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RESEARCH

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Pre-service elementary teachers' science and engineering teaching self-efficacy and outcome expectancy: exploring the impacts of efficacy source experiences through varying course modalities

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Abstract

Background Teacher efficacy is one of the most influential components for effective instruction, highlighting the importance of providing preservice teachers (PSTs) with opportunities to learn how to teach engineering during their college preparatory coursework. Making space for engineering instruction within science methods coursework could provide opportunities for PSTs to enhance their engineering teaching efficacy but also requires course instructors to give up some time previously devoted to science-focused instruction. The purpose of the current study was to explore how infusing engineering learning opportunities into a science methods course impacts PSTs' engineering and science teaching efficacy and outcome expectancy.

Results Pre/post-surveys were completed by PSTs enrolled in a Kindergarten-8th grade science methods course offered in four modalities (i.e., face-to-face, hybrid, online, rapid shift online). The course offered multiple engineering-focused learning activities and vicarious experiences. PSTs' science teaching efficacy beliefs, engineering teaching efficacy beliefs, science teaching outcome expectancy, and engineering teaching outcome expectancy all significantly increased from pre- to post-test. There was no significant difference between efficacy gains based on course modality. The purposeful inclusion of multiple engineering activities and vicarious experiences allows for significant gains in science and engineering teaching efficacy and outcome expectancy regardless of the modality in which the course is taken.

Conclusions This study shows that having varied efficacy source experiences while learning engineering design can result in increased efficacy, even in the absence of field experience and face-to-face coursework, and that the inclusion of these engineering experiences with science methods coursework does not detract from enhancing science teaching efficacy beliefs and outcome expectancy. Further research is needed to more closely examine individual components of science methods courses and the impacts each component has when implemented using different course modalities.

Keywords Self-efficacy, Elementary school, Quantitative, Preservice teachers, NGSS, Teaching efficacy, Engineering education

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Introduction

Since the release of USA's Next Generation Science Standards (NGSS), 80% of states have adopted or adapted NGSS and now include engineering in their state standards (National Academies of Sciences & Medicine [NASEM], 2020). Supporting the integration of engineering in the elementary education curriculum along with other subjects is extremely pertinent, especially considering that many current educators have not been trained to teach engineering (Banilower et al., 2018). Given that teachers often do not feel prepared or competent enough to teach engineering (Hammack & Ivey, 2017), it is essential for them to undergo training to boost their confidence levels and competence. Unfortunately, most teachers did not have access to coursework that focused on how to teach engineering during their teacher preparation programs (Banilower et al., 2018; Hammack & Ivey, 2019; Hammack et al., 2020), and teachers cite this lack of preparation as an influence on their lack of confidence or efficacy to teach engineering (Hammack & Ivey, 2019). Existing studies strongly suggest that teacher efficacy is one of the most influential components of effective instruction (e.g., Cakiroglu et al., 2012; Tschannen-Moran & Hoy, 2001), highlighting the importance of providing preservice teachers (PSTs) with opportunities to learn how to teach engineering during their college preparatory coursework.

Teacher efficacy has been identified as the most important characteristic for change-agent projects (Gibson & Dembo, 1984). New reforms are more likely to be implemented by high efficacy teachers (Lawrent, 2022). Rooted in social cognitive theory, complex definitions of teaching efficacy are founded upon Bandura's (1997) ideas and vary in adherence to this seminal, theoretical work (Lawrent, 2022; Ross et al., 1996). Bandura's (1977) self-efficacy theory consists of two constructs: response–outcome expectancies and self-efficacy expectations, with response–outcome expectancies referring to one's belief that an outcome can be achieved and self-efficacy expectations referring to one's belief that they can achieve a desired outcome. Throughout the remainder of the paper, we refer to the self-efficacy expectations construct as "self-efficacy" and the response–outcome expectancies construct as "outcome expectancy."

The self-efficacy of educators has been consistently related to the attitude of educators and the outcomes of students (Colvin et al., 1993). Educators who have high self-efficacy displayed various qualities such as patience, competence, and knowledge of how to use research-based practices to help students who may have deficiencies in certain skills (Bandura, 1977; Berliner, 1988; Daunic et al., 2006; Henson, 2001). High teacher self-efficacy has been linked to higher student achievement outcomes, a willingness to be open to new teaching ideas, and persistence in the face of classroom challenges (Allinder, 1994; Tschannen-Moran & Hoy, 2001). In addition, Bandura (1977) and Lewis-Moreno (2007) found that educators with low self-efficacy can pass on negative beliefs to their students, which can consequently discourage students and hinder their academic success. As such, educators' self-efficacy is vital in the management of classrooms, educational practices, and outcomes of learning.

Researchers are beginning to identify strategies to help better prepare PSTs to be engineering teachers. For example, Fogg-Rogers et al. (2017) found that PSTs had enhanced engineering teaching self-efficacy after participating in an engineering design process training and later teaching engineering to children in afterschool programs. Similarly, Perkins Coppola (2019) reported an increase in PSTs' engineering teaching self-efficacy after developing and teaching engineering lessons to Kindergarten—5th grade students. These studies illustrate the value of having PSTs teach engineering lessons to children; however, this is not an option for many PSTs due to programmatic constraints on classroom placement, which often limit how long and what subjects they are able to teach. In addition, most elementary teacher preparation programs do not include explicit coursework related to engineering or how to teach engineering (Banilower et al., 2018). In order to provide engineering education training for PSTs enrolled in such programs, instructors must find ways to incorporate engineering instruction within other coursework, such as science methods courses. This model of engineering integration fits NGSS recommendations to equalize engineering design and science inquiry throughout Kindergarten—12th grade science learning experiences (NGSS Lead States, 2013). Making space for engineering instruction within science methods coursework could provide opportunities for PSTs to enhance their engineering teaching self-efficacy. However, this approach would also require course instructors to give up some of the time previously devoted to science-focused instruction, which could negatively impact PSTs' science teaching self-efficacy, which is lower for elementary PSTs' than their secondary peers (Savran et al., 2003). It is important, then, to explore how incorporating engineering education training within science methods courses impacts both science and engineering teaching self-efficacy. Furthermore, some universities are beginning to offer fully or partially online teacher preparation programs to provide opportunities for students to earn their teaching credential remotely (Barnes et al., 2020; Dani & Donnely, 2021). Both the COVID-19 shift to online instruction, as well as the increasing frequency with which preservice teachers are able to take methods courses in online and blended environments (Dani & Donnely, 2021; Mukhtar, 2020) highlight the need to explore how course modality impacts preservice teachers' science and engineering teaching self-efficacy.

The purpose of the current study was to explore how infusing engineering learning opportunities into a science methods course (in the absence of teaching to children) impacts PSTs' engineering and science teaching self-efficacy and outcome expectancy throughout different course modalities. Specifically, we sought to answer the following research question and related sub-questions:

How does participating in a Kindergarten—8th grade science methods course containing multiple engineering-focused elements impact preservice elementary teachers' science teaching efficacy beliefs (STEB), engineering teaching efficacy beliefs (ETEB), science teaching outcome expectancy (STOE), and engineering teaching outcome expectancy (ETOE)?

(a) How do the STEB, ETEB, STOE, and ETOE of preservice elementary teachers compare pre and post a science methods course with engineering learning opportunities infused?
(b) Are there differences in STEB, ETEB, STOE, and ETOE, between participants enrolled in different course modalities?

We hypothesize that participants' teaching efficacy increases from pre- to post-course due to their engagement in multiple engineering-focused activities within the course.

Background and conceptual framework

Bandura's (1977) theory of self-efficacy guides our work and forms the starting point for our conceptual framework. The development of self-efficacy is context specific (Ross et al., 1996), and we argue that the modality of course delivery is an important part of the context that shapes the development of self-efficacy. As such, the conceptual framework that guides this study connects teaching efficacy and the modality in which efficacy source experiences occur. The following sections explore the literature related to each of the constructs that comprise our conceptual framework: science teaching efficacy, engineering teaching efficacy, and course modality.

Sources of efficacy

A review of the literature reveals that teaching efficacy research is split into three levels (1) general teaching efficacy, (2) collective teaching efficacy, and (3) personal teaching efficacy. General teaching efficacy, also known as outcome expectancy, is a teacher's belief that teaching can bring about student learning (Bandura, 1997), while personal efficacy, or self-efficacy, is the belief in having agency and skill to individually affect student outcomes (Bandura, 2000). Collective teaching efficacy, held by a group of teachers in a school, is the belief that their combined efforts can bring about student learning (Gaddard et al., 2000). We recognize that although outcome expectancy, collective efficacy, and personal self-efficacy are often measured separately, these levels are nested within an individual and interact to create an efficacy identity for a teacher with relationships to the self, institution, and profession. Numerous researchers have found evidence that outcome expectancy and personal self-efficacy are of relative independence (Cantrell et al., 2003). Yet, the constructs of both levels provide reference points for the teacher in the efficacy of self. Teachers may believe the profession as a whole to have low efficacy while holding an outlier high efficacy of self; conversely, the teacher may believe the profession as a whole to have high efficacy while considering low self-efficacy the exception (Cantrell et al., 2003). Though the two efficacy constructs at the levels of self (teaching efficacy) and profession (outcome expectancy) are not correlated in Cantrell's example, they interact within the individual as reference points of the teacher's efficacy identity contributing to the complex nature of teacher efficacy.

