Teaching the E in STEM: A Synthesis of the Engineering Teaching Self-Efficacy Literature

Over the last decade in the United States, education reforms have called for a fundamental shift in K-12 science teaching and learning in order to prepare future generations to solve real-world problems using interdisciplinary knowledge and skills, including engineering (NGSS Lead States, 2013; NAE & NRC, 2014). The new vision requires those training current and future science teachers to overhaul courses to equip them to understand and implement NGSS standard-based learning in classrooms (French & Burrows, 2018; Reimers et al., 2015; Tuttle et al., 2016). It is long established that teachers with high self-efficacy are more likely to incorporate inquiry-based practices in their teaching and to foster learner-centered environments in their classrooms (Lakshmanan et al., 2011; Watters & Ginns, 2000). However, elementary school teachers often have low self-efficacy in teaching engineering and leave their preservice teacher (PST) preparation programs feeling unprepared to teach engineering (Banilower et al., 2018; Custer & Daugherty, 2009; Reimers et al., 2015).

Given that self-efficacy beliefs are the strongest predictors of motivation and performance, their influence on the ability of preservice and inservice elementary teachers to teach science effectively is widely studied (Knaggs & Sondergeld, 2015; McDonald et al., 2019; Pajares & Schunk, 2001). Current findings suggest that PST preparation programs and inservice teacher (IST) professional development enhance science teaching self-efficacy (e.g., Author, 2020; Authors, 2018; Sinclair et al., 2011). However, there is less evidence surrounding engineering teaching self-efficacy. As part of our larger NSF-funded research project, we conducted a systematic review of literature that explored the research question: What does the existing literature on self-efficacy reveal about fostering elementary teachers' science and engineering teaching self-efficacy? For the purpose of this presentation, we will focus specifically on engineering teaching self-efficacy, an emerging area of study.

Theoretical Framework

Long an influential construct in teacher education, self-efficacy derives from Social Cognitive Theory (Bandura, 1986; Nespor, 1987; Pajares, 1992), which blends behaviorist and cognitive theories and recognizes that "cognitive processes play a prominent role in the acquisition and retention of new behavior patterns" (Bandura, 1977, p. 192). Bandura (1981) conceptualized self-efficacy as a judgment about one's ability to "organize and execute courses of action" (p. 587) to achieve the desired goal. Gist and Mitchell (1992) defined self-efficacy as "judgment about task capability that is not inherently evaluative" (p. 185) and extended the construct into organizational behavior by proposing a model that encompasses self-efficacy's "complexity and malleability" (p. 183). Consistent with Bandura, Tschannen-Moran et al. (1998) defined teacher efficacy as the beliefs that shape teachers' ability to execute certain actions in given desired situations, which can bring desired results. Here, teacher efficacy is context-specific, situational, and subject-matter specific, as with elementary teachers who may prefer other subjects to science because they perceive their engineering teaching as inadequate.

Self-efficacy is comprised of two dimensions: (1) personal efficacy and (2) outcome expectancy (Bandura, 1977). Researchers have posited that the dimensions are related but can act independently. In this context, personal efficacy involves teachers' beliefs in their ability to motivate and support student learning by creating rich-learning environments (Bandura, 1993);

outcome expectancy links to beliefs in whether their actions will yield desired student outcomes. Bandura (1997) proposed four major sources of self-efficacy beliefs: mastery experiences, vicarious experiences, verbal persuasion and emotional arousal (Bandura, 1995; 1997). These sources of self-efficacy beliefs influence an individual's expectations related to performing a specific action. Within engineering teaching self-efficacy literature, these dimensions of self-efficacy are framed specifically as personal engineering teaching efficacy (PETE) and engineering teaching outcome expectancy (ETOE).

Grounded in the self-efficacy literature, we developed a framework (see Figure 1) that allows for an in-depth understanding of experiences critical to the development of self-efficacy within the preservice teacher preparation years, during the first years of teaching, and beyond the beginning years of teaching. The framework guided our systematic literature review in order to identify gaps and recommendations for future research in the field of engineering teaching self-efficacy specifically. The model recognizes the dynamic nature of self-efficacy: self-efficacy can change with experiences gained within various formal and informal professional contexts. We posit that the experiences teachers have in preparation programs and professional development contexts influence their behaviors and outcome expectancies, which thereby influence their teaching effectiveness and retention in the field.

[INSERT FIGURE 1 APPROXIMATELY HERE]

Analysis of Literature

We conducted a systematic review based on Newman and Gough's (2020) recommendations to answer our research question: What does the existing literature on science and engineering teaching self-efficacy reveal about fostering elementary teachers' science and engineering teaching self-efficacy? First, we defined our inclusion criteria for article selection: (1) published between 2010 and 2022, (2) empirical studies only, (3) focus on elementary (K-6) teachers (preservice and inservice), (4) focus on self-efficacy for teaching science and/or engineering, (5) peer-reviewed, and (6) published in English.

Second, we conducted several searches in databases, including EBSCO Education Source, APA PsychInfo, and Education Resources Information Center (ERIC). Several combinations of search terms were tested in preparation for the final search. The search terms that yielded the most relevant results are shown in Table 1. In addition to these search terms, we used the search functions to limit publication dates to 2010-present and restrict search results to peer-reviewed publications.

[INSERT TABLE 1 APPROXIMATELY HERE]

In reviewing the 572 results from the database search, we identified several prominent journals that were not represented in the findings. We conducted a second round of individual searches within these journals (*School Science and Mathematics*, *Journal of Science Teacher Education*, and *International Journal of Science and Mathematics Education*), resulting in an additional 94 articles. With the 666 resulting publications, we conducted several rounds of review, coding, and analysis of the studies (see Figure 2). We initially screened the titles and abstracts to determine if they still fit within our inclusion criteria. 485 articles were excluded at this stage. The full texts of the remaining 181 articles were downloaded and reviewed in detail. From the full article review, an additional 66 were excluded because they did not align with our inclusion criteria. This resulted in a total of 117 articles included in our full systematic review.

[INSERT FIGURE 2 APPROXIMATELY HERE]

Findings

Among the 117 articles included in our full systematic review of science and engineering teaching self-efficacy, only 13 empirical studies focused specifically on engineering teaching self-efficacy. In this section, we will describe our synthesis of these 13 studies. These studies were all published between 2017 and 2022, demonstrating the emergent nature of research into engineering teaching self-efficacy. Eight of the studies focused on preservice teachers, while five focused on inservice teachers' engineering teaching self-efficacy. Five utilized mixed methods, six were quantitative, and two were qualitative. Twelve of the 13 studies were conducted in the U.S., and the remaining study was conducted in the United Kingdom.

Preservice Engineering Education

In exploring the contexts of studies focusing on engineering teaching self-efficacy, we found that four out of eight studies were conducted within semester-long courses. Among the four, only two courses explicitly focused on engineering design, and other associated activities involving Lego Mindstorms EV3 Educational Robotics kits (e.g., Yesilyurt et al., 2021), activities from Engineering is Elementary (EiE®) curriculum (Perkins Coppola, 2019) occurred throughout the semester. Vicarious experiences such as watching videos of expert classroom teachers' engineering instruction and reading children's books on engineering were additional elements within the course. Other studies discussed two-week interventions focusing on 3D printing (e.g., Kaya et al., 2019) or engineering activities in conjunction with other disciplines, such as science, language arts, and mathematics (Webb & LoFaro, 2020). While engaging PSTs in engineering design inquiry-based activities (e.g., Nesmith & Cooper, 2021) stood out as a common feature of methods courses, four studies mentioned integrated field experience within the course. In studies conducted by Capobianco et al. (2021) and Perkins Coppola (2019), PSTs created mini-units on engineering that they taught to students in grades K-6. In other studies, using a paired-peer model, PSTs paired with undergraduate engineering student to design engineering lessons and implemented those lessons in elementary classrooms (Fogg-Rogers et al., 2017; Lewis et al., 2021).

While five out of eight studies utilized mixed-methods, the other three studies utilized either quantitative or qualitative methods only. Studies used either the Engineering Teaching Efficacy Beliefs Instrument (ETEBI; Kaya et al., 2019) or Teaching Engineering Self-Efficacy Scale TESS (Yoon et al., 2014) to determine the changes in self-efficacy beliefs from the beginning to the end of the semester or after the two-week long intervention. Three out of eight studies found statistically significant differences for both PETE and ETOE; however, there was a larger effect size for PETE as compared to ETOE. In contrast, Perkins Coppola (2019) found no significant change between ETOE scores from beginning to the end of the semester; however, the small effect size could be a factor. Kaya and colleagues (2019) found similar results with ETOE not being significant after preservice teachers were exposed to a two-week long 3D printing experience. Both studies (Kaya et al., 2019; Perkins Coppola, 2019) indicated the need for improving preservice teachers' practical knowledge and allowing for opportunities to apply what they learned, but also mentioned time as a significant barrier. In the studies that involved a field-experience component as part of a teaching methods course, preservice teachers found mastery, or firsthand teaching, experiences involving lesson planning and implementing the lessons with 5th and 6th graders beneficial in changing their perceptions of teaching engineering. Vicarious experiences and emotional states contributed to self-efficacy but to a lesser degree than mastery experiences.

Preservice Gaps and Future Directions

Several gaps in the PST literature emerged from this review. First, most studies on PSTs' engineering teaching self-efficacy have been framed within the context of methods courses that are semester-long; however, many of the engineering-focused interventions have had short durations. Among the eight studies exploring PSTs' engineering teaching self-efficacy within methods courses, only one study explicitly focused on engineering activities throughout the semester, while other studies reported on two weeks of engineering design-based interventions. While there has been an increased emphasis on engaging PSTs in engineering practices and engineering design, the time devoted to engineering in science methods courses is often limited (Webb & LoFaro, 2020).

Second, although the semester-long studies found positive changes in personal engineering teaching self-efficacy, it is difficult to claim the achievement as a lasting one. More longitudinal studies are needed to explore whether the changes in engineering teaching self-efficacy sustain over time and translate into practice. Long-term studies would also be helpful to explore the factors that impact changes in self-efficacy beyond the intervention, thereby assessing whether changes are due to interventions alone or may be due to other mediating factors.

Third, findings related to significant changes in engineering teaching outcome expectancy are inconsistent. For instance, outcome expectancy had a low effect size in some studies (e.g., Yesilyurt et al., 2021), while other studies found no significant changes in outcome expectancy but significant positive changes personal engineering teaching self-efficacy (e.g., Perkins Coppola, 2019; Kaya et al., 2019). Several questions arise: What supports are needed to enhance PSTs' engineering teaching outcome expectancy? What contextual factors inform both personal and outcome expectancy?

Lastly, few studies provided firsthand engineering teaching experiences to preservice teachers, even though benefits of practicum experiences that explicitly focus on classroom engineering teaching have been emphasized. While there is a strong need for inquiry and engineering design-based mastery experiences for PSTs, research should continue to explore how engineering teaching self-efficacy is shaped within contexts such as practicum, formal classroom teaching, and informal settings (e.g., science museums).

Inservice Engineering Professional Development

Among the five engineering self-efficacy studies that focused on inservice elementary teachers, one (Hammack & Ivey, 2017) collected descriptive data from a large sample of teachers (n = 542), with the goal of identifying teachers' engineering teaching self-efficacy levels. Utilizing the TESS (Yoon et al., 2014), Hammock & Ivey (2017) established that teachers had significantly lower scores on the engineering pedagogical content knowledge self-efficacy subscale than they did on subscales that measured engineering engagement self-efficacy, engineering disciplinary self-efficacy, and engineering outcome expectancy. There were no significant differences in self-efficacy scores based on participant ethnicity, grade level taught, education attainment level, pathway to certification, years of teaching experience, or Title I school status.

The four additional studies of inservice elementary teachers considered whether particular professional development approaches supported improved engineering teaching self-efficacy among participants. The total number of participants ranged from 14-43 in these studies. Three of the studies (Ficklin et al., 2020; Parker et al., 2020; Utley et al., 2019) focused specifically on PD related to the Engineering is Elementary (EiE®) curriculum, and the fourth study (Rich et al., 2017) also included experiences that utilized EiE® materials. These PD experiences ranged from a single day of training (Ficklin et al., 2020) to a full year of weekly PD sessions (Rich et al., 2017). Findings revealed positive effects of the PD experiences on elementary teachers' engineering teaching self-efficacy (Ficklin et al., 2020; Parker et al., 2020; Rich et al., 2017; Utley et al., 2019). While long-term PD is known to be beneficial to teachers (e.g., Desimone, 2009), these findings suggest that even short-term engineering PD experiences can be beneficial to elementary teachers.

Inservice Gaps and Future Directions

While the aforementioned studies provide promising results related to the effects of PD on inservice teachers' engineering teaching self-efficacy, it is important to note that significant gaps in the literature remain. With only five studies, the generalizability and replication of findings are unclear. Longitudinal studies are greatly needed to better understand shifts in self-efficacy over time, and studies that employ a range of research methods to explore a range of inservice contexts, including a variety of PD programs, will deepen our understanding of engineering teaching self-efficacy development. Further, it is unclear whether positive shifts in self-efficacy translate to improved teaching practices. Additional studies are also needed to pinpoint the specific aspects of professional development experiences that advance engineering teaching self-efficacy to inform the design of PD experiences moving forward.

Contribution to Science Teacher Education and Interest to ASTE Members

As we reviewed the body of research on PST and IST engineering teaching self-efficacy, we synthesized the insights found therein while simultaneously recognizing persistent gaps in the literature. We acknowledge the dynamic nature of teaching self-efficacy and recognize the need for a deeper examination of the nature, characteristics, and specific aspects of contexts that support the development of engineering teaching self-efficacy among elementary teachers.
Our hope is for our future empirical studies to generate a set of research-based recommendations for preservice and inservice education and training opportunities that support engineering teaching self-efficacy development, and thereby influence teaching effectiveness and teacher retention. This presentation will be of interest to ASTE members involved in preservice teacher preparation and inservice teacher professional learning related to engineering education. In particular, those with an interest in elementary teaching will find this presentation useful.

Table 1
Search Terms used for Database Search

Search Term	Location
self-efficacy	Abstract
teach*	Abstract
elementary	All Text
(preservice OR pre-service OR inservice OR in-service)	All Text
(science OR engineering)	All Text

Note. * is used to broaden a search by finding words that start with the same letters. For example, teach* would find teacher, teaching, etc.

Figure 1
Teaching Self-Efficacy Model

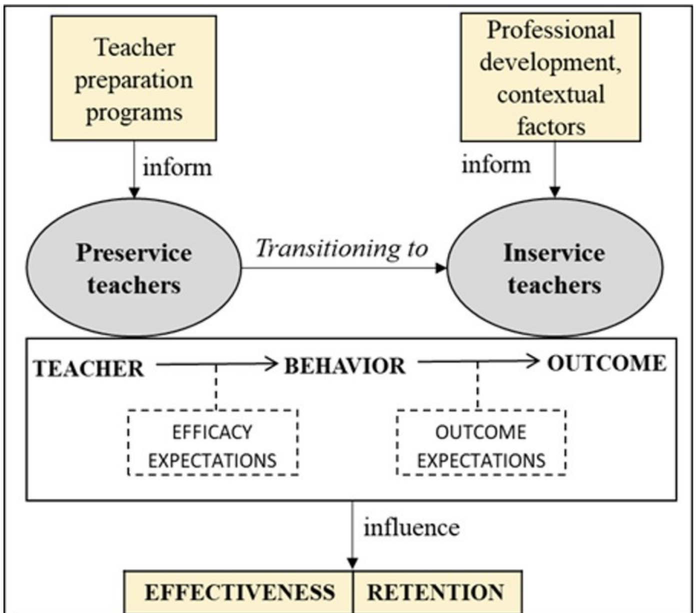
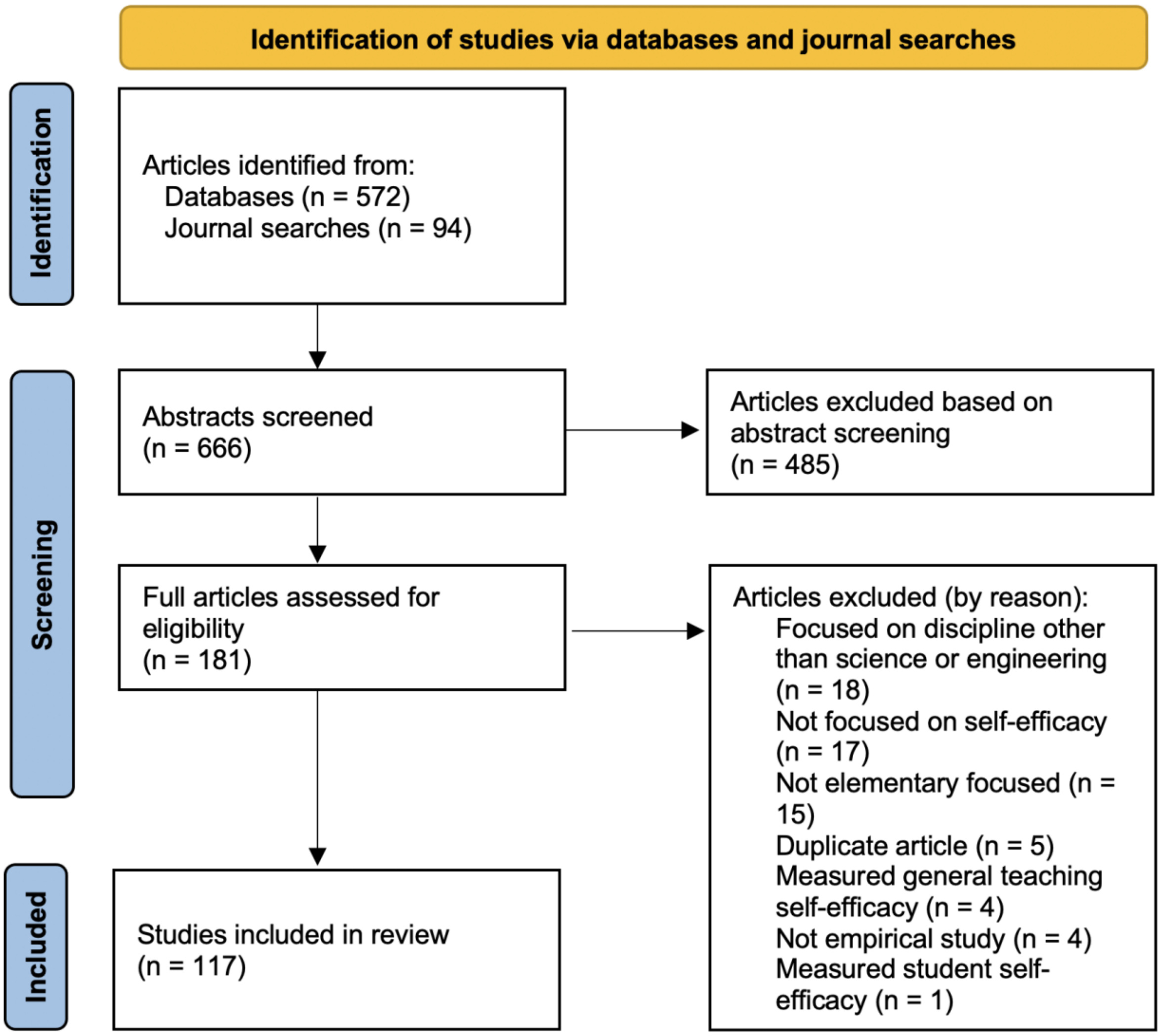


Fig 1. A Research-based Framework for Teacher Self-efficacy

Figure 2

Systematic Review Flow Diagram



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