.6	4	ns (0.10)
	post-test		4.39	1.25				4.6	0.57		
SEI	pre-test	16	3.45	0.79	27	0.03*	9	2.81	0.72	0	0.00*
	post-test		4.24	1.36				4.67	0.33		
ITI	pre-test	16	4.03	0.96	32	ns (0.60)	9	3.49	0.63	3	0.02*
	post-test		4.31	1.06				4.16	1.38		

BEI = beliefs on engineering integration; SEI = self-efficacy for engineering integration; ITI = integration to integrate engineering; ns = no significant differences between iterations; **p* value < 0.05

will become very familiar to them… and prepare them for even more complex problems in future grades and in real life." A carnival-lesson PST suggested that early exposure can introduce engineering as a career explaining that the students realized that "anyone can have what it takes to be an engineer… you don't have to look a certain way to want to become an engineer." Another filter lesson reflected on the value of engineering for promoting teamwork, explaining that "the students learned that in order to come up with a solution they need to work with and consider others."

Although most PSTs viewed engineering as age-appropriate and valuable for elementary learners, a few expressed concerns that it might be too complex for younger students. These PSTs recommended introducing engineering in upper elementary, middle, or high school instead. Overall, the qualitative data suggest that PSTs held positive perceptions about the value of engineering in elementary education, and that these beliefs became more favorable due to participating in the project. Their reflections indicate a developing awareness of engineering's potential to support not only academic skills but also collaboration and identity development among young learners.

Self-efficacy for teaching engineering in elementary education

There was a significant increase between the pre- and post-test values for PSTs' self-efficacy in both iterations, indicating an overall gain in PSTs' assessment of their ability to integrate engineering into their future instruction (see Table 4). Twenty-three of the 26 PSTs reported higher self-efficacy at the post-test. Of the three assessed beliefs, this variable showed the largest gain, averaging about 1.2 points per PST, suggesting that the intervention had more influence on the PSTs' self-efficacy than on their beliefs about engineering education or their intention to integrate engineering into their instruction. There were no statistically significant differences between the iterations, $H(1)=0.043$, $p=0.835$. However, it should be noted that the filter-lesson PSTs had a numerically larger gain (1.86 vs. 0.79) and a higher mean post-test score (4.67 vs. 4.24). These statistics align with qualitative data that suggest that while PSTs in both iterations gained confidence in their ability to teach engineering, the filter-lesson PSTs expressed a higher appraisal of their ability.

PSTs believed that they were able to teach engineering, even though it was new to them. In analyzing the qualitative data to discuss PSTs' self-efficacy, we looked first at how the PSTs evaluated the success of their lessons. The PSTs were prompted to use the results of multiple-choice quizzes they gave the students to evaluate student learning. A filter-lesson PST concluded, "I think we did a good job explaining the EDP and engineers in general. Based on the [quiz] results, it seems like the students really understood what they [engineers] do." Many PSTs also looked at students' design success to evaluate their performance. These observations are reminiscent of their noticing that students are capable and can make design decisions independently. Several PSTs reported being impressed, or even surprised, by the success and creativity of the students' solutions. One carnival-lesson PST said, "We were shocked that each team's design succeeded since we could not even create a successful design ourselves." While this surprise and self-criticism might not immediately suggest the PSTs felt self-efficacious, it serves as an example of how the students' success contributed to the PSTs' self-efficacy for teaching engineering by creating a mastery teaching experience (Bandura, 1997). When the students successfully designed an effective solution, the PSTs felt successful in teaching. They succeeded in what they perceived to be a very challenging teaching situation. For example, a carnival-lesson PST explained:

> *I would have never thought I would be able to teach engineering concepts to kids effectively because I did not have a good understanding of it myself but now I see that it is extremely important and achievable to teach to young children.*

The enjoyment PSTs witnessed in their students and felt upon seeing the students' engagement may also have contributed to PST self-efficacy via an affective pathway first described by Bandura (1997). As a carnival-lesson PST recalled:

> *The best part was seeing the smiles on the students' faces not only while they were constructing their designs but especially when their kicking machine was successful. It put a smile on my face and I enjoyed the lesson more so from seeing their excitement.*

These examples signify the importance of PSTs' noticing that students find engineering fun and engaging: when PSTs perceived that students learned about engineering, were able to create successful designs, and enjoyed the lessons, they experienced a sense of mastery and positive physiological arousal (Bandura, 1997), supporting the development of their self-efficacy.

The PSTs expressed confidence in the success of many aspects of their lessons. Most PSTs said they felt confident in their ability to introduce the EDP to the students, interact with them as they designed and tested their prototypes, and guide them in *making evidence-based decisions* related to their designs. Some PSTs expressed particular confidence in the specific parts of the lesson they personally led. This was more common in spring when PSTs shared teaching responsibilities with the engineering students and, as a result, were not responsible for teaching all aspects of the lesson. One carnival-lesson PST explained, "I felt the most confident with the introduction of the design challenge, which was my part to speak to the students… I rehearsed my part over and over before it was performed."

PSTs in both iterations reported lacking confidence with time management and suggested the students needed more time to build and test their designs. The time crunch left some teams unable to adequately complete the latter parts of the design process, namely, improving the design and sharing the results with others. One PST expressed a desire for a longer lesson extended over multiple days:

> *I learned that ideally I would like to stretch a lesson out. I think students would gain the most benefit from having this exercise after having a lot of the elements of it introduced ahead of time. Then you would be activating what they have already learned to work on the paddleboat, instead of trying to teach it all at once.*

She concluded that the lesson asked the PSTs "to do too much with fourth graders in a short period of time."

Other PSTs similarly applied a critical lens to their teaching tasks, attributing the difficulties they faced to aspects of the project design. For instance, one carnival-lesson PST remarked that their team's challenge (a claw) "may have been a little bit too challenging for this age group." Likewise, several filter-lesson PSTs noted that the emphasis on meeting budget criteria took too much time, "stifled their creativity," and distracted students from building their filters. These critiques indicate an emerging awareness of pedagogy and the ability to assess the suitability of instructional materials. Taking this a step further, some carnival-lesson PSTs questioned the guidance provided by their instructor. In the Spring, when PSTs developed their own lesson rather than using a premade one as the filter-lesson PSTs did, a few voiced concerns about inadequate instruction on lesson planning, which they felt affected both their assignment performance and lesson delivery overall. One carnival-lesson PST noted that a model lesson plan was provided only after the lesson plan was due, stating, "When we originally made our lesson we did not have tons of information and scored poorly. I think if we were at least shown a sample lesson [plan] before forming our own lesson it would've helped us do a lot better." These critiques connect to PST self-efficacy by attributing their success or struggles to external factors while also demonstrating their growing understanding of pedagogy and how instructor decisions impact student outcomes.

Continuing our examination of self-efficacy, we explored how confident the PSTs said they were to teach engineering moving forward. When asked to rate on a scale of 1 (low) to 5 (high) how confident they would be in their ability to teach the same lesson to a new group of students on their own, most carnival-lesson PSTs rated themselves at a "3," whereas most filter-lesson PSTs rated themselves at a "4." Carnival-lesson PSTs had concerns about what they characterized as their lack of expertise with engineering and this often translated into an apprehension that they would not be able to respond to students' questions about engineering effectively. One carnival-lesson, PST said, "I do feel like I could explain kinetic and potential energy and the engineering design process quite well, but engineering is definitely not a strong subject for me." Another connected their reflection to student engagement, stating, "I would be able to get the students involved and excited to create but I would not be prepared to answer some of the engineering-related questions." In contrast, the filter-lesson PSTs were more likely to express logistical concerns related to teaching the lesson alone and apprehension about managing students' behavior. For example, a filter-lesson PST said, "It would be hard to juggle everything between presenting the information to keeping the students under control." These differences in responses suggest that the filter lesson PSTs, who taught without engineering student partners, may have felt more confident that their knowledge of engineering was adequate for teaching the elementary students, whereas the carnival-lesson PSTs may have found their engineering content knowledge lacking in reference to that of their engineering student partners. Such referential comparisons have been found to undermine the development of self-efficacy (Bandura, 1997).

PSTs discussed gaining confidence from the experience of teaching the lesson as well as from other preparatory activities, such as engaging in the design challenge as students and participating in a lesson rehearsal. For example, one highly confident carnival-lesson PST who rated her ability to teach the lesson again at a five said, "I would be very confident, 5, because I now know the steps of the engineering design process, and we have played it out in front of a group of students once as well as the dress rehearsal so it has made it easier to be able to teach it again." A filter-lesson PST also acknowledged the importance of repetition and practice in building her confidence, "I would be very confident because it would be my third time doing the lesson."

In summary, PSTs in both iterations increased their self-efficacy for teaching engineering through participation in the project. These gains were linked to their engagement as learners in the EDP, lesson rehearsals, and significantly, witnessing the enjoyment and success students experienced with the lessons they delivered.

PSTs' intention to integrate engineering into their future instruction

The quantitative analysis of the PSTs' intention to integrate engineering was inconclusive. There was a significant pre-to-post-test increase in the filter-lesson PSTs' intention to integrate engineering. At the same time, there was no significant difference in the carnival-lesson PSTs' pre- and post-test scores. However, the Kruskal–Wallis test indicated no significant difference between the groups, $H(1)=0.003$, $p=0.950$, leading to the inconclusive results. It can be concluded that PSTs reported a relatively high intention to integrate (means above 4.1), and 16/25 PSTs reported a higher intention to integrate engineering in their instruction at the post-test. However, these means were the lowest of the three measured beliefs, suggesting PSTs may not feel as strongly about their intention to teach engineering as they feel about the importance of elementary students learning engineering and their confidence in their ability to do so. Likewise, the pre–post-gains were the lowest of the measured variables, suggesting the intervention had less influence on PSTs' intention to integrate engineering than it had on the other outcomes. The qualitative data also revealed some uncertainty in PSTs' commitment to teaching engineering, particularly for those PSTs who planned to teach younger grades.

PSTs believed that teaching engineering could be fun, easy, and beneficial for students, but were unsure they would teach it in their classrooms. PSTs had positive experiences teaching their engineering lessons to the fourth graders. They witnessed the students' excitement for the engineering challenges and came away with very positive beliefs about the benefits of elementary students learning engineering. Many of the PSTs translated these positive experiences and beliefs into an intention to integrate engineering into their future classroom practice. As a carnival-lesson PST said, "I really enjoyed teaching the lesson and feel I could have a lot of fun with them when I am teaching [engineering]." They described wanting to teach engineering, because it is fun, novel, creative, hands-on, and a good problem-solving challenge for students. As mentioned earlier, PSTs saw the universality of the EDP and thus believed it could easily be integrated into their instruction. For example, a filter-lesson PST returned to the idea that engineering is everywhere when she said, "I learned that teaching engineering doesn't have to be complicated. The various steps of the EDP can easily be integrated into the school day." A few PSTs who plan to teach younger grades (K-1) qualified their intentions, explaining how they might scale down their lessons, because they worry that engineering is too complicated for that age group. PSTs who said they were unlikely to teach engineering regularly or did not plan to integrate engineering unless required shared their dislike for engineering. For example, a filter-lesson PST said, "If I had to [teach engineering], yes, otherwise no, I just do not enjoy engineering." Another filter-lesson PST concurred, "I'm not really the best at teaching things that I don't really have an interest in."

Discussion, limitations, and implications

Discussion

One of the most critical findings from this research is that providing novice PSTs with authentic opportunities to teach engineering to elementary students enhances their engineering-related knowledge and beliefs. This result aligns with research by prior authors (e.g., Lux et al., 2022; Rose et al., 2017; Sun & Strobel, 2014) and demonstrates the powerful potential of creating novel engineering field experiences within teacher preparation programs. In the following discussion, we go beyond recommending that PSTs teach engineering to elementary students; we explain what happens when they do and why this is important.

When a PST teaches engineering, they learn about engineering

Both the quantitative and qualitative data revealed growth in PSTs' engineering-related knowledge, regardless of the iteration in which they participated. This is significant, because teachers' levels of engineering-related knowledge can influence whether they choose to teach engineering (Deniz et al., 2020).)Authors underscore the importance of engaging students in the epistemic practices of engineering (Cunningham & Kelly, 2017; Yesilyurt et al., 2024). For teachers to facilitate this critical work, they need firsthand experience in recognizing and participating in these practices. By planning and teaching an engineering lesson, the PSTs were able to observe and engage directly with engineering practices. Working within their team to develop and refine their lessons, they gained experience in the engineering practices of *working effectively in a team* and *innovating processes, methods, and designs*. By persevering through the process of completing the design challenges as students and observing students iterate through multiple designs, they embraced the engineering practice of *persisting and learning from failure*. In education, failure is typically framed as something to avoid or minimize, so PSTs had to adopt a new perspective, recognizing its constructive role in engineering (Lottero-Perdue & Parry, 2017). They observed engineering as a discipline, where the stigma of failure is lifted, allowing students to view it not as a setback or source of shame, but as a chance to try new approaches. PSTs also came to see that engineering is all around them and that they engage with design processes and engineered products every day. These experiences deepened the PSTs' understanding of engineering practices, equipping them to incorporate these practices more effectively into their future classrooms.

When a PST teaches engineering, they learn about pedagogy. The quantitative and qualitative data both indicate growth in PSTs' pedagogical knowledge and engineering-pedagogical knowledge. The quantitative gain in engineering-pedagogical knowledge was the largest of all six measured outcomes, with post-test means around 4.4. This suggests that the project had the strongest influence on the PSTs' perceptions of their knowledge about teaching engineering and that PSTs felt confident in their engineering-pedagogical knowledge at the end of the project. PSTs observed that students enjoyed themselves, displayed creativity, collaborated on design decisions, evaluated solutions with minimal assistance, and persisted through failure when engaged in engineering tasks. Most of these observations focused on students' behaviors and emotional responses, which is typical for novice PSTs. Benedict-Chambers and Aram (2017) also found that early elementary PSTs mainly noticed student actions and affect, rather than connecting their instructional choices to student outcomes. Building these connections is essential, as what PSTs notice can shape their future teaching responses (Levin & Richards, 2010). In our data, some PSTs were beginning to make these instructional connections, highlighting the importance of supporting them in understanding how their choices influence student thinking (e.g., Davis, 2006).

Many engineering practices (Cunningham & Kelly, 2017) were displayed as the students engaged in the engineering design process during the lessons. PSTs noticed how students *worked effectively in teams, communicated effectively, considered problems in context, investigated the properties and uses of materials, envisioned multiple solutions, applied math and science knowledge, constructed models and prototypes, made evidence-based decisions, made trade-offs between criteria and constraints*, and *assessed the implications of solutions*. Furthermore, PSTs came to appreciate how engineering pedagogy involves guiding rather than directing students through these practices and that their role as teachers may require them to stand back and allow students to experience the practice of *persisting through and learning from failure*. This transition from direct instruction to a more responsive approach aligns with previous findings, where PSTs reported a shift from lecturing to guiding students after teaching engineering lessons (Kidd et al., 2024; Watkins et al., 2018; Wendell et al., 2016). While crucial for engineering, responsive teaching also supports student sensemaking across disciplines. Thus, participating in the project enhanced PSTs' pedagogical skills generally, while it helped prepare them to teach engineering specifically. Witnessing these practices in action and acknowledging how they contributed to students' autonomy not only helped prepare the PSTs to support engineering practices in their future classroom, but it may also have made them more likely to choose to integrate the practices.

When a PST teaches engineering, their beliefs about engineering evolve. PSTs frequently noticed that engineering was fun and engaging for students and that student teams could independently tackle engineering tasks. Witnessing students' positive reactions, PSTs often felt a similar excitement, as if the children's excitement was contagious. PSTs reported feeling successful when their students succeeded, and genuinely enjoyed the experience, because their students were having fun. However, these positive reflections were often paired with surprise. Many PSTs were caught off guard by the fourth graders' enthusiasm and success, having initially expected that students might not find engineering interesting or would struggle to design viable solutions. These early expectations reflected the PSTs' initial beliefs about engineering—they often lacked confidence in their engineering-related knowledge, and some even expressed a distaste for the subject, viewing it as too complex and beyond young learners' abilities. Such reservations are common among elementary teachers and pose a barrier to incorporating engineering in elementary education (Cunningham, 2008; Liu & Szabo, 2009). Teaching engineering lessons and witnessing students' enjoyment and success helped make engineering accessible to PSTs, allowing them to see it as something within their and their students' reach. They began embracing the idea that engineering is for everyone, recognizing that all people are problem-solvers and that students can use engineering to tackle real-world challenges. This new understanding of who can and should participate in engineering contributed to PSTs' positive beliefs about the role of engineering in elementary schools and reinforced the importance of the engineering practice of *having students see themselves as engineers* and engineering as a tool that helps students *develop processes to solve problems.* By the end of the project, most PSTs believed that engineering could—and should—be taught in elementary schools, with some even suggesting it could be introduced to very young students. Our findings indicate that when PSTs have opportunities to teach engineering and witness student enjoyment and success, it can greatly help dismantle negative beliefs that impede the integration of engineering into elementary classrooms. When PSTs experience positive emotions and a sense of accomplishment in teaching engineering, they may be more inclined to teach it again (Hsu et al., 2011).

When a PST teaches engineering, they become more confident in their ability to teach engineering. When PSTs observed their students feeling joyful and succeeding in the design challenges, they gained confidence in their ability to teach engineering. The experience of positive emotions can influence self-efficacy (Bandura, 1997). Changes in affective states influence self-efficacy as individuals note their physiological arousal (Bandura, 1997). Feeling energized during a task can be a powerful signal of capability, bolstering self-efficacy. The quantitative and qualitative results both revealed gains in PSTs' self-efficacy for teaching engineering. High post-test means suggest PSTs felt confident in their ability to integrate engineering into their future instruction. The qualitative data indicated that the PSTs derived confidence from teaching their lessons to the children, but that other preparation activities, including engaging in the EDP as students, rehearsing their lessons in front of peers, and receiving feedback on their performance, contributed to their sense of competence. We believe the project created a mastery experience (Bandura, 1997) that supported the PSTs' self-efficacy in teaching engineering and their confidence in teaching more broadly (including teaching unfamiliar content). PSTs' observation of students' engagement and enjoyment was a critical factor in developing their engineering-related beliefs overall. PSTs focused heavily on student engagement in their recollections of their teaching experiences and described students' enjoyment and excitement with the engineering design challenge as a critical factor influencing their intention to teach engineering in the future. Simply put, PSTs expressed motivation to teach engineering, because they observed the students enjoying it.

Limitations

Several factors limited the findings in this study. First, the study was conducted at one university and in the context of an NSF-funded, multi-year collaboration between education and engineering faculty. The course instructor had several years of experience engaging PSTs in engineering activities and had support from engineering faculty and outside experts in the development of the lesson preparation activities. Similar studies in other contexts may yield different results. Next, the study focused on PSTs' perceived knowledge related to engineering and may not reflect their actual knowledge. Next, the trends we found in PSTs' engineering-related perceived knowledge and engineering-related beliefs may have been influenced by the specific lesson focus, the instructor, or the broader context of the study. For example, some PSTs may have reported more (or less) favorable attitudes, because they were more (or less) interested, or knowledgeable, about their lesson topic. In addition, PSTs may have been swayed by the instructor's attitude toward engineering or responded to the end-of-project reflection more positively, because it was an assignment graded by the instructor, introducing social desirability bias (Krumpal, 2013). The inclusion of quantitative survey data mitigated this concern. This study was also limited by a small sample size and departure from normality in the data distribution. To compensate, we used nonparametric approaches to analyze the data. While these are more robust, they can be less powerful than parametric approaches (Tanizaki, 1997). A study with a larger sample size could enhance the validity of the findings. Finally, this study examined PSTs' implementation of engineering lessons as part of required teacher preparation coursework. Future work could follow these PSTs to assess the quantity and quality of engineering lesson implementation when they enter the field and may have more discretion over the lessons they teach.

Implications

This study contributes to the literature (e.g., DiFrancesca et al., 2014; Hammack & Ivey, 2017) regarding how to prepare PSTs to engage students in engineering. Based on our findings, we assert that providing PSTs with opportunities to teach engineering lessons to elementary students is an effective strategy for addressing the challenge of preparing future teachers to address the new science standards. We use this next section to offer a few suggestions for structuring such teaching opportunities and point out areas, where more research is needed.

Our first recommendation is simply that teacher educators create opportunities for PSTs to teach engineering lessons to elementary students. The elementary students who participated in the project lessons were excited, engaged, and produced successful solutions to design challenges, which helped shift PSTs' perceptions of engineering from being foreign and complicated to something feasible and enjoyable. The students' enjoyment and success provided a positive emotional experience that contributed to the PSTs' self-efficacy and intention to integrate engineering into their future instruction. Similar findings in prior research indicate that PSTs are more enthusiastic about leading STEM activities after witnessing students' excitement (Carrier, 2009). Students' positive responses affirmed the PSTs' ability to teach engineering, creating a mastery experience. Only through authentic teaching experiences, such as these, can PSTs gather evidence regarding their ability to teach engineering to elementary students (Gale et al., 2021; Tschannen-Moran et al., 1998). Therefore, we recommend that teacher educators explore engineering-based field experiences through on-site visits to elementary schools, as with the carnival lessons, or by inviting local elementary students to campus, as in the filter lesson. Our findings support both settings as effective for bringing PSTs and elementary students together to engage in engineering, ultimately strengthening PSTs' confidence and competence in teaching engineering.

Second, like many engineering education researchers (e.g., Cunningham & Carlsen, 2014; Watkins et al., 2021), we suggest that teachers should engage as students in the design-based lessons they will teach. This approach helps them become familiar with engineering practices and the EDP, and builds engineering-pedagogical knowledge by allowing them to anticipate the types of support their students may need (Cunningham & Kelly, 2017). Our PSTs agreed that participating in the challenges first as students was beneficial, boosting their confidence and enhancing their pedagogical skills by helping them anticipate and plan for students' responses. Our findings thus support engaging PSTs as students in well-structured design challenges.

Third, we recommend incorporating lesson rehearsals. Practicing lessons and receiving feedback before working with elementary students proved particularly effective in developing pedagogical knowledge. PSTs consistently reported that rehearsing with peers, who role-played as elementary students, increased their confidence and allowed them to refine their instructional approach. This aligns with research on microteaching, a related practice emphasizing brief, focused teaching experiences followed by feedback and reflection. Studies have shown that microteaching supports growth in science content knowledge (Long et al., 2019), teaching confidence (Arsal, 2014; Özonur & Kamışlı, 2019), and self-assessment and reflection skills (Elias, 2018; Karlström & Hamza, 2018). One study that included microteaching of engineering lessons in a science methods course reported positive benefits on PSTs' self-efficacy for teaching engineering (Webb & LoFaro, 2020). Our findings suggest that structured rehearsal opportunities, like microteaching, can be critical in preparing preservice teachers to deliver engineering instruction effectively.

The aforementioned aspects of the project were highly valued by PSTs in both iterations and appeared universally effective in preparing them to engage elementary students in engineering early in their teacher preparation programs. We confidently recommend these practices to fellow teacher educators. However, the impact of other elements—such as placement within teacher preparation programs, PST involvement in lesson design, team composition, and lesson focus—was less definitive, and we are, therefore, not ready to make specific recommendations in these areas. Instead, we suggest that further research is needed and provide the rationale for this conclusion.

Early field experiences are recognized for helping PSTs bridge theory and practice, build confidence, and begin developing a professional identity (Coffey, 2010; Ferguson & Sutphin, 2024; Maheady et al., 2007; Wallace & Brooks, 2015). Williams and Sembiante (2022) highlight that effective early field experiences are grounded in a strong theoretical framework, including community connections, promoting reflective practice, and balancing autonomy with collaboration. This study meets these criteria in an experience situated at the start of PSTs' programs, many of whom were teaching for the first time. The engineering design process provided a consistent planning framework, and PSTs made community connections, exercised pedagogical autonomy, collaborated with partners, and engaged in structured reflection. Addressing a gap noted by Williams and Sembiante (2022), this study contributes both qualitative and quantitative evidence to the growing literature on early field experiences in teacher preparation. Furthermore, it makes the case that incorporating engineering instruction via a field experience early in teacher preparation, though atypical, can be both feasible and beneficial.

PSTs were challenged to teach unfamiliar content to unfamiliar students alongside peers they had just met. Despite this, PSTs were successful, persisting through discomfort and gaining insights into their strengths and areas for improvement. Research indicates that self-efficacy is strengthened when individuals succeed at challenging tasks (Bandura, 1997), so experiencing success in this early, demanding context may have bolstered PSTs' general teaching self-efficacy and increased their willingness to tackle unfamiliar content in the future (Kazempour & Sadler, 2015; Yoon et al., 2018). Furthermore, it may have primed the PSTs for subsequent instruction in pedagogy, giving them a personal experience on which to reflect and relate new concepts and practices, such as responsive teaching, building on students' prior knowledge, questioning strategies, and lesson planning. Our findings, supported by prior research (Cima et al., 2021), suggest that introducing engineering teaching opportunities early in PST programs can foster growth in pedagogical knowledge, self-efficacy, and positive beliefs about elementary engineering education. This is noteworthy, as most research on engineering education for PSTs is conducted within science methods courses later in their programs (e.g., Capobianco & Radloff, 2022; Kaya et al., 2017; Perkins Coppola, 2019; Yesilyurt et al., 2021). However, while early exposure is beneficial, it remains unclear what courses, besides science methods, could best accommodate engineering instruction.

Engineering teaching experiences require careful planning and a range of activities (e.g., engaging in the EDP as students, opportunities to rehearse) that may shift focus from other course objectives. The course in which PSTs participated in this study did not include pedagogical objectives. Although PSTs gained valuable pedagogical knowledge for their professional development, accommodating the project required condensing other instructional activities. We recommend further investigation into the impact of engineering teaching experiences early in PST programs, a comparison of early vs. later experiences, and an examination of the effects of multiple experiences. Research indicates a single experience is not sufficient to fully support a change in PSTs' practice (Desimone et al., 2002), and there is often a delay in teachers' use of instructional strategies illustrated in teacher education experiences (Grossman et al., 2000; Munter & Correnti, 2017).

Closely related to the questions of where and how often within teacher preparation to insert engineering teaching experiences is how much involvement PSTs should have in the development of the lessons they teach. Our findings showed no major differences in PST outcomes between those who taught premade challenges and those who developed their own. Therefore, we suggest that PSTs can benefit from either approach, though teacher educators should consider PSTs' developmental levels. Designing lessons is a demanding task that requires time and support. PSTs without limited pedagogical training, such as those in an initial course, may struggle without substantial scaffolding. While succeeding in a challenging task can boost self-efficacy, failure may have the opposite effect, and discourage PSTs from engaging with engineering. Our qualitative data suggests PSTs experienced less frustration during lesson preparation and gained more self-efficacy when teaching a premade lesson, which may be a preferable option for PSTs in their first education course. Struggling through the design of a lesson may be a more appropriate task for PSTs in methods courses focused on pedagogy.

Next, the ideal composition of teaching teams remains uncertain. PSTs reported advantages to working with engineering students, such as developing an appreciation for the role of engineering in everyday life. At the same time, teaching without the engineering students seemed to promote gains in self-efficacy and confidence in teaching all aspects of the lesson. This study suggests that both models offer unique benefits. Previous research also highlights the advantages of PSTs teaching alongside engineering students (e.g., Cima et al., 2021; Fogg-Rogers et al., 2017; Gutierrez et al., 2022; Lewis et al., 2021) as well as teaching independently or with other pre-/in-service teachers (e.g., Kidd et al., 2024; Lux et al., 2021; Perkins Coppola, 2019). Future research should explore the strengths and limitations of including engineering students as teammates when PSTs deliver engineering lessons to elementary students.

Finally, the focus of the lessons influenced how PSTs supported students' engagement in engineering practices, such as their *application of science knowledge* in design decisions and *assessing implications of solutions*. The carnival-themed challenges emphasized physical science principles (e.g., utilizing potential energy from a twisted rubber band) rather than societal issues (e.g., plastic pollutants in waterways). Consequently, carnival-lesson PSTs primarily guided students in applying science content, while the filter-lesson PSTs encouraged students to consider community impacts (e.g., the effects of the filters on boaters), emphasizing assessment of design implications. Each challenge highlighted different engineering practices (Cunningham & Carlsen, 2014) and science knowledge. Teacher educators could strategically select engineering challenges to reinforce specific engineering practices and science concepts and guide PSTs toward developing lessons that meaningfully integrate science content into design challenges, an area where both novice and veteran teachers struggle (Pleasants et al., 2021). Further research could examine the effectiveness of targeted design challenges in supporting science instruction and specific engineering practices.

In conclusion, we find that teaching engineering to elementary students is an effective approach for preparing elementary PSTs to meet engineering standards, enhancing both their engineering-related knowledge and beliefs. However, further research is essential to help teacher educators identify when to offer such experiences and the most effective ways to structure them.

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JK, DR, and KG made substantial contributions to the conception of the work. JK, DR, KG, SR, KK, OA, and PP made substantial contributions to the design of the work. JK and SR, made substantial contributions to the acquisition of the data. All authors made substantial contributions to the analysis and interpretation of the data. JK, DR, KG, PP, and FC drafted the work or substantively revised it. All authors approved the submitted version and are personally accountable for their contributions.

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Data availability
Due to the nature of the research which includes personally identifiable information of minors, supporting data are not available.

Declarations

Ethics approval and consent to participate
This study has been approved by Old Dominion University's Institutional Review Board Ed + engineering: An Interdisciplinary Partnership Integrating Engineering into P-6 Teacher Preparation [1451315-23]. REFERENCE #: 19-113; 20-180; 21-156; 22-159; 23-147; 24-134. All the data upon which this article is based was obtained from participants who consented to participate in the approved study.

Consent for publication
The individuals pictured in this paper, or in the case of minors, the parent/guardian of the pictured individual, have signed a consent form indicating approval for their (or their child's) image to be broadly used in web- and paper-based publications.

Competing interests
The authors report there are no competing interests to declare.

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