Teacher efficacy on the personal level is nuanced and complex. Teaching self-efficacy is context-dependent and can change by class period (Ross et al., 1996), indicating that teachers with high self-efficacy in one area may have low self-efficacy in another. Each individual has an efficacy identity with relationship to self, institution, and profession with complex theoretical frameworks, and individuals construct efficacy based on social cognition. Bandura (1997) identified four sources of self-efficacy (1) mastery experience, (2) vicarious experience, (3) social persuasion, and (4) physiological and emotional states.

Lawrent (2022) offers valuable insights into the sources of efficacy experiences among teachers. According to Lawrent's research, mastery experiences, learning by experience, and the ability to overcome challenges emerged as the most influential sources of teacher self-efficacy. The findings reveal that mastery experiences, learning from experience, and overcoming challenges emerged as the most influential sources of teacher efficacy for teachers in a school system that was undergoing expansions and faced with inadequate funding and low morale. Lawrent's (2022) study holds significant implications for science education. It underscores how the specific context, in this case, the implementation of a secondary education expansion policy, profoundly affects teacher efficacy. Within this context, mastery experiences, learning from practical situations, and effectively addressing challenges emerge as the primary drivers of teacher efficacy.

Mulholland et al. (2004) hypothesized that differences in time spent within school-based supervised teaching experiences may have influenced outcome expectancy scale results in their study. The study validated the two-factor structure of teaching efficacy, consisting of Personal Science Teaching Efficacy Beliefs (PSTEB) and Science Teaching Outcome Expectancy (STOE). Notably, the study found that completing science teaching coursework within the preservice program significantly influenced PSTEB but had no significant effect on STOE. In addition, the number of high school science subjects studied by preservice teachers had a notable impact on PSTEB, highlighting the enduring influence of early science education on teaching self-efficacy. The authors posited that lack of practical classroom experiences may have affected STOE scores, recommending future study. In this case, mastery experiences rooted in content were related to increased self-efficacy whereas mastery experiences rooted in pedagogy were posited to have impacted outcome expectancy. Mastery experiences have widely been used to describe a mastery of pedagogical skills, however, this framing of mastery experiences is not readily available to PSTs who are often not in classroom settings, yet Palmer (2006) included understanding of content matter within the definition of mastery experience. Palmer's definition expands the concept of the mastery experience to include opportunities for PSTs even in the absence of classroom placement. In the case of PSTs, content is twofold, focused on both engineering as a discipline and engineering as a pedagogy. In the context of Mulholland et al. (2004), mastery experience in science content and pedagogy related to increased personal efficacy, yet mastery experiences in pedagogy, according to Palmer's (2006) definition, were not present either in practical experience or through learning about pedagogy as content. Pedagogy as content may overlap with vicarious experiences. Vicarious experiences take reflective forms including symbolic modeling, effective actual modeling, cognitive self-modeling, and self-modeling; self-modeling includes watching and reflecting upon taped lessons by a master teacher (Bandura, 1997). The reflective experiences utilizes pedagogy as content as the point of reference. Vicarious experiences are not as evident in teaching efficacy research (Lawrent, 2022). Bautista (2011) examined enactive, cognitive content, and pedagogical content as mastery experiences as well as vicarious experiences. The participants included 46 preservice elementary teachers enrolled in a field experience-based elementary science education course and 20 inservice teachers. Pretest and post-test assessments were conducted using the Science Teaching Efficacy Belief Instrument B (STEBI-B), along with field experience-related questions. The primary contributors to self-efficacy were enactive mastery, cognitive pedagogical mastery, symbolic modeling, and cognitive self-modeling. Bautista (2011) recommended including multiple efficacy source experiences in PST science courses to increase self-efficacy and outcome expectancy.

Social persuasion focuses on positive feedback and interaction with mentors, peers, or instructors whereas physiological and emotional states refer to strong reactions of stress and anxiety from teaching tasks or decisions (Bandura, 1997). Lawrent (2022) found that physiological and emotional states, as well as social persuasion, were affected by student performance which is not a variable available to PSTs without a classroom placement. Personal teaching self-efficacy is multidimensional and relies on teaching context including (1) student performance outcome, (2) student ability, and (3) scope of influence (Guskey, 1987).

The literature on outcome expectancy and its connection to sources of efficacy remains notably scarce. A small case study conducted by Ward et al. (2020) suggested that the origins of efficacy for outcome expectancy may trace back to early life experiences. Watter and Ginns (1995) specifically linked improvement in PSTs' outcome expectancy to successful classroom teaching experiences. However, the body of research on this intricate relationship is limited, leaving room for further exploration. Given the vital role of outcome expectancy in shaping educators' confidence and effectiveness, it becomes imperative to delve deeper, providing opportunities for a richer understanding of self-efficacy and outcome expectancy as related to PSTs' experiences.

Science teaching, self-efficacy, and outcome expectancy

The Science Teaching Efficacy and Belief Instrument (STEBI) developed by Riggs (1988) has been widely utilized in science teaching self-efficacy research. This instrument, now known as STEBI-A, was aimed at in-service science teachers and was later adapted by Enochs and Riggs (1990) for PSTs and labeled STEBI-B. Deehan (2017) aggregated 107 STEBI-A and 140 STEBI-B studies with qualitative, quantitative, and mixed methodologies and found that science teaching self-efficacy scale scores were consistently higher, and displayed a higher growth pattern, than outcome expectancy scores. Hechter (2011) pointed to the number of total science courses taken in high school and college and the quality of those experiences to be influential content mastery sources of experience for self-efficacy. Furthermore, Hector (2011) reported that these experiences did not affect or interact with outcome expectancy scores. Enochs and Riggs (1990) also found previous courses to affect teaching self-efficacy but found that perceived effectiveness in teaching science correlated significantly to outcome expectancy scores. Existing literature consistently illustrates increases in science teaching self-efficacy scores interacting with pedagogical mastery experiences, yet conflicting claims regarding the interaction of master experiences with outcome expectancy scores.

Despite its widespread use, concerns over the shortcomings of the STEBI-A have been described in the literature (Deehan, 2017; Unfried et al., 2022). Furthermore, the way student learning is framed in the literature and when training teachers has changed considerably since the STEBI-A was developed more than 30 years ago, leading to concerns about the wording of some of the items (Unfried et al., 2022). Teaching self-efficacy is a complex construct which requires multidimensional, differentiated measures, making it challenging for researchers to "realize the full richness" of the construct (Zee & Koomen, 2016, p. 1009) without appropriate measures. As a response to the aforementioned concerns with the STEBI-A, Unfried et al. (2022) examined the validity of the T-STEM as an alternative to the STEBI-A. The T-STEM is a suite of instruments originally developed by the Friday Institute (2012) that contains designated scales for measuring teachers' self-efficacy and outcome expectancy for each of the STEM disciplines. Using a sample of 727 K-12 teachers from the USA, Unfriend et al. (2022) provided evidence that the T-STEM science instrument is a valid and reliable alternative to the STEBI-A.

Pedagogical mastery experiences, or teaching interaction with students, is prominent in teaching efficacy literature. Plourde (2002) found that student teaching field experiences had a significantly positive effect on personal self-efficacy scores but no significant effect on teacher outcome expectancy scores. Cantrell et al. (2003) found that planning science lessons for students followed by spending more than an hour a week teaching students increased personal teaching self-efficacy. Furthermore, Putman (2012) found significant differences in self-efficacy between experienced teachers and novice teachers but no significant difference between novice and preservice teachers suggesting (1) experience is a critical factor in teaching self-efficacy and (2) preservice teachers may carry and keep their teaching self-efficacy during their career startups.

Angle and Moseley (2009) conducted a study that revealed a noteworthy association between outcome expectancy scores and teacher effectiveness, as assessed through state testing proficiency scores. They observed that when teachers evaluated quantifiable student outcomes resulting from their teaching (i.e., student proficiency scores on a state test), outcome expectancy showed both positive and negative correlations with student scores. This study raises the possibility that measurable success which attributes value to mastery experiences could influence outcome expectancy scores. Furthermore, this outcome suggests that feedback loops paired with vicarious experiences and reflection may attribute value to action taken during mastery experiences, effectively affecting mastery experiences themselves.

Engineering teaching, self-efficacy, and outcome expectancy

Engineering has not been a part of formal Kindergarten—12th grade education settings for as long as science education, thus studies focused on measuring Kindergarten—12th grade engineering teaching efficacy are not as prevalent as those for science efficacy and have approached the topic using multiple instruments, including the Teaching Engineering Self-efficacy Scale (Yoon et al., 2014) and modified versions of the STEBI-B. Prior studies report that elementary teachers experience low engineering teaching self-efficacy (Hammack & Ivey, 2017) and report low confidence in teaching engineering (Banilower et al., 2018). A handful of studies indicate that exposing elementary pre-service teachers to engineering design during science methods courses can enhance engineering teaching self-efficacy beliefs (Kaya et al., 2019; Perkins Coppola, 2019; Yesilyurt et al., 2021). However, these same studies did not find changes in PSTs' engineering outcome expectancy. It has been suggested that changes in outcome expectancy were limited due to PSTs' lack of experience in classroom settings (Perkins Coppola, 2019; Yesilyurt et al., 2021). Perkins Coppola (2019) blended engineering content knowledge, engineering pedagogical knowledge, and field experience teaching students which resulted in significant increases in personal self-efficacy subscales but not a significant increase in outcome expectancy scores. Furthermore, Yesilyurt et al. (2021) delineated that an explicit-reflective approach to engineering activities could increase teaching self-efficacy but not significantly impact outcome expectancy scores. In contrast, Nesmith and Cooper (Nesmith and Cooper 2021) found significant pre- to post-gains in outcome expectancy for PSTs who engaged in an engineering design lesson as part of their science methods course. These PSTs were simultaneously enrolled in a practicum field experience; however, they did not have the opportunity to teach engineering to the children in their practicum placements. In explaining their findings, Nesmith and Cooper (2021) mentioned the short duration of the engineering lesson, its location at the end of the semester, and the importance of not ruling out the Dunning–Kruger effect as a possible explanation. This limited shift of outcome expectancy may be attributed to the lack of classroom experience available to PST's, as suggested by prior researchers. After reviewing the aforementioned literature, it is clear there is a dearth of scholarship related to engineering teaching self-efficacy beliefs and outcome expectancy at the elementary school level, warranting additional attention. These findings underscore the complexity of the issue and the need for further investigation into the relationship between engineering teaching self-efficacy beliefs and outcome expectancy for pre-service teachers at the elementary school level.

Course modality

In 2020, the COVID-19 pandemic resulted in a massive shift to emergency online learning, which brought the topic of online learning to the forefront of education conversations across the globe. According to the National Center for Education Statistics ([NCES], 2022), in fall 2019, 37% of students enrolled in a US degree-granting postsecondary institution were taking at least one online course. The percentage jumped to 74% of students in fall 2020, and in fall 2021, still remained well above pre pandemic levels, with 59% of students enrolled in online courses (NCES, 2022). While these statistics point to a COVID-19 pandemic related change in online enrollment, they overlook the rise in online enrollment that was occurring prior to the pandemic. In fact, the prevalence of online education has been on the rise for decades as the quality and availability of information technology has improved (Palvai et al., 2018). While there was a steady decline in US college enrollment between 2011 and 2016 (Fain, 2017), the number of US students enrolled in at least one online course during that same time period was on the rise, with 30% of undergraduates and 39% of graduate students in 2016 being enrolled in online coursework (Lederman, 2018). As these statistics suggest, online learning at the postsecondary level is on the rise, and the trend is only expected to continue (Palvai et al., 2018).

As postsecondary institutions continue to offer more coursework online or in blended modalities, particularly courses that prepare students for professional practice, such as those that cover methods for teaching Kindergarten—12th grade children, it is important that post-secondary instructors understand effective online teaching practices. According to Hodges et al. (2020), online instructors must recognize "learning as both a social and cognitive process, not merely a matter of information transmission." This is supported by Bandura's (1997) four sources of self-efficacy which include social and cognitive elements. Furthermore, instructors must consider how to support student-content, student–student, and student–teacher interactions, which have been shown to increase learning outcomes when meaningfully integrated into online instruction (Bernard et al., 2009). This is additionally connected to Bandura's (1997) social persuasion source of self-efficacy in which peers, mentors, and instructors are listed as interactive sources. Within the context of teacher preparation courses, there is a dearth of literature that examines how these interactions play out across different course modalities, particularly with respect to their impacts on students' teaching self-efficacy.

Methods

A preliminary version of this study using a smaller data set was shared at the American Society for Engineering Education's annual conference (Hammack & Yeter, 2022 © American Society for Engineering Education). The study focused on the pre-to-post-mean difference in participants' engineering teaching self-efficacy beliefs, which were found to increase significantly after participating in a science methods course containing engineering-focused elements. The current study expands upon this work by examining the pre-to-post-mean differences in participants' engineering teaching self-efficacy beliefs, engineering teaching outcome expectancy, science teaching self-efficacy beliefs, and science teaching outcome expectancy, across different course modalities. The research protocol approved by the ethics review board overseeing the research team only allowed for data that was collected from participants as part of their science methods course to be used for research purposes. This meant that the research team was granted permission to use the survey data that the course instructor already administered as part of the course, but they were unable to conduct observations or outside interviews with participants, resulting in a purely quantitative study.

Participants

Participants included 161 undergraduate students and 9 post-baccalaureate students attending a large, land-grant university in the US Mountain West. At the time of data collection, all participants were enrolled in a single semester K-8 science methods course as part of an initial elementary teacher licensure program. Participants ($n=170$) were predominantly female ($n_{\mathrm{female}}=151$, $n_{\mathrm{male}}=19$) and white ($n_{\mathrm{white}}=159$, $n_{\mathrm{Hispanic}}=4$, $n_{\mathrm{NativeAmerican}}=2$, $n_{\mathrm{Asian}}=1$, $n_{\mathrm{multiple}}=2$). All participants had completed three college science courses (one life, one Earth, and one physical) prior to enrolling in the K-8 science methods course.

Data collection

To answer the research questions, four subscales from the Teacher Efficacy and Attitudes toward STEM (T-STEM) Survey were chosen (Friday Institute, 2012): (1) Engineering Teaching Efficacy and Beliefs (ETEB, 11 items), (2) Engineering Teaching Outcome Expectancy (ETOE, 9 items), (3) Science Teaching Efficacy and Beliefs (STEB, 11 items), and (4) Science Teaching Outcome Expectancy (STOE, 9 items). Each subscale consists of statements that the participant must rank on a five-point Likert scale requiring participants to rate each statement with one of the following choices: Strongly Disagree, Disagree, Neither Agree nor Disagree, Agree, or Strongly Agree. The items on the engineering and science subscales have the same wording except for the use of the discipline (i.e., engineering, science) to allow for comparison between the engineering and science subscales. For example, an ETEB item reads "I am continually improving my engineering teaching practice," while the corresponding STEB item reads "I am continually improving my science teaching practice." The T-STEM was developed to address some of the concerns with the long-standing STEBI-A instrument, such as the instrument being "out of step with more growth-oriented conceptualization of student learning" (Unfried et al., 2022, p. 9). The research team chose to use the T-STEM rather than the STEBI and TESS for two reasons: (1) they felt that the T-STEM was better aligned with the pedagogical approaches utilized in the science methods course and addressed multiple shortcomings previously cited about the STEBI and (2) the T-STEM instrument had scales for both science and engineering, allowing the use of similarly worded items for both constructs rather than using two different instruments (i.e. STEBI and TESS). The research team felt this would allow for a better comparison of changes in science and engineering self-efficacy beliefs and outcome expectancy. There is not a separate version of the T-STEM for use with preservice teachers. After reviewing the items of the T-STEM, the research team decided to employ the T-STEM in the form in which it was originally written and validated. The T-STEM subscale items were entered into a Qualtrics form, along with demographic questions, and a link was given to participants through the university's online course management system. Participants completed the pre-survey during the first week of their science methods course and completed the post-survey during the final week of their science methods course.

Course structure

The single-semester course was focused on preparing elementary education majors to teach science at the kindergarten—8th grade level. The course is a required component of the degree program and is typically taken during the junior (3rd) year of college coursework. Based on university workload policies, students were expected to spend approximately 135 total clock hours engaging in course-related activities, which could be split between synchronous classroom instruction and asynchronous assignments. The course included instruction on the nature of science, scientific inquiry, interpreting the NGSS, assessment, student misconceptions, equity in science instruction, and interdisciplinary science instruction. While this was a science methods course, there were numerous classroom activities and assignments that focused on engineering, due to the presence of engineering in science standards at the national and state levels. Engineering-focused activities included: (1) a 1.5-h introduction to engineering design lesson using the Tower Power activity from Engineering is Elementary®; (2) a 4-h problem-based engineering design challenge that required students to design, create, and test devices that limit heat transfer; (3) a 2-h video case analysis assignment that required students to watch a series of video clips of engineering being taught in elementary classrooms and then analyze the engineering teaching practices they observed; (4) a 1-h lesson focused on engineering with Kindergarteners through the design of shade structures; (5) a series of readings devoted to engineering design, engineering habits of mind, how to assess engineering lessons, and how to connect engineering to other disciplinary standards (i.e., math, language arts); and (6) creation of a BSCS 5E lesson (Bybee et al., 2006) that contained an engineering component. While there was some explicit instruction devoted to engineering (i.e., engineering design process), the majority of the course engineering components were embedded within the course topics. For example, during the video case analysis assignment that featured engineering instruction, students were not instructed to focus solely on the "engineering specific" aspects of the instruction. Rather, they were examining the pedagogical moves of the highlighted teacher, looking at things such as questioning techniques, accessing and building on students' prior knowledge, the use of academic vocabulary, and formative assessment techniques. Both science and engineering were addressed simultaneously during this and multiple other course activities.

The course was designed to be inquiry-oriented and experiential in nature through the use of hands-on activities and collaborative group work. Even for the asynchronous modality, participants were completing hands-on inquiry-based tasks at home using their own materials and collaborating through the online learning platform. The course activities were purposefully designed with self-efficacy in mind. For example, the activities were designed to increase participants' knowledge of engineering as well as knowledge of engineering pedagogy and, in doing so, provide mastery experiences. Furthermore, video analysis activities, as well as instructor modeling, provided opportunities for vicarious learning, while discussion post interactions and instructor feedback loops offered space for social persuasion.

The course was presented in four different modalities, (1) face-to-face (2) hybrid, (3) rapid shift to online instruction, and (4) online, asynchronous. The rapid shift online and hybrid offerings were a direct result of social distancing protocols required in the university's response to COVID-19. The face-to-face participants ($n=100$) had two 90-min classes per week on campus for the duration of the 15-week semester. The hybrid participants ($n=30$) met on campus for six 90-min classes (one class per week for the first 6 weeks of the semester) and completed the remainder of the coursework online, meeting every other week for 90 min of instruction on Webex. The rapid shift to online participants ($n=31$) completed the first 7 weeks of the semester on campus, meeting in person for 180 min each week. After spring break, the remaining 8 weeks of instruction were fully asynchronous due to a COVID-19 lockdown in Spring 2020. The online participants ($n=9$) completed all instruction asynchronously via the course learning management system at their own pace over an 8-week period.

Table 1 Reliability statistics (pre- and post-survey)

Subscale	Pre-test Cronbach's alpha value	Post-test Cronbach's alpha value	No. of items
STEB	0.775	0.838	11
STOE	0.780	0.866	9
ETEB	0.870	0.883	11
ETOE	0.869	0.911	9

Table 2 Descriptive statistics ($N=167$)

Variable	Time	*M*	SD	Median
STEB	Pre	3.118	0.650	3.182
STEB	Post	4.040	0.592	4.000
STOE	Pre	3.472	0.663	3.444
STOE	Post	3.784	0.631	3.778
ETEB	Pre	2.576	0.902	2.545
ETEB	Post	3.874	0.728	3.909
ETOE	Pre	3.366	0.914	3.333
ETOE	Post	3.770	0.748	3.889

Data analysis

Data were analyzed using the data analysis software R (Version 4.2.2). First, we ran a paired samples t test to investigate the effects of the kindergarten—8th grade science methods course on four dependent variables, namely STEB, STOE, ETEB, and ETOE. Because the paired samples t tests showed significant differences between the pre- and post-scores for all four variables (more details below), we performed a two-way mixed ANOVA analysis to investigate whether the change in pre- and post-course survey scores (time) varied by the modality of the course (face-to-face, hybrid, online, and rapid shift to online). Before conducting the analyses, the dataset was thoroughly inspected to ensure its accuracy. There was no missing data. However, three cases were identified as outliers: F21_22, F22_04, and S21_06 (see Appendix A). The researcher may remove or retain the outliers once detected (Hair et al., 2006). To minimize the potential impact of these outliers on the results, we removed these three cases and their corresponding pre- and post-course scores from the dataset. The cleaned dataset was used for subsequent statistical analyses. An inter-item reliability analysis was run to measure the consistency of responses across items which measure the same variable (subscale). Cronbach's alpha is frequently used in the literature to assess the reliability, or internal consistency, of a scale measure, and a score above 0.7 is widely considered to be desirable (Taber, 2018). As Table 1 shows, the scales used in this study have good inter-item reliability (>0.7).

Results

Effects of K-8 science methods course on STEB, ETEB, STOE, and ETOE

Table 2 and Fig. 1 show that there was an increase in scores from pre- to post-surveys for all four variables. For example, STEB scores increased from 3.12 (SD=0.65) to 4.04 (SD=0.59). Similarly, STOE increased from 3.48 (SD=0.66) to 3.78 (SD=0.63), ETEB from 2.58 (SD=0.90) to 3.87 (SD=0.73), and ETOE from 3.67

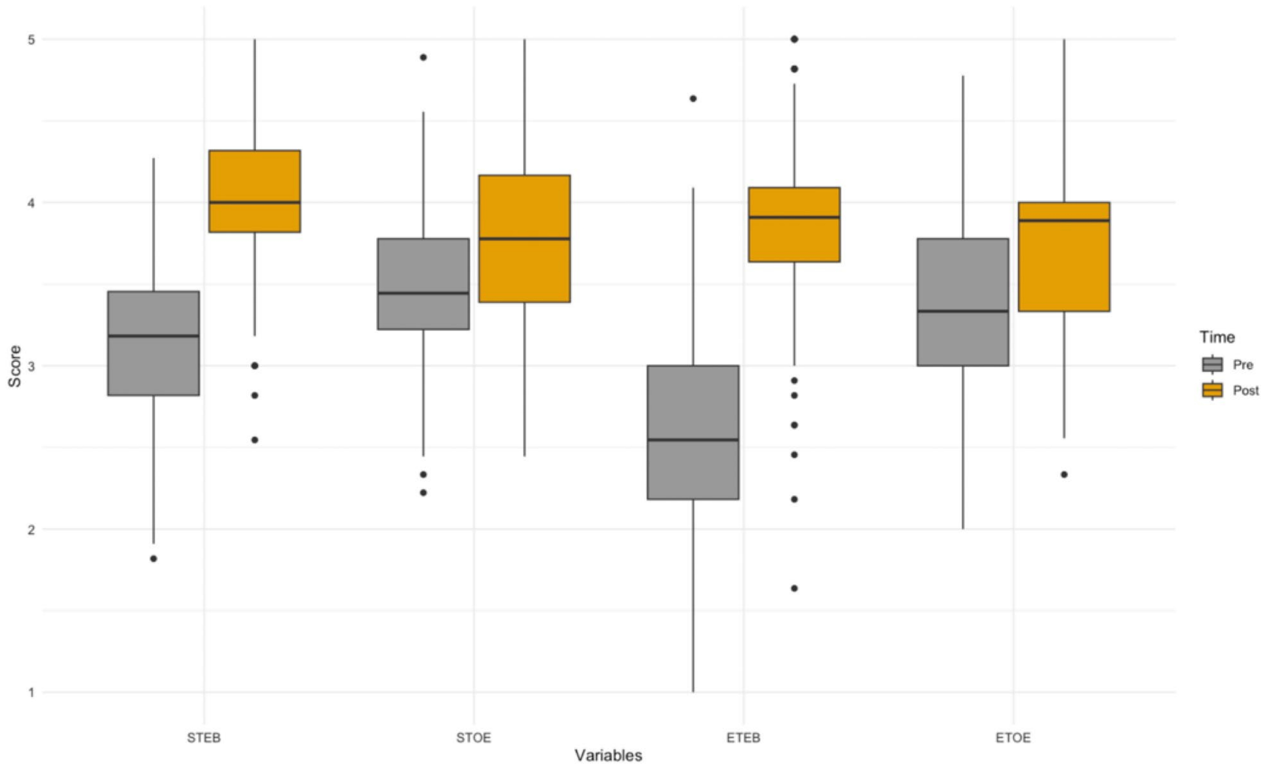

Fig. 1 Comparison of pre- and post-course scores in STEB, STOE, ETEB, ETOE

Table 3 Results of paired samples *t* tests

Variable	*t* value	*df*	*p*	95% CI lower	95% CI upper	Mean difference
STEB	− 22.718	166	0.00***	− 1.0029	− 0.8425	− 0.9227
ETEB	− 22.781	166	0.00***	− 1.4102	− 1.1853	− 1.2978
STOE	− 8.5803	166	0.00***	− 0.3838	− 0.2402	− 0.3120
ETOE	− 8.7912	166	0.00***	− 0.4954	− 0.3137	− 0.4045

*$p<0.05$, **$p<0.01$, ***$p<0.001$

(SD = 0.91) to 3.77 (SD = 0.75). To ensure that we could use paired-samples *t* tests, we assessed the assumption of normality. Q–Q plots were assessed to test the assumption of normality, and the Q–Q plots for pre- and post-course scores of all four variables showed a fairly linear pattern, indicating that the normality assumption was met (Appendix A).

Paired-samples *t* tests were conducted to examine the differences between pre- and post-scores for each of the four variables: STEB, ETEB, STOE, and ETOE (Table 3). The results of the paired samples *t* tests show that there were significant differences between the pre- and post-scores for all four variables. The mean difference between pre- and post-scores for STEB was − 0.92, $t(166) = -22.718$, $p < 0.001$, with a large effect size (Cohen's $d = 1.42$). For ETEB, the mean difference was − 1.30, $t(166) = -22.781$, $p < 0.001$, with a large effect size (Cohen's $d = 1.49$). For STOE, the mean difference was − 0.31, $t(166) = -8.5803$, $p < 0.001$, with a medium effect size (Cohen's $d = 0.61$). And for ETOE, the mean difference was − 0.40, $t(166) = -8.7912$, $p < 0.001$, with a medium effect size (Cohen's $d = 0.72$).

Effects of course modality on STEB, ETEB, STOE, ETOE and the changes in pre- and post-survey scores

A two-way mixed ANOVA analysis including two main effects (time and modality) and one interaction effect (TimeXModality) was conducted. First, we checked

Table 4 Means and SDs of variables across modalities

Modality	STEB (*M*, SD)		STOE (*M*, SD)		ETEB (*M*, SD)		ETOE (*M*, SD)	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
F2F	3.13 (0.52)	4.07 (0.44)	3.50 (0.43)	3.81 (0.55)	2.58 (0.66)	3.92 (0.54)	3.36 (0.48)	3.82 (0.54)
Hybrid	3.16 (0.41)	4.12 (0.47)	3.40 (0.46)	3.77 (0.40)	2.60 (0.70)	3.81 (0.52)	3.37 (0.51)	3.65 (0.51)
Online	2.99 (0.33)	3.77 (0.30)	3.48 (0.43)	3.72 (0.56)	2.46 (0.25)	3.67 (0.22)	3.36 (0.59)	3.72 (0.66)
Rapid shift	3.08 (0.42)	3.94 (0.45)	3.45 (0.49)	3.74 (0.53)	2.57 (0.55)	3.86 (0.58)	3.38 (0.55)	3.74 (0.54)

Table 5 Results of two-way ANOVA

Variable	Source	SS	MS	*df*	*F*	*p*
STEB	Modality	0.686	0.229	3	1.6362	0.1830
	Time	33.291	33.291	1	238.3633	< 0.001*
	Modality × time	0.188	0.063	3	0.4490	0.7184
STOE	Modality	0.1023	0.0341	3	0.3054	0.8214
	Time	3.7835	3.7835	1	33.8928	< 0.001*
	Modality × time	0.0751	0.0250	3	0.2243	0.8794
ETEB	Modality	0.451	0.150	3	0.5441	0.6528
	Time	67.404	67.404	1	243.7140	< 0.001*
	Modality × time	0.197	0.066	3	0.2374	0.8702
ETOE	Modality	0.1614	0.0538	3	0.3055	0.8214
	Time	5.5723	5.5723	1	31.6531	< 0.001*
	Modality × time	0.4090	0.1363	3	0.7745	0.5098

*$p < 0.001$

the assumptions of normality and homogeneity of variances. It was found that the residuals were normally distributed (Appendix A). Bartlett's test was run to assess the assumption of homogeneity of variances. The results indicated no significant differences in variances for all variables: STEB ($\chi^2(3) = 2.83$, $p = 0.419$), STOE ($\chi^2(3) = 1.08$, $p = 0.783$), ETEB ($\chi^2(3) = 2.56$, $p = 0.465$), and ETOE ($\chi^2(3) = 1.16$, $p = 0.763$). Therefore, the assumption of homogeneity of variances was not violated, and both assumptions were met.

A two-way mixed ANOVA analysis was conducted to examine the main effects of modality and time, as well as their interaction effect on students' pre- and post-course survey scores (Tables 4, 5). There was no significant main effect of modality on STEB scores, $F(3, 164.19) = 1.6362$, $p = 0.1830$, and the interaction effect between modality and time (pre and post) was also found to be non-significant, $F(3, 163.27) = 0.4490$, $p = 0.7184$. Similarly, there was no significant main effect of modality on STOE scores, $F(3, 164.85) = 0.3054$, $p = 0.8214$, on ETEB scores, $F(3, 160.19) = 0.5441$, $p = 0.6528$, and on ETOE scores, $F(3, 164.54) = 0.3055$, $p = 0.8214$. The interaction effect between modality and time (pre and post) was also found to be non-significant for STOE, $F(3, 163.08) = 0.2243$, $p = 0.8794$, for ETEB, $F(3, 159.89) = 0.2374$, $p = 0.8702$, and for ETOE, $F(3, 163.53) = 0.7745$, $p = 0.5098$. These results suggest that the differences in students' scores did not vary significantly across the four course modalities, and neither did the change in students' scores significantly vary from the pre- to post-course surveys across all four course modalities (see Fig. 2; Table 5).

In summary, our findings indicate that there were significant increases in pre- and post-survey results of all four variables (STEB, ETEB, STOE, and ETOE) regardless of the modality. There were no significant differences in the change in scores across modalities for any of the variables (see Figs. 3, 4).

Discussion

In addressing our overarching research question, "How does participating in a K-8 science methods course containing multiple engineering-focused elements impact preservice elementary teachers' STEB, ETEB, STOE, and ETOE?", we found that PSTs' STEB, ETEB, STOE, and ETOE all significantly increased from pre- to post-test. Prior studies have demonstrated that science methods courses can enhance PSTs' science teaching self-efficacy

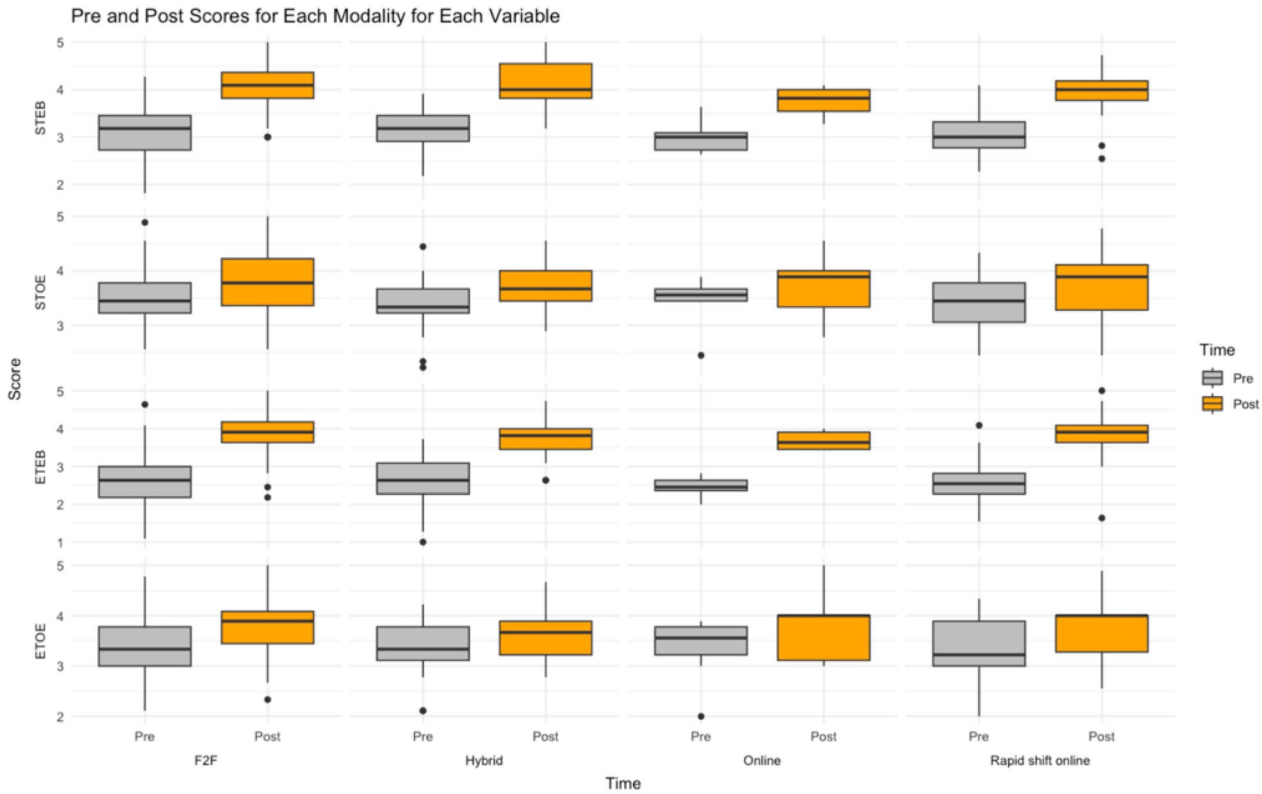

Fig. 2 Pre- and post-scores for variables by modality

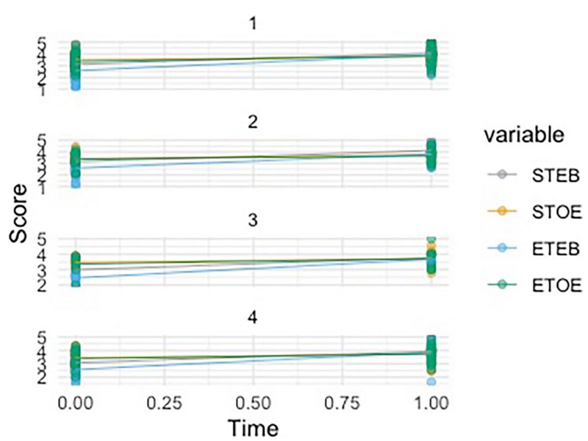

Fig. 3 Changes in mean scores by modality. *Note.* 1=F2F, 2=Hybrid, 3=Online, 4=Rapid Shift Online

beliefs (Bleicher & Lindgren, 2005; Palmer, 2006) and engineering teaching self-efficacy beliefs (Nesmith & Cooper, 2021; Perkins Coppola, 2019); however, a direct comparison of the two has been thus far absent from the literature. Our finding that both STEB and ETEB significantly improved is an important finding because it demonstrates that a considerable amount of engineering instruction can be incorporated within science methods courses without jeopardizing participants' opportunities to improve science teaching efficacy beliefs. This is a valuable finding for the field because most teacher preparation programs do not offer separate methods courses for engineering (NASEM, 2020) resulting in science methods instructors covering both areas within a single course.

While the current methods course contained distinct science and engineering elements, there were a number of elements in which science and engineering were addressed simultaneously, while also being connected to the sources of self-efficacy beliefs described by Bandura (1977). For example, the heat transfer unit was problem-based and first engaged PSTs in activities (i.e., content mastery experiences) to build science practices and content knowledge related to heat transfer and material properties that were then applied in an engineering design challenge. Likewise, the 5E lesson plan focused on pedagogy application and required PSTs to create a science lesson that also included an engineering component somewhere within the lesson. These are just a few of many examples. By engaging as learners in both science inquiry and engineering design activities, the PSTs were provided with content learning mastery experiences to enhance their personal science and engineering

Fig. 4 Changes in the distribution of scores by modality for each variable

knowledge and self-efficacy. Increases in personal content knowledge can, in turn, lead to increases in content teaching self-efficacy (Swackhamer et al., 2009). PSTs also had opportunities for vicarious learning through the video teaching case analysis assignments as well as the pedagogical modeling provided by their course instructor who was a former K-8 teacher. Having this opportunity to witness and critically reflect on elementary science and engineering instruction via classroom video footage as well as experience their methods instructor teaching science and engineering lessons could have helped demystify what science and engineering teaching look like and enabled the PSTs to picture themselves in the shoes of the teachers on the video or their instructor. Furthermore, social persuasion experiences were provided through interaction and discussion with their peers and instructor (e.g., face-to-face discussions, online discussion boards). Discussion post assignments required students to respond to their peers' posts while simultaneously building upon their ideas. Having a peer respond positively to a post and use it as a stepping stone for further discussion would indicate to the original poster that their ideas were valuable and respected, thus allowing the discussion post interactions to serve as a form of social persuasion. Furthermore, throughout the course, the instructor provided constructive formative feedback, highlighting the strengths of participants' thinking around engineering and engineering pedagogy, providing additional opportunities for social persuasion. Throughout the entire course, PSTs were navigating psychological and emotional states related to their roles as learners and novice educators of science and engineering. This purposeful interweaving of science and engineering efficacy source experiences throughout the methods course could be a possible contributing factor to the increase of both STEB and ETEB, indicating that K-8 science methods courses can be comprised of well-developed science and engineering elements that lend to the development of teaching self-efficacy in both disciplines.

Furthermore, the layering of multiple experiences over the course of the semester provided opportunities for the interaction of efficacy source experiences. For example, the PSTs worked on their 5E lessons across the semester, turning in multiple drafts to receive instructor feedback that served as a form of social persuasion. The drafts were timed such that PSTs had opportunities to engage in different self-efficacy building experiences between each draft. For instance, PSTs completed the teaching case video activity before turning in the second draft of the 5E lesson, providing them the opportunity to apply the vicarious video learning opportunity to their lesson plan development. After turning in the second draft, PSTs participated in a gallery walk style presentation of their lessons. Peer feedback and discussions during the gallery walk provided further social persuasion and vicarious learning opportunities prior to turning in the final draft of their lesson plans. Rather than each class activity providing a discrete self-efficacy building opportunity, self-efficacy building experiences within the class interacted with each other.

Interestingly, ETOE and STOE both increased significantly from pre to post. This finding is in opposition to previous studies that did not identify significant changes in engineering teaching outcome expectancy after participating in a science methods course (Perkins Coppola, 2019; Yesilyurt et al., 2021). Prior studies suggest that because PSTs lack classroom teaching experiences, they may lack the necessary conceptualizations of classroom practice to fully comprehend the outcome expectancy questions (Hechter, 2011; Tosun, 2000b) and thus emphasize the need for engineering-focused field teaching experiences. While we also recognize the importance of engineering-focused field teaching experiences, we hypothesize that the saturation and interaction of efficacy source experiences in the current study translated to a higher outcome expectancy. PSTs deeply reflected on the science and engineering instructional practices they witnessed throughout the duration of the course (i.e., video cases; instructor modeling). PSTs were provided with time to purposefully dissect the pedagogical strategies they observed and discuss their effectiveness in K-8 classroom settings. This extensive time spent discussing and reflecting upon the vicarious experiences helped PSTs better conceptualize real-life science and engineering teaching and provided them the understanding they needed to influence their outcome expectancy. PSTs were simultaneously engaged in content mastery experiences, the most influential of efficacy source experiences (Lawrent, 2022). Our hypothesis of interaction lies here. PSTs were mastering content as students while reflecting upon and dissecting pedagogy as future teachers. Two layers of efficacy (self-efficacy and outcome expectancy) and their experiences interacted. While in-service teachers utilize teaching experiences as a reference point for vicarious experiences, PSTs do not have that point of reference in their teaching self-efficacy identity. Therefore, we hypothesize the reflection and dissection of pedagogy and its effect on PST outcomes were based upon the change affected in themselves as learners during mastery content experiences and its purposeful interaction between the remaining three sources of personal self-efficacy. This would mean that mastery content experiences were utilized as reference points for vicarious experiences, social persuasions, and psychological and emotional states. Mastery of science and engineering content increased from discussed pedagogy translating to physiological and emotional states. PSTs were also able to transfer this result to future students through vicarious reflection.

In answering our first research sub-question, "How do the STEB, ETEB, STOE, and ETOE of preservice elementary teachers compare?", we found that PSTs began the course with considerably lower ETEB than STEB. This is not surprising as teaching self-efficacy is influenced by past experiences with subject matter content (Tosum, 2000a), and K-12 students often have fewer experiences with engineering content when compared with science content (NRC 2012). At the end of the methods course, participants' STEB was still higher than their ETEB, however, the difference was greatly reduced. In fact, gains in ETEB were the highest for all four subscales, indicating that the inclusion of multiple, engineering-focused components within the science method course can greatly impact engineering teaching self-efficacy beliefs and allow participants to begin overcoming the deficit in engineering experiences prior to the course.

The means for STOE and ETOE on the pretest were higher than the pre-test means for STEB and ETEB, indicating that PSTs began the course with higher outcome expectancy than teaching self-efficacy beliefs. Prior to this study, the PSTs had little to no prior experience teaching science and engineering to students. Because of their limited experiences, it is plausible that they were left to consider their own experiences as learners when answering the outcome expectancy questions, thinking about how their own K-8 teachers' pedagogical choices impacted their learning as students. In essence, they were reflecting on their past experiences as learners and through this metacognitive process their outcome expectancy beliefs were being influenced vicariously.

In addressing the second research sub-question, we found that there were no significant differences in self-efficacy gains and teaching outcome expectancy between course modalities. This indicates that the coursework presented in face-to-face, hybrid, and online modalities can enhance PSTs' science and engineering teaching self-efficacy as well as science and engineering teaching outcome expectancy. Initially, this finding surprised us because we thought engaging in hands-on learning experiences in person with peers would provide rich opportunities to build self-efficacy that would be hard to match online. However, our findings indicate that the cumulative effect of the efficacy source experiences were equally effective across course modalities. Unfortunately, the quantitative nature of the current study limits our ability to infer the reasons for this finding. Perhaps some experiences were more (or less) beneficial in specific modalities but the cumulative effect was the same.

Limitations

The current study does have limitations. First, the data presented were solely quantitative, making it impossible to identify the nuances with which individual participants experienced the efficacy source experiences within each course modality. These nuances may help explain the gains in self-efficacy and outcome expectancy seen from pre- to post-course assessment. Furthermore, some of the participants were actively living through a pandemic at the time they were enrolled in the course and completing the survey. It is possible that this might have influenced the ways in which they engaged in the course and, in turn, may have influenced their efficacy. In addition, while the population of our participants (majority white female) mirrors that of the elementary teaching population in the USA, it does limit our ability to generalize the findings to other demographic groups. While this study does add to the understanding of science and engineering teaching efficacy in PSTs, the study's limitations do highlight important opportunities for future research.

Avenues for future research

Given the limitations described above, along with additional questions that came to light based on our findings, we have identified additional areas for future research. Survey studies are limited in quality by the instruments they employ. While Unfried et al. (2022) found the T-STEM science scale to be a valid and reliable alternative to the STEBI-A, additional research on the T-STEM engineering scale is warranted. Additional studies could provide further evidence to support the use of T-STEM engineering scale by assessing its criterion validity. This could be done by correlating its scores with other measures of engineering teaching self-efficacy, such as the Teaching Engineering Self-Efficacy Scale (TESS) (Yoon et al., 2014), a 23-item scale that measures K-12 teachers' self-efficacy related to teaching engineering. Future research in this area could also consider conducting a factor analysis of the Engineering T-STEM instrument to assess its construct validity. This would reveal the underlying latent factors contributing to the instrument's scores and the items that load onto each factor. This information could be used to refine the instrument and ensure that it measures the intended construct of engineering teaching self-efficacy.

Additional research is needed to explore the ways that efficacy source experiences play out across different course modalities. Since COVID-19, there has been an increase in the number of college students taking science methods coursework in online and blended modalities (Mukhtar, 2020). Furthermore, multiple institutions are beginning to offer methods courses online in an attempt to reduce operating costs and limit barriers that may prevent individuals from pursuing teacher licensure, especially for non-traditional students and those in rural areas who may have to commute a great physical distance to a university campus (Palvia et al., 2018). This highlights the need for additional research in this area. In particular, research that looks more closely at the individual components of the course and the impacts each component has when implemented using different course modalities would help instructors make important course design decisions. For example, this finding raises new questions about social persuasion as a source of efficacy and how it interacts with the other three efficacy sources. While the content that was delivered across the four modalities was comparable, the ways in which PSTs engaged with the content and their peers differed greatly across modalities. For example, students in face-to-face sections had daily opportunities to interact with their peers and instructor through collaborative activities and in person discussions, while students in hybrid courses had fewer in-person peer and instructor interactions and online students had none. Given that learning is "both a social and cognitive process" (Hodges et al., 2020) that instructors must support through student-content, student–student, and student–teacher interactions (Bernard et al., 2009), understanding how these different interactions play out across different modalities is crucial. What is the effect of efficacy experience interactions and is pedagogy targeted at efficacy experiences and their interactions a worthwhile focus of PST courses? What role did social persuasion play in the efficacy gains within each of these contexts? How did different course assignments provide opportunities for social persuasion experiences? One example to consider would be that students in all course modalities utilized a discussion board hosted on the course learning management system. However, it is not known if the interactions with the discussion board were of similar importance to students in different modalities. Did social persuasion through the discussion boards play a greater role in efficacy development for online students who had no face-to-face interactions? Did interacting with discussion posts prompt later in-person conversations during hybrid and face-to-face meetings or were the posts of minimal persuasion due to a reliance on in-person interactions? Does reading discussion boards without any response have an effect on efficacy experience interactions? How does the interaction of vicarious experiences and mastery experiences affect outcome expectancy scores when teacher preparation courses include (1) feedback loops focused on measurable outcomes from mastery experiences and (2) teacher reflection on the feedback loop? These are a few of many questions for further exploration.

Fully exploring these questions will require employing qualitative and mixed methods research approaches that make use of observational and interview data. Qualitative methods, such as case studies, could provide opportunities for researchers to provide "thick descriptions" (Denzin, 2001, p. 83) that help identify the nuances in how PSTs are engaging with various efficacy source experiences and internalizing those experiences to support or detract from their science and engineering teaching self-efficacy.

Conclusion

The current study adds to the literature on engineering teaching self-efficacy in two important ways. Firstly, an important contribution of the current study is the reporting of reliability statistics for the Engineering Teaching Efficacy Beliefs and Engineering Teaching Outcome Expectancy subscales of the T-STEM instrument when used with elementary pre-service teachers. Inter-item reliability analyses revealed Cronbach's alpha coefficients to be greater than 0.7 for all pre- and post-test scales, indicating good reliability. Consequently, our work provides evidence supporting the Engineering T-STEM as a reliable tool for measuring elementary pre-service teachers' engineering teaching self-efficacy.

Second, our work provides evidence that the inclusion of multiple engineering-focused components spread across a science methods course can enhance elementary preservice teachers' science and engineering teaching self-efficacy beliefs and outcome expectancy, even in the absence of practicing teaching engineering to children. It is crucial for pre-service educators, specifically those teaching at the elementary level, to have the chance to personally experience scientific inquiry and engineering design. This study shows that having varied efficacy source experiences while learning engineering design can result in increased self-efficacy, even in the absence of field experience and face-to-face coursework, and that the inclusion of these engineering experiences with science methods coursework does not detract from enhancing science teaching self-efficacy beliefs and outcome expectancy. Specifically, the inclusion of multiple vicarious learning experiences that allow metacognitive reflection provides opportunities to enhance self-efficacy and outcome expectancy in the absence of mastery experiences connected to teaching children.

Given the large implications teacher efficacy has on classroom teaching and learning, it is pertinent that preservice teachers are provided with opportunities to enhance their teaching self-efficacy. As seen in this study, the incorporation of multiple, varied efficacy source experiences, in the form of engineering-focused activities, within a single methods course can boost self-efficacy when it comes to elementary engineering education. Additional studies need to be carried out to better understand the effects of each course component and how the impact magnitude of each component varies with course modality. Furthermore, additional data should be gathered to explore the possible interactions of efficacy source experiences (i.e., vicarious experiences as a form of mastery experience) and further refine the hypothesis of interaction. Qualitative approaches could provide a more nuanced understanding of these effects and how they influence participants' experiences.

Appendix A

Outliers

See Fig. 5.

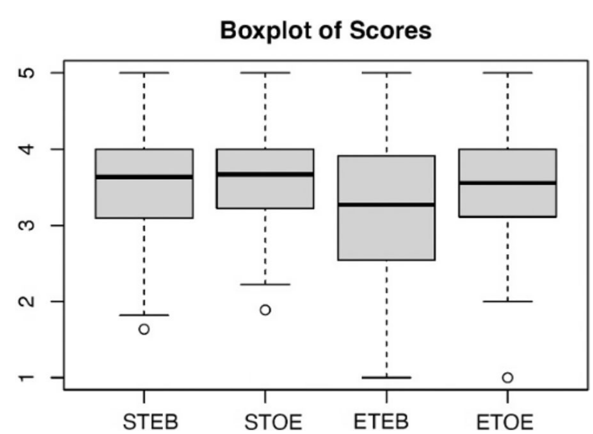

Fig. 5 Boxplot of scores and outliers

Normality assumption

See Figs. 6 and 7.

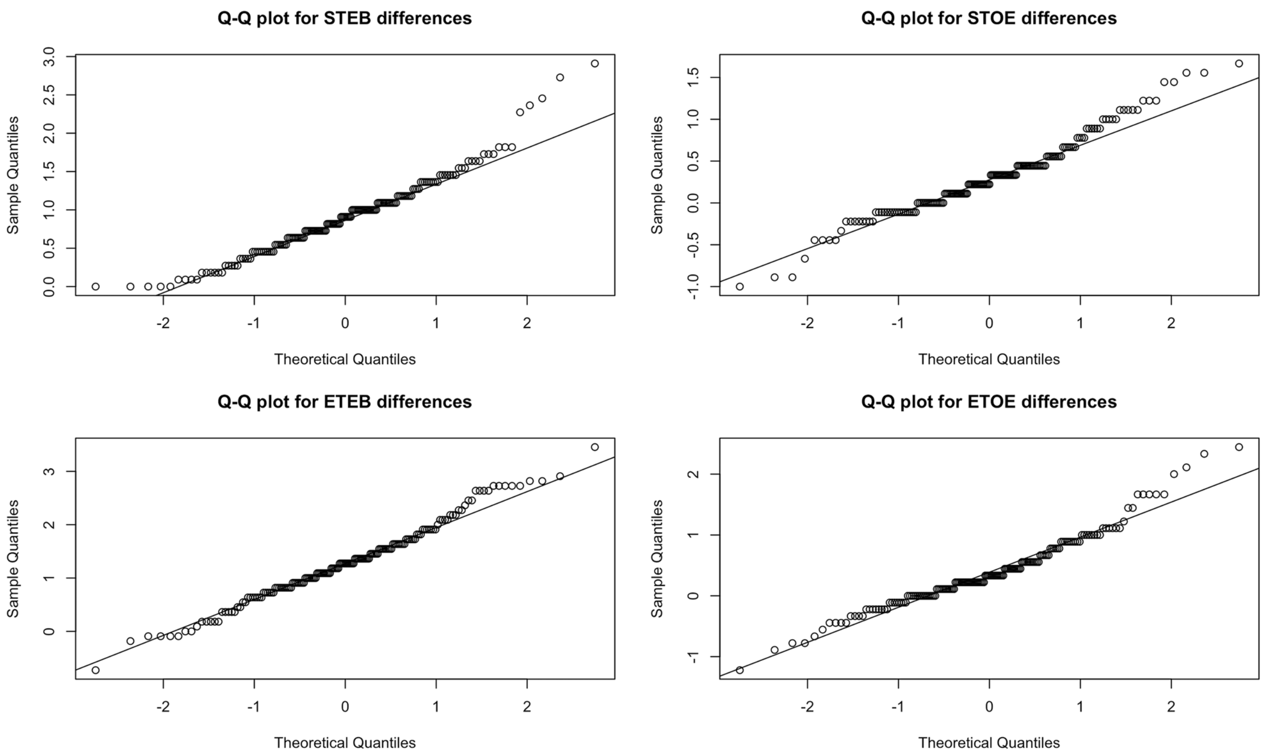

Fig. 6 Q–Q plots for pre- and post-survey differences

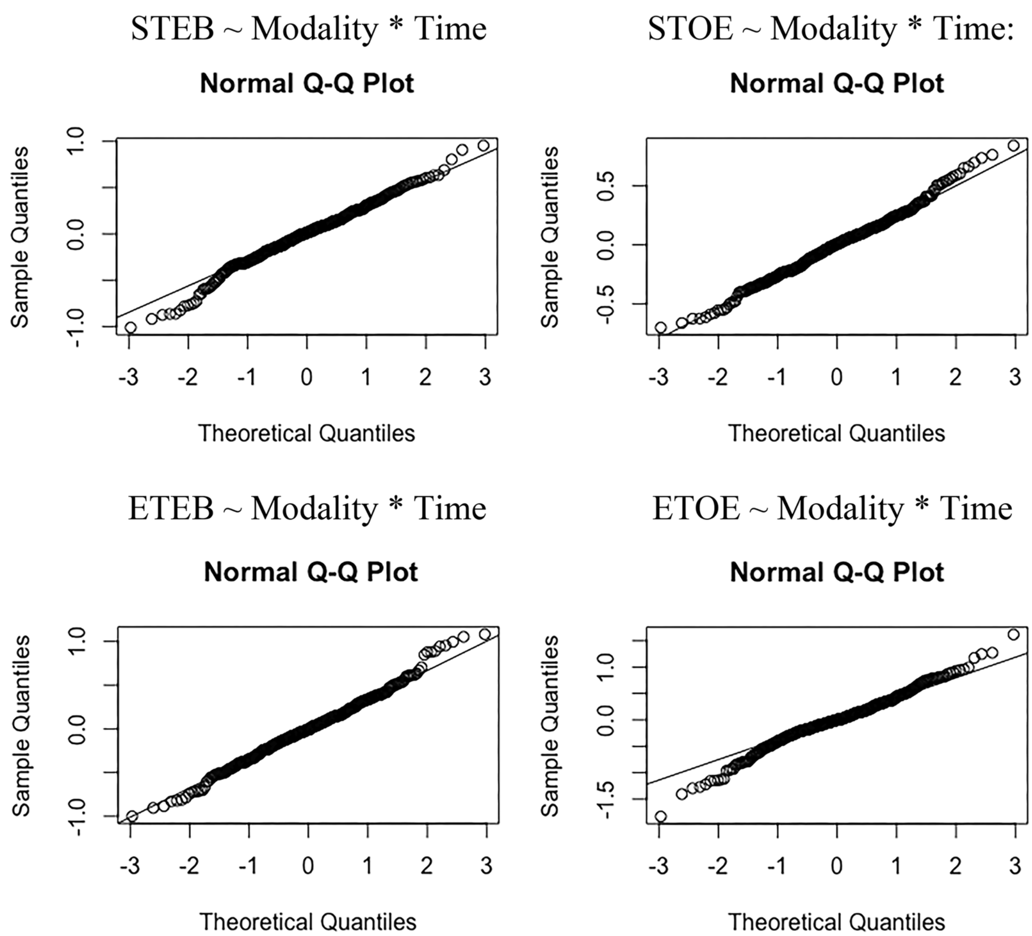

Fig. 7 Q–Q plots for each model

Abbreviations

NGSS	Next Generation Science Standards
PST	Preservice teacher
ETOE	Engineering teaching outcome expectancy
ETEB	Engineering teaching efficacy beliefs
STOE	Science teaching outcome expectancy
STEB	Science teaching efficacy beliefs
T-STEM	Teacher Efficacy and Attitudes Toward STEM Survey

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Author contributions
RH developed and implemented the engineering components of the course and collected the data. All authors drafted the research questions and contributed to the writing and editing of the manuscript. IY and TB completed data analysis. All authors read and approved the final manuscript.

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Availability of data and materials
Due to ethical and Institutional Review Board restrictions, the data set used for this paper is not available to the public. However, the authors welcome inquiries about the materials.

Declarations

Competing interests
The authors declare that they have no competing interests.

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References

Allinder, R. (1994). The relationship between efficacy and the instructional practices of special education teachers and consultants. *Teacher Education and Special Education, 17*(2), 86–95. https://doi.org/10.1177/088840649401700203

Angle, J., & Moseley, C. (2009). Science teacher efficacy and outcome expectancy as predictors of students' end-of-instruction (EOI) biology I test scores. *School Science and Mathematics, 109*(8), 473–483. https://doi.org/10.1111/j.1949-8594.2009.tb18294.x

Bandura, A. (1977). Self-efficacy: Toward a unifying theory of behavioral change. *Psychological Review, 84*(2), 191–215. https://doi.org/10.1037/0033-295x.84.2.191
Bandura, A. (1997). *Self-efficacy: The exercise of control*. New York: WH Freeman.
Bandura, A. (2000). Exercise of human agency through collective efficacy. *Current Directions in Psychological Science, 9*(3), 75–78. https://doi.org/10.1111/1467-8721.00064
Banilower, E. R., Smith, P. S., Malzahn, K. A., Plumley, C. L., Gordon, E. M., & Hayes, M. L. (2018). Report of the 2018 NSSME+. *Horizon Research, Inc.*
Barnes, R., Hall, R., Lowe, V., Pottinger, C., & Popham, A. (2020). Lessons from an online teacher preparation program: Flexing work experience to meet student needs and regulators' requirements in the United States. *Journal of Education for Teaching, 46*(4), 528–535. https://doi.org/10.1080/02607476.2020.1802203
Bautista, N. U. (2011). Investigating the use of vicarious and mastery experiences in influencing early childhood education majors' self-efficacy beliefs. *Journal of Science Teacher Education, 22*(4), 333–349. https://doi.org/10.1007/s10972-011-9232-5
Berliner, D. C. (1988). Effective classroom management and instruction: A knowledge base for consultation. In J., L. Graden, J. E. Zins, & M. J. Curtis (Eds.), *Alternative educational delivery systems: Enhancing instructional options for all students*, 309–326.
Bernard, R. M., Abrami, P. C., Borokhovski, E., Wade, C. A., Tamin, R. M., Surkes, M. A., & Bethel, E. C. (2009). A meta-analysis of three types of interaction treatments in distance education. *Review of Educational Research, 79*(3), 1243–1289. https://doi.org/10.3102/0034654309333844
Bleicher, R. E., & Lindgren, J. (2005). Success in science learning and preservice science teaching self-efficacy. *Journal of Science Teacher Education, 16*(3), 205–225. https://doi.org/10.1007/s10972-005-4861-1
Bybee, R. W., Taylor, J. A., Gardner, A., Van Scotter, P., Powell, J. C., Westbrook, A., & Landes, N. (2006). The BSCS 5E instructional model: Origins and effectiveness. *Colorado Springs, Co: BSCS, 5*(88–98). Retrieved from https://www.jstor.org/stable/26901398
Cakiroglu, J., Capa-Aydin, Y., & Hoy, A. W. (2012). Science teaching efficacy beliefs. *Second international handbook of science education* (pp. 449–461). Netherlands: Springer. https://doi.org/10.1007/978-1-4020-9041-7_31
Cantrell, P., Young, S., & Moore, A. (2003). Factors affecting science teaching efficacy of preservice elementary teachers. *Journal of Science Teacher Education, 14*(3), 177–192. https://doi.org/10.1023/A:1025974417256
Colvin, G., Kameenui, E. J., & Sugai, G. (1993). Reconceptualizing behavior management and school-wide discipline in general education. *Education & Treatment of Children, 16*(4), 361–381.
Daunic, A. P., Smith, S. W., Brank, E. M., & Penfield, R. D. (2006). Classroom-based cognitive– behavioral intervention to prevent aggression: Efficacy and social validity. *Journal of School Psychology, 44*(2), 123–139. https://doi.org/10.1016/j.jsp.2006.01.005
Deehan, J. (2017). *The science teaching efficacy belief instruments (STEBI a and B): A comprehensive review of methods and findings from 25 years of science education research* (1st ed.). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-319-42465-1
Denzin, N. K. (2001). *Interpretive interactionism* (Vol. 16). USA: Sage.
Enochs, L. G., & Riggs, I. M. (1990). Further development of an elementary science teaching efficacy belief instrument: A preservice elementary scale. *School Science and Mathematics, 90*(8), 694–706. https://doi.org/10.1111/j.1949-8594.1990.tb12048.x
Fain, P. (2017). *National enrollments decline for sixth straight year, but at slower rate. Inside Higher Ed.* https://www.insidehighered.com/news/2017/12/20/national-enrollments-decline-sixth-straight-year-slower-rate
Fogg-Rogers, L., Lewis, F., & Edmonds, J. (2017). Paired peer learning through engineering education outreach. *European Journal of Engineering Education, 42*(1), 75–90. https://doi.org/10.1080/03043797.2016.1202906
Friday Institute for Educational Innovation (2012). Teacher efficacy and attitudes toward STEM survey. North Carolina State University. http://miso.ncsu.edu/articles/t-stem-survey-2
Gibson, S., & Dembo, M. H. (1984). Teacher efficacy: A construct validation. *Journal of Educational Psychology, 76*(4), 569–582.
Goddard, R. D., Hoy, W. K., & Hoy, A. W. (2000). Collective teacher efficacy: Its meaning, measure, and impact on student achievement. *American Educational Research Journal, 37*(2), 479–507.
Guskey, T. (1987). Context variables that affect measures of teacher efficacy. *The Journal of Educational Research, 81*(1), 41–47.
Hair, J., Black, W., Babin, B., Anderson, R., & Tatