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To cite this article: Deepika Menon, Jeanna R Wieselmann, Sarah Haines & Sumreen Asim (08 Jan 2024): A Meta-Synthesis of the Literature on Science & Engineering Teaching Self-Efficacy: Current Gaps and Future Research Directions, Journal of Science Teacher Education, DOI: [10.1080/1046560X.2023.2297499](https://doi.org/10.1080/1046560X.2023.2297499)

To link to this article: <https://doi.org/10.1080/1046560X.2023.2297499>



Published online: 08 Jan 2024.



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A Meta-Synthesis of the Literature on Science & Engineering Teaching Self-Efficacy: Current Gaps and Future Research Directions

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ABSTRACT

Self-efficacy is a topic of great interest in elementary preservice and inservice teacher education given that elementary teachers often have low self-efficacy for STEM teaching. In this article, we synthesize the existing literature on science and engineering teaching self-efficacy to (1) explore trends in science and engineering teaching self-efficacy research, (2) identify current gaps that exist in the literature, and (3) propose a visual model to provide future direction in research. Utilizing a qualitative meta-synthesis, we analyzed 88 articles focused on science and engineering teaching self-efficacy. Of these articles, 66 studied preservice teachers, 21 studied inservice teachers, and one included both preservice and inservice teachers. Findings indicate that the diversity of teacher education programs, both across the United States and globally, offers a rich context for considering a range of programmatic features that impact elementary teachers' science and engineering teaching self-efficacy. While efforts to increase self-efficacy span across preservice preparation courses and inservice professional development programs, details concerning the contexts in which science and engineering teaching self-efficacy develop are often limited, making it difficult to claim that gains in self-efficacy are lasting. Based on the meta-synthesis of the existing research findings and gaps in the literature, we offer recommendations to assist researchers and curriculum developers involved in preservice or inservice programs to address the persisting challenges related to science and engineering teaching self-efficacy. The implications for future research and practice in multiple contexts, such as educator preparation programs, teaching, and professional development that target increases in teacher self-efficacy, are discussed.

KEYWORDS

Elementary teaching; meta-synthesis; science and engineering instruction; teaching self-efficacy

Over the last decade in the United States, education reforms have called for a fundamental shift in K-12 science education in order to prepare future generations to solve real-world problems using interdisciplinary knowledge and skills, including engineering (National Academy of Engineering & National Research Council [NAE & NRC], 2014; NGSS Lead States, 2013). *A Framework for K-12 Science Education*

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This article has been corrected with minor changes. These changes do not impact the academic content of the article.

(National Research Council [NRC], 2012) emphasized designing instruction such that “students continually build on and revise their knowledge and abilities over multiple years and support the integration of such knowledge and abilities with the practices needed to engage in scientific inquiry and engineering design” (p. 2). The Next Generation Science Standards (NGSS) recommend three-dimensional learning centered on disciplinary core ideas, science and engineering practices, and cross-cutting concepts to build a comprehensive understanding of phenomena (NGSS Lead States, 2013). This vision requires those training future elementary teachers to overhaul courses to equip them to understand and implement learning aligned with the NGSS 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 foster learner-centered environments in their classrooms (Bleicher, 2017; Lakshmanan et al., 2011; Watters & Ginns, 2000). However, elementary school teachers often have low self-efficacy in teaching science and engineering (Banilower et al., 2018; Custer & Daugherty, 2009; Reimers et al., 2015). Further, there are documented issues with the amount and quality of elementary science instruction (e.g., Brobst et al., 2017). Especially concerning is that many elementary teachers find their preservice teacher (PST) preparation ineffective, leaving them unprepared to teach not only science (Banilower et al., 2018; Gess-Newsome, 1999; Trygstad et al., 2013) but also engineering (Banilower et al., 2018; Reimers et al., 2015). Because engineering instruction involves new content, materials, and teaching styles still uncommon in educator preparation programs (Rogers & Portsmore, 2004), it is unsurprising that elementary teachers have low efficacy in teaching engineering (Hammack & Ivey, 2017).

Given that self-efficacy beliefs are strong preappendctors of motivation and performance, their influence on elementary teachers’ ability 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 (PD) enhance science teaching self-efficacy (e.g., Menon, 2020; Menon & Sadler, 2018; Sinclair et al., 2011). In addition, context-specific characteristics may differ across different contexts (discipline-specific contexts, global contexts, formal or informal teaching contexts) leading to differences in self-efficacy. Still, questions remain: How do different teaching contexts affect PSTs’ science and engineering teaching self-efficacy? What types of PD experiences are most beneficial for enhancing ISTs’ self-efficacy?

Focus of this research

In this article, we aim to (1) explore the trends in science and engineering teaching self-efficacy research, (2) identify research issues and current gaps that exist in the literature, and (3) propose a visual model aimed to provide future directions in research. The research questions that guided our work were:

- (1) What does the existing literature on self-efficacy reveal about fostering preservice elementary teachers’ science and engineering teaching self-efficacy?
- (2) What does the existing literature on self-efficacy reveal about fostering inservice elementary teachers’ science and engineering teaching self-efficacy?

- (3) What are the existing gaps in the research on preservice and inservice science and engineering teaching self-efficacy?

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’s seminal work (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. Consistent with Bandura, Tschannen-Moran et al. (1998) defined teacher efficacy as the beliefs that shape teachers’ abilities to execute certain actions in given situations, which can bring desired results. Teacher efficacy is context-specific, situational, and subject-matter specific (Tschannen-Moran et al., 1998), as with elementary teachers who may prefer other subjects to science because they may perceive their science teaching as inadequate (Appleton & Kindt, 2002).

Self-efficacy comprises two dimensions: personal efficacy and outcome expectancy (Bandura, 1977). Researchers have posited that the dimensions are related but have different implications and can act independently in teacher education (Guskey & Passaro, 1994). In this context, personal efficacy involves teachers’ beliefs in their abilities to motivate and support student learning by creating rich-learning environments; outcome expectancy links to beliefs in whether their actions will yield desired student outcomes (Bandura, 1993). Self-efficacy has also been linked to behavior and interest; self-efficacy beliefs can promote effort and perseverance when dealing with taxing situations (Bandura, 1982).

Bandura (1997) proposed four sources of self-efficacy beliefs: mastery experiences, vicarious experiences, verbal persuasion, and emotional arousal. Within teacher education, mastery experiences involve firsthand teaching in a classroom or student practicum (Gunning & Mensah, 2011; McDonnough & Matkins, 2010; Palmer, 2006a) and could also include lesson planning, group discussions, and teaching reflections (Brand & Wilkins, 2007; Rice & Roychoudhury, 2003). Vicarious experiences allow teachers to observe others thriving in similar situations, promoting confidence in their own teaching (Bandura, 1997). Verbal persuasion refers to the positive feedback teachers receive from instructors, mentor teachers, and supervisors, enhancing motivation and confidence; other verbal persuasion includes support from peers, colleagues, and family (Bandura, 1997; Gunning & Mensah, 2011). Related to emotional arousal, physiological and affective states help individuals interpret and respond to the demands of a given task (Bandura, 1997). For instance, a teacher may be “more inclined to expect success” with teaching science when they are “not beset by aversive arousal” (Bandura, 1997, p. 106). In contrast, those who feel tense and “viscerally agitated” (Bandura, 1997, p. 106) by science or engineering may not believe that they are effective in teaching these disciplines.

Palmer (2006b) suggested three additional sources of self-efficacy: cognitive content mastery (hands-on learning), cognitive pedagogical mastery (knowledge about reform-based pedagogies and how to apply them), and stimulated modeling (self-images of teaching). These lie in specialized content courses, methods courses, and classroom experiences. Similarly, instructor modeling of reform-based approaches like inquiry and the 5E (Engage,

Explore, Explain, Elaborate, and Evaluate) model for scientific investigations (Bybee, 1997; Rice & Roychoudhury, 2003; Seung et al., 2019), lesson development using argumentation (Aydeniz & Ozdilek, 2016), and implementation of the engineering design process (Perkins Coppola, 2019) likewise enhance self-efficacy. Field experiences accomplish this by engaging PSTs in practice-based science (Menon & Azam, 2021a; Cantrell, 2003; Palmer, 2006a; Varma & Hanuscin, 2008) and critical reflections on teaching practices (Mangano & Menon, 2020; Brand & Wilkins, 2007; Mulholland & Wallace, 2001). More recently, it has been found that inquiry-based specialized content courses that blend content and pedagogy together have elements to promote PSTs' self-efficacy beliefs (Menon & Sadler, 2016; Avery & Meyer, 2012; Narayan & Lamp, 2010).

Methodology

Research design: qualitative meta-synthesis

We utilized a qualitative meta-synthesis (Timulak, 2009) as our methodological approach to synthesize the existing literature with an aim to provide a concise and comprehensive picture of findings from studies that investigated science and engineering teaching self-efficacy across multiple contexts. The meta-synthesis was well suited for the current work because the process includes an “integrative interpretation of the findings” (Finfgled, 2003, p. 894) to identify gaps in the current research and provide new insights that advance the field's understanding of science and engineering self-efficacy. To answer our research questions, we conducted a qualitative meta-synthesis based on Newman and Gough's (2020) and Timulak's (2009) recommendations.

Search criteria and search strategy

First, we defined our search and 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 the initial round of searches in databases, including EBSCO Education Source, APA PsychInfo, and Education Resources Information Center. Several combinations of search terms were tested, and the terms that yielded the most relevant results are shown in Table 1. We also used the search functions to align with the screening criteria, limiting publication dates to 2010-present and restricting search results to peer-reviewed publications. In reviewing the 572 results from the first

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

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

round of database searches, 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.

Considering quality appraisal and fit

With the 666 resulting articles, four researchers with qualitative analysis experience divided and initially screened the titles and abstracts to determine the article fit according to our inclusion criteria. In addition to our search criteria, we considered one additional inclusion criterion: we only included studies that described activities intended to support self-efficacy development within teaching contexts; thus, we did not include articles that merely offered descriptive information about the self-efficacy levels of a certain population. As we screened the articles for fit, we considered article quality in several ways related to our search criteria. First, articles from *peer-reviewed journals* were included, while dissertations, conference presentations, and book chapters were not, even though we acknowledge that those venues bring important contributions. Second, *empirical* studies that explored the self-efficacy beliefs of *elementary* PSTs and ISTs teaching science or engineering were included. Practitioner journal articles either demonstrated an instructional strategy or suggested inquiry lessons where self-efficacy was only implicitly addressed as one outcome, so these were excluded. While the study designs varied in relation to their rigor, we maintained all studies that met our inclusion criteria, were published in peer-reviewed journals, and reported empirical data.

Each article was screened by two researchers to ensure an assessment of the quality and fit of the included studies. At this stage, 485 articles were excluded. Reasons for exclusion at this stage included (1) lacking a focus on self-efficacy, (2) focusing on preK-12 student (rather than PST or IST) self-efficacy, (3) focusing on teacher self-efficacy at non-elementary grades, and (4) focusing on self-efficacy in disciplines other than science and engineering.

The full texts of the remaining 181 articles were downloaded and reviewed in their entirety for further consideration of quality and fit with our inclusion criteria. At this point, an additional 93 articles were excluded because they did not align with our inclusion criteria, resulting in a total of 88 articles included in our meta-synthesis (see [Figure 1](#)). The articles excluded at this stage included studies with large datasets aimed to develop or validate a self-efficacy instrument or provide aggregate quantitative self-efficacy results from their preservice programs without detailing activities or teaching contexts that shaped self-efficacy. Without additional information about the context or types of activities that influenced self-efficacy, it was impossible to identify implications or programmatic recommendations for fostering self-efficacy based on the provided information. Thus, given the goal of this study to identify experiences that help explain *how* to foster self-efficacy (not just *whether* self-efficacy changes over the course of a program), we looked for articles with details about research contexts and the nature of interventions or experiences that shaped PSTs' or ISTs' self-efficacy beliefs.

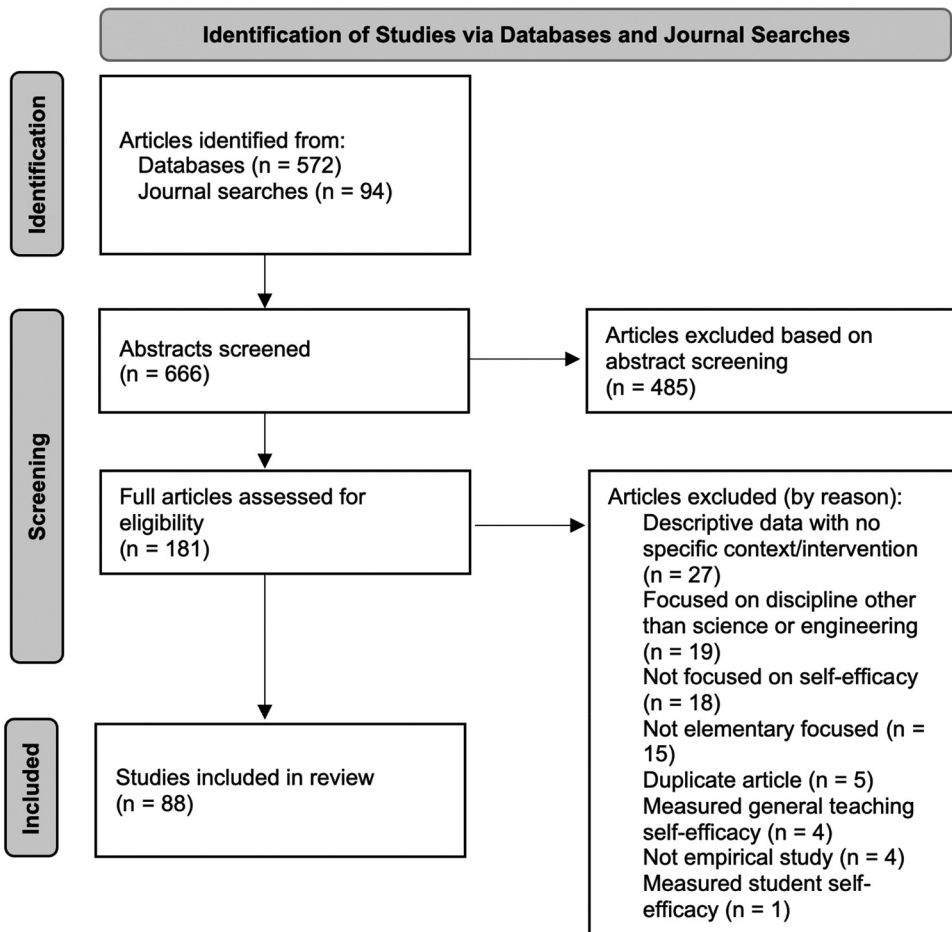


Figure 1. Meta-synthesis flow diagram.

Analysis and synthesis

The articles were analyzed using thematic analysis (Nowell et al., 2017) as a three-step process. First, the research team met to develop a strategic plan to determine the unit of analysis to analyze the selected articles for several criteria: content focus (science or engineering), methodology (qualitative, quantitative, mixed-methods), participant type (preservice or inservice), number of participants, the country in which the study was conducted, research context, intervention details (type of intervention, duration, nature of experience), data sources (instruments used and/or qualitative sources of data), and key findings. We created a spreadsheet with columns for reporting on each of the criteria. Second, four researchers randomly selected and independently analyzed ten articles. After the discussion and reaching a consensus, ten additional articles were analyzed. With an established analysis procedure, the researchers analyzed the remaining articles so that all 88 were analyzed. To avoid researcher bias, a second researcher was assigned to cross-check the analysis conducted by the initial researcher for each article.

The third round of review and analysis was conducted to analyze the significance of the findings, gaps, and future directions highlighted in the articles. The findings, discussion, and conclusion sections of each article were revisited to take note of the key issues, gaps, and recommendations suggested. Each researcher revisited the same article for analysis, followed by another round of cross-checking the analysis conducted by a second researcher. The individual article analysis results were further grouped into categories representing patterns in the data to understand the trends in the literature related to science and engineering teaching self-efficacy, persistent gaps and research issues, and recommendations for future research.

Validation and methodological integrity

Several steps were taken to ensure validity and integrity during the meta-synthesis with the goal of establishing trustworthiness in our research design and approach to support our meta-synthesis. We adopted the key principles of methodological integrity and validity as a guide for researchers to remain true to their specific aims and methods, and to understand that there are strengths and limitations when working together as a team of researchers (Fingeld-Connett, 2018). We also ensured validity checks for qualitative research including “appropriateness of the tools, processes, and data” (Leung, 2015, p. 325). At least two researchers considered each article at each analysis phase to determine whether the inclusion/exclusion decision was appropriate, and areas of uncertainty were brought to the full research team before a final decision was made. Throughout the course of the analysis, the researchers met weekly to revisit the research questions and analytical approach, discuss expectations, develop data reporting procedures, identify and resolve differences when analyzing articles, increase awareness and transparency about their own perspectives, and maintain notes and procedures on the spreadsheet.

Findings

Our meta-synthesis included 88 articles focused on science and engineering teaching self-efficacy. Of these articles, 66 studied preservice teachers, 21 studied inservice teachers, and one included both preservice and inservice teachers. The findings are organized into three parts according to the research questions. First, we discuss the trends in literature around preservice science and engineering teaching self-efficacy (research question 1). Second, we present the findings from the synthesis of articles related to inservice science and engineering teaching self-efficacy (research question 2). Finally, we summarize the gaps in the literature on PST and IST science and engineering teaching self-efficacy (research question 3).

Preservice science teaching self-efficacy: trends

Out of 66 studies of PST science teaching self-efficacy, 49 were conducted in science methods courses, with two different designs that were prominent: science methods course with no practicum ($n = 33$), and science methods course with an embedded field-based component ($n = 16$). Many studies reported increases in self-efficacy based on qualitative methods only; however, the Science Teaching Efficacy Belief Instrument (STEBI) Form

B (Enochs & Riggs, 1990) was the most popular survey employed within studies that used quantitative or mixed methods.

In general, science methods courses supported the development of PSTs' self-efficacy in a variety of ways in that they engaged learners in inquiry-based activities (Seung et al., 2019; Soprano & Yang, 2013) that modeled reform-based pedagogies such as the 5E model (Bergman & Novacek, 2021; Bybee, 1997), science and engineering practices (Kang et al., 2019), and students' use of scientific argumentation (Aydeniz & Ozdilek, 2016; Eymur & Çetin, 2017). Lesson design, implementation of the lesson in an elementary classroom, and reflections on teaching were important elements for courses with an embedded practicum experience (Mangano & Menon, 2020; Menon & Azam, 2021a; Aydeniz & Ozdilek, 2016; Bergman & Novacek, 2021; Eckhoff, 2017; Leonard et al., 2011; McDonnough & Matkins, 2010; Rinke et al., 2016). Evidence highlights the significance of field experiences and student teaching in instilling self-efficacy for science teaching, but whether field teaching should be part of the science methods course or follow immediately after remains a subject of debate. Studies reporting the impact of field experiences have yielded mixed results in terms of the significant gains in personal science teaching efficacy and science teaching outcome expectancy (Hechter, 2011; McKinnon & Lamberts, 2014).

The results from the studies conducted within the context of specially designed content courses (courses that integrate pedagogy with content) ($N = 17$) for PSTs seem positive in terms of their impact on self-efficacy. Studies have identified various supports for PSTs during specialized content courses, including hands-on inquiry (Menon & Sadler, 2016, 2018; Avery & Meyer, 2012; Gray, 2017), instructor role modeling pedagogies such as the learning cycle and argumentation (Menon & Sadler, 2018; Knaggs & Sondergeld, 2015; Narayan & Lamp, 2010), and instructor enthusiasm (Palmer et al., 2015). Although these findings are promising, the enduring impact on self-efficacy stands undetermined; Menon & Sadler (2018) found that PSTs remained hesitant about their content preparedness. The reinforcement of content learned in methods courses may uphold gains in self-efficacy.

Preservice engineering teaching self-efficacy: trends

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 with other associated activities involving Lego Mindstorms EV3 Educational Robotics kits (e.g., Yesilyurt et al., 2021) and activities from Engineering is Elementary (EiE®) curriculum (Perkins Coppola, 2019) 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 courses. 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). Engaging PSTs in engineering design and inquiry-based activities (e.g., Nesmith & Cooper, 2021) stood out as a common feature of methods courses, integrated field experience in engineering was mentioned in four studies only. In studies conducted by Capobianco et al. (2022) and Perkins Coppola (2019), PSTs created mini-units on engineering that they taught to students in grades K-6. In other studies, PSTs paired with

engineering students to design and implement engineering 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 used either quantitative or qualitative methods. 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 over time. Three out of eight studies found statistically significant differences for both personal engineering teaching efficacy and engineering teaching outcome expectancy; however, there was a larger effect size for personal engineering teaching efficacy as compared to engineering teaching outcome expectancy. In contrast, Perkins Coppola (2019) found no significant change in engineering teaching outcome expectancy scores from the beginning to the end of the semester; however, the small effect size could be a factor. Kaya et al. (2019) found similar results, with engineering teaching outcome expectancy 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 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.

Inservice science teaching self-efficacy: trends

The 18 studies of science teaching self-efficacy among elementary ISTs explored a range of PD contexts, including professional learning communities (Mintzes et al., 2013), collaborative teacher curriculum design (Velthuis et al., 2015), informal science education organizations (McKinnon & Lamberts, 2014), a massive open online course (Tzovla et al., 2021), video case-based PD (Sang et al., 2012), research experiences for teachers (Enderle et al., 2014), and online graduate coursework (Gosselin et al., 2010). Despite the range of experiences, all studies provided evidence of improved self-efficacy as a result of participation in PD, likely because these experiences were specifically designed to promote growth.

These science teaching self-efficacy studies also ranged in the number of teacher contact hours and duration. Some were relatively short in duration, with PD experiences lasting as little as four hours (McKinnon & Lamberts, 2014) or occurring across five or six weeks (e.g., Enderle et al., 2014; Tzovla et al., 2021), while others spanned multiple years (e.g., Kang et al., 2019; Lumpe et al., 2012; Mentzer et al., 2017; Mintzes et al., 2013; Sandholtz & Ringstaff, 2014; Sandholtz et al., 2019). Notably, even those studies that utilized relatively short-term PD interventions demonstrated some positive effects on science teaching self-efficacy. For example, Tzovla et al. (2021) found that teacher participation in an online course focused on teaching biological concepts demonstrated medium to high effect sizes for self-efficacy improvements compared to teachers who did not participate.

The studies provide mixed evidence about whether PD experiences result in improvements in personal efficacy and outcome expectancy. Some studies (e.g., Gosselin et al., 2010; Mintzes et al., 2013; Sandholtz & Ringstaff, 2014; Sinclair et al., 2011; Tzovla et al., 2021) found both to be positively impacted by PD. Other studies (e.g., Enderle et al., 2014;

McKinnon & Lamberts, 2014; Sang et al., 2012) reported positive effects of PD on personal science teaching efficacy only, suggesting that science teaching outcome expectancy may be more difficult to influence through PD. Mentzer et al. (2017) found that teachers already had high levels of outcome expectancy, so they attributed a lack of change in this area to ceiling effects.

Few studies considered the nature of PD experiences and the specific elements that contributed to improved teacher self-efficacy. One notable exception is Palmer (2011), who specifically studied the sources of self-efficacy beliefs among teachers who experienced a PD intervention intentionally designed to provide them with a range of experiences. In this study, increases in self-efficacy were primarily the result of cognitive mastery (perceived success in understanding how to teach science) and verbal persuasion (feedback on instructional practices); vicarious experiences and enactive mastery were less central in influencing self-efficacy beliefs. Mintzes et al. (2013) also considered various sources of self-efficacy beliefs, identifying that mastery and vicarious experiences, as well as emotional reinforcement and social persuasion, all contributed to shifts in teaching self-efficacy.

A handful of studies focused on understanding teachers' views on their perceived needs to succeed in the profession and the factors that affected their science instruction. The interview responses from teachers suggested poor academic preparation in science as a common barrier to self-efficacy and effective elementary science instruction; in contrast, feelings of empowerment associated with specific hands-on activities, opportunities for collaboration and emotional support, and directly observed positive outcomes for students can impact elementary teachers' self-efficacy for teaching science (Mintzes et al., 2013; Sandholtz & Ringstaff, 2014). Other studies identified several contextual factors (e.g., limited instructional time for science, a lack of quality curriculum resources, financial and administrative support) and socioeconomic barriers (e.g., anxiety, frustration, inadequacy), and a lack of science professional development (Loach, 2021; Sandholtz et al., 2019).

While self-efficacy is a useful goal in itself, it is important to consider whether teachers with higher teaching self-efficacy also demonstrate higher quality instruction. Indeed, some studies have found this to be true, with growth in self-efficacy translating into classroom practice in terms of the amount of instructional time or quality of instructional practices (e.g., Kang et al., 2019; Sandholtz & Ringstaff, 2011, 2014). However, van Aalderen-Smeets and van der Molen (2015) note that despite improvements, only 27% of teacher participants reported teaching science at least once a month, showing much room for improvement remains even after PD experiences. Mentzer et al. (2017) found that changes in instruction took two or three years to observe. Further, not all studies showed that improved self-efficacy was linked to changes in instruction. Despite growth in science teaching self-efficacy, elementary teacher participants in Enderle et al. (2014) research experiences for teachers did not demonstrate improved instructional practices. Granger et al. (2019) found that teachers who entered their PD experience with high levels of self-efficacy experienced less learning; interestingly, this was also true of these teachers' students, who learned less than students of teachers who entered with lower self-efficacy levels. In another study that explored connections between PD, self-efficacy, and student outcomes, Lumpe et al. (2012) found that student science achievement was predicted by the number of hours their teachers participated in

the PD program. However, many other factors, including resources, instructional time, testing requirements in mathematics and language arts, classroom practices, and administrative and peer support, also likely influence the links between teacher self-efficacy and student outcomes (e.g., Lumpe et al., 2012; Sandholtz & Ringstaff, 2011, 2014; Sandholtz et al., 2019).

Inservice engineering teaching self-efficacy: trends

The four studies of engineering teaching self-efficacy among inservice elementary teachers considered whether particular PD 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), and findings revealed positive effects of PD experiences on elementary teachers' engineering teaching self-efficacy. For example, Utley et al. (2019) highlighted that PD experiences can support teachers in simultaneously developing content knowledge in science and engineering, while also advancing their engineering teaching self-efficacy; this allowed participants to develop a more comprehensive understanding of engineering and overcome uncertainties and misconceptions. Ficklin et al. (2020) qualitative analysis of teacher interviews revealed that after experiencing PD, elementary teachers recognized that they had already been utilizing engineering teaching practices and saw engineering integration as achievable with adequate professional supports. Parker et al. (2020) highlighted quantitative findings from the same project as Ficklin et al. (2020) and utilized repeated measures to demonstrate that engineering teaching efficacy and beliefs, engineering teaching outcome expectancy, and engineering instructional practices increased over time in association with the PD experience. Rich et al. (2017) found that while PD was one factor that mediated teachers' engineering self-efficacy beliefs, their background in engineering, actual experiences implementing engineering instruction, and disposition to experiment with untested ideas also served as mediating factors. 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 advance elementary teachers' engineering self-efficacy.

Gaps in the literature on science and engineering teaching self-efficacy

While the studies included in this qualitative meta-synthesis provided promising results related to interventions that support PSTs' and ISTs' science and engineering teaching self-efficacy, it is important to note that significant gaps in the literature remain. First, findings related to personal teaching self-efficacy and outcome expectancy are inconsistent, and it is unclear why some interventions support improved outcome expectancy while others do not. For instance, in exploring PSTs' engineering teaching outcome expectancy specifically, some studies demonstrated low effect sizes for outcome expectancy (e.g., Yesilyurt et al., 2021), while others found no significant changes in outcome expectancy but significant positive changes in personal engineering teaching self-efficacy (e.g., Kaya et al., 2019;

Perkins Coppola, 2019). Similarly inconsistent findings are also shown within the IST literature. These inconsistencies raise questions such as: What specific supports are needed to enhance PSTs' and ISTs' teaching outcome expectancy? What contextual factors inform both personal and outcome expectancy?

Second, the studies report a wide range of contexts for preservice and inservice learning. With varying programmatic elements, foci, and durations, it is difficult to disentangle the effects of the many factors that may relate to self-efficacy. Further, at times, the specific contexts in which these learning experiences occur are insufficiently detailed, leaving questions about the possibility of replication. Research should continue to explore how self-efficacy is shaped within contexts such as practicum and student teaching placements, formal classroom teaching, and informal settings (e.g., science museums), as well as what types of professional development experiences teachers believe would promote a deeper sense of self-efficacy.

Third, these concerns about a clear understanding of key intervention features and generalizability are further magnified within engineering contexts, with a literature base that is just emerging. While engineering practices and engineering design are increasingly emphasized in PST programs, the time devoted to engineering in science methods courses is often still limited (Webb & LoFaro, 2020). For example, among the studies that explored PSTs' engineering teaching self-efficacy within methods courses, only one study (Perkins Coppola, 2019) explicitly focused on engineering activities throughout the semester, while other studies (e.g., Kaya et al., 2019; Yesilyurt et al., 2021) reported on short-term engineering design-based interventions such as 2-week interventions or a mini-engineering unit as part of the science methods course. Only four studies of ISTs' engineering teaching self-efficacy were included in the meta-synthesis, demonstrating the need for more research that focuses on engineering specifically.

Finally, studies varied widely in the duration of interventions. Although semester-long coursework and short-term PD programs often found positive changes related to self-efficacy, it is impossible to claim the achievement as a lasting one. Longitudinal studies are greatly needed to better understand shifts in self-efficacy over time and whether positive effects persist. The sustainability of these outcomes must be considered (Sandholtz et al., 2019), particularly as teachers face new challenges and constraints in their teaching contexts. Further, it is unclear to what extent and in which contexts positive shifts in self-efficacy translate to improved teaching practices. Qualitative and mixed-methods research that elaborates on the learning context to understand how or why changes occur (Hatch, 2002) is much needed. Long-term studies would also be helpful in exploring the factors that impact changes in self-efficacy beyond a given intervention, thereby assessing the wide range of mediating factors that likely relate to shifts in self-efficacy beyond designed interventions. By addressing these gaps in the literature, teacher educators and researchers can increasingly ensure that learning experiences are intentionally designed to advance science and engineering teaching self-efficacy and practice.

Discussions and recommendations for future research

In this section, we summarize the findings found through the meta-synthesis, followed by recommendations for future research in the field of self-efficacy in light of the challenges

and gaps identified in the previous section. Reflecting on the research findings, we stress that self-efficacy is a powerful construct for deepening our understanding of teacher motivation, behavior, and performance. Elementary science teaching, however, has long been beset by low teaching self-efficacy. Magnified by the growing emphasis on engineering in elementary science education, similar concerns now exist for engineering teaching self-efficacy as well.

While studies suggesting increases in PST science or engineering teaching self-efficacy during training seem promising (e.g., Mangano & Menon, 2020; Menon & Azam, 2021b; Yesilyurt et al., 2021), much remains unclear about developing and sustaining self-efficacy over the long term. Conflicting findings, especially involving increases in personal teaching efficacy versus outcome expectancy in preservice methods courses and field experiences, indicate the need for additional investigation. With few studies directly asking teachers about what would help improve their self-efficacy, additional research could contribute to a deeper understanding of teachers' own perceived needs. Furthermore, that many findings are from short-term or semester-long interventions makes generalization difficult. In addition, the studies are insufficiently detailed about context, demanding greater specification to understand how self-efficacy is shaped within, for example, PST preparation coursework, informal and formal school contexts, and PD programs. Because various factors mediate self-efficacy within a particular context, more studies are needed to explore the processes that lead to changes in self-efficacy. The field will benefit from empirical studies that establish the "plasticity of the determinants of self-efficacy" (Gist & Mitchell, 1992, p. 184). This would require an expanded focus on the factors that affect lasting changes in self-efficacy, sources of self-efficacy as valued by teachers within a particular context, and challenges associated with facilitating changes in self-efficacy across contexts.

The issues identified in our review provide a strong rationale for a set of recommendations for researchers and educators to build an agenda for addressing these gaps. Based on the insights from the existing research on science and engineering teaching self-efficacy, we offer three important recommendations to help guide future researchers to move the field forward. These are

- Track changes in elementary teachers' science and engineering self-efficacy as they shift from preservice programs to inservice teaching positions.
- Identify key time points in the teaching career trajectory when self-efficacy wanes or increases, as well as identify the elements (the role of context) of PST and IST training that support science and engineering self-efficacy at these time points.
- Investigate the critical links between self-efficacy, teaching effectiveness, and retention in the field of teaching.

We propose a model that emphasizes the proposed recommendations (see [Figure 2](#)). In the following sections, while referencing [Figure 2](#), we detail each of the key components, drawing upon the relevant literature.

Self-efficacy among PSTs

The model positions PST education programs (science content courses, science methods courses, and field experiences, collectively) as a suitable context for PSTs' development of

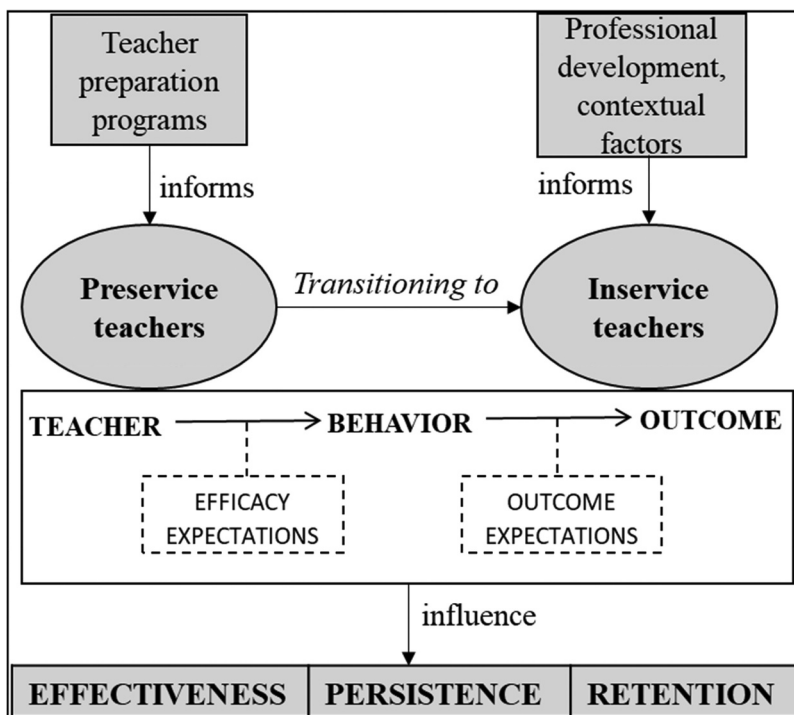


Figure 2. A model for self-efficacy research.

science and engineering teaching self-efficacy beliefs. We propose that investigating changes in PST self-efficacy collectively throughout the educator preparation program will provide a deeper understanding of how the program structure, course content and instructional design, and other mediating factors influence the development of self-efficacy. In sum, long-term studies that investigate overall changes in self-efficacy during educator preparation programs are warranted.

As PSTs take a variety of courses, teacher educators (as instructors of these courses) hope that PSTs will be able to see connections across them. This is challenging because many PSTs take content courses that rely on traditional approaches; methods courses may be their introduction to reform-based pedagogies, which they have not seen applied in content courses. Longitudinal studies across the span of educator preparation programs will not only help researchers understand how each course impacts PSTs' science and engineering teaching self-efficacy beliefs but may also invite teacher educators to seek a strategic approach to better integrate topics addressed in various preservice courses (e.g., more strategic dialogue and discussion between content and methods course instructors). At the same time, studies must focus on the various course-related factors that engender self-efficacy.

From preservice to inservice: the transition

Self-efficacy beliefs about motivation, action, and performance determine one's ability to mobilize an effort to achieve the desired goal, termed the "mobilization

component” (Bandura & Wood, 1989; Gist & Mitchell, 1992, p. 185). The proposed framework recognizes the dynamic nature of self-efficacy: self-efficacy can change with experiences gained within various formal and informal professional contexts. Evidence suggests that PSTs are anxious about science and engineering teaching, which negatively affects goal setting and performance (Capobianco et al., 2022). Higher self-efficacy yields greater effort, a key phenomenon during the little-studied transition from preservice to inservice teaching. In order to succeed, PSTs need the confidence to overcome the challenges they may initially experience. It is important to capture how and why shifts in science and engineering teaching self-efficacy occur so we may better understand the continuity in self-efficacy beliefs (Clandinin & Connelly, 1999). Our definition of *continuity*, as conceptualized by Clandinin and Connelly (1999), is research that builds on PSTs’ prior experiences and experiences within the teacher programs, within the school contexts, and beyond (e.g., PD programs, out-of-school experiences).

Studies have shown that the nature of prior science experiences may influence self-efficacy as PSTs enter educator preparation programs (Menon & Sadler, 2016; Yoon et al., 2006). Because self-efficacy is a dynamic construct, we contend that new experiences in a variety of courses—whether content, methods, or field-based—reshape PST beliefs about science and engineering teaching. Educator preparation programs inform the self-efficacy of PSTs, which in turn predicts how well they transition into their beginning years of teaching while managing the stress of performing in a new environment. Deehan et al. (2020) investigated the transition and found that although high self-efficacy levels from teacher preparation were maintained, the school science culture was a significant factor that impacted teacher practices. Self-efficacy beliefs shaped by educator preparation programs continue to develop throughout this transition; however, little is known about how self-efficacy is supported during this time. Investigating PSTs’ self-efficacy trajectories as they transition to inservice teachers is crucial to understand what factors from past, present, and future influence retention.

Self-efficacy among ISTs

Self-efficacy continues to develop as teachers progress through their early years of teaching and beyond, as the inputs in [Figure 2](#) show. We know from the research literature that a wide range of PD opportunities can advance teaching self-efficacy. However, existing research has not isolated the specific elements of these PD experiences that are most closely related to this improvement. In addition, researchers must consider the personal and contextual factors that both support and hinder self-efficacy, including teachers’ personal reflections on what would be beneficial in supporting their self-efficacy. As previous research has shown, teachers experiencing the same PD can have different takeaways based on their contexts (Bruce et al., 2010). Further, these contextual factors certainly inform teacher self-efficacy outside of the PD experience. There is, therefore, a deep need to consider the supports and challenges to teaching self-efficacy both within and beyond PD experiences.

Further investigation of science and engineering teacher self-efficacy

Moving further in our proposed model, we suggest a deeper investigation of the links between teacher self-efficacy, teacher behavior, and associated outcomes in light of personal efficacy and outcome expectancies. A teacher's perceived efficacy may directly influence their classroom behavior, including but not limited to their choice of activities, organization of science and engineering lessons, and judgment of their ability to handle challenging situations (Bandura, 1997). Moreover, behavioral changes have important implications for performance in the classroom, which can then link to outcomes. In the field of teaching, outcomes can be informed by decisions and actions that teachers may take to produce desired results. Outcome expectancies help teachers set goals, which further bring motivational effects on their efforts to execute actions needed to achieve the goals. Shifts in outcome expectancies are less evident in preservice and inservice teacher education, which calls for further investigation into how to bring desired changes in outcome expectancies through interventions targeted to improve self-efficacy.

Furthermore, we argue that a comprehensive understanding of science and engineering teaching self-efficacy may be better achieved by utilizing and studying multiple frameworks together, rather than isolating self-efficacy as a stand-alone construct in teacher education. For instance, Menon (2020) found that elementary PST development of self-efficacy is closely connected to science teacher identity, and sources of efficacy emerged as strong contributors toward multiple dimensions of identity. Mangano & Menon (2020) drew upon the constructs of science teaching self-efficacy and reflective practice, and their findings suggested that reflective practice provided a critical lens for understanding self-efficacy development. Moreover, there are few studies that conceptualize self-efficacy as multi-dimensional to explore the interplay between personal, social, and contextual factors in shaping teachers' science teaching self-efficacy. The three interrelated factors that influence overall human behavior have been conceptualized by Bandura's triadic reciprocal causation (Bandura, 1977); each of the three factors is linked such that the influence is bi-directional. More examination of these critical links through the lens of reciprocal determinism is needed to understand the interaction between learners (PST or IST), their behaviors (personal and social), and the environment (context) in which self-efficacy develops.

While literature suggests associations between self-efficacy beliefs, teacher effectiveness, and retention in the field, much work remains to solidify these links. With studies that have connected high teaching quality among elementary teachers with their persistence in the field (e.g., Krieg, 2006), it is important to consider how self-efficacy may improve teaching effectiveness and retention. While other researchers have defined teacher effectiveness in a variety of ways, we conceptualize teacher effectiveness broadly rather than solely evaluating a teacher based on student achievement gains. Teacher effectiveness is impacted by a variety of mediating factors; Campbell et al. (2003) argued that "classroom factors, such as teaching methods, teacher expectations, classroom organization, and use of classroom resources, have an impact on students' performance" (p. 3). Self-efficacy beliefs can be posited as a strong predictor of teacher performance and outcomes—collectively, teacher effectiveness.

High self-efficacy may serve as a coping mechanism for early-career teachers to overcome challenges and remain in the profession. Indeed, Klassen and Chiu (2010) found that teachers with greater classroom management and instructional strategy self-efficacy had

greater job satisfaction, and Coladarci (1992) found that high self-efficacy correlates with a commitment to teaching. Further, the model in Figure 2 posits a link between self-efficacy and job satisfaction (Klassen & Chiu, 2011), persistence in working within challenging school environments, and resiliency despite the challenges that occur while negotiating the contextual factors and self-confidence to teach science and engineering (Yost, 2006). By studying both early-career and veteran elementary teachers' science and engineering teaching practices and factors that impact their self-efficacy, teacher educators can design PST and IST support programs that promote self-efficacy and lead to effectiveness and retention in the teaching profession.

Limitations

Because of the well-researched issues of low science preparation, as well as the relatively recent inclusion of engineering instruction within elementary contexts, we chose to focus solely on elementary science and engineering teaching self-efficacy. This review is therefore limited because it only includes studies focusing on science and engineering teaching self-efficacy, while studies of integrated STEM, mathematics, and technology teaching self-efficacy are beyond the scope of this work. Studies involving self-efficacy at other grade levels (e.g., middle or secondary school) or conducted prior to 2010 or those that appeared after February of 2022 were not part of our review process. While we were strategic in our methodology to incorporate means to avoid or minimize the researchers' bias by having multiple researchers code the data, maintaining transparency during our discussions, and checking for alternative explanations to reach a consensus, it is possible that researcher bias influenced our interpretation of findings. We acknowledge that additional literature exists that addresses science and engineering, or STEM teaching self-efficacy among middle and high school teachers. These studies were beyond the scope of the present work.

Conclusions and implications

The proposed model provides a visual illustration to help researchers design long-term studies to address some of the unanswered issues about science and engineering teaching self-efficacy. Our model attends to the dynamism of the self-efficacy construct, allowing researchers to capture shifts over time and across contexts. We theorize that the field will benefit from long-term investigations of self-efficacy beliefs as PSTs *transition* to ISTs. In our model, we treat developing self-efficacy as an *ongoing process* that requires a deeper examination of the nature, characteristics, and specific aspects of contexts.

PSTs entering educator preparation programs vary in their science experiences and teaching beliefs (Menon & Azam, 2021b; Knaggs & Sondergeld, 2015), and many PSTs have not experienced engineering design as part of their K-12 formal schooling (Capobianco et al., 2022; Webb & LoFaro, 2020). Because these experiences shape PST beliefs about science teaching and overall instructional practices, the model positions *continuity* as an important feature in the investigation of self-efficacy, especially as PSTs transition to ISTs. Especially key is the role of personal, situational, and contextual factors in explaining how self-efficacy relates to teacher effectiveness and retention.

In conclusion, this meta-synthesis holds important implications for future research on science and engineering teaching self-efficacy. First, the diversity of teacher education

programs, both across the United States and globally, offers a rich context for considering a range of programmatic features and their relationship to elementary teachers' science and engineering teaching self-efficacy, effectiveness, and retention. Both PSTs and ISTs represent a range of individuals with diverse geographic contexts, personal characteristics and experiences, and varying degrees of teaching experience. As suggested by the literature, a long-term study of elementary PSTs will enable a deeper investigation of self-efficacy, effectiveness, and intent to remain in teaching. Second, the proposed model can serve as a guideline for identifying programmatic features that most support elementary PSTs' and ISTs' self-efficacy in teaching science and engineering. These features can inform not only PST education program design but also resource allocation and professional learning designs to benefit ISTs. Third, the model will help design studies to identify patterns in teachers' science and engineering efficacy over time, which can inform interventions for when efficacy ebbs. Finally, the proposed model is not meant to replace existing frameworks on self-efficacy and provides neither a fixed nor a linear model. Rather, we wish to build upon existing frameworks to advance toward more optimal models of support for current and future teachers as they navigate what has proven to be a challenge.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This material is based upon work supported by the National Science Foundation under Grant Nos. 2151056, 2151045, 2151057, and 2151012. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

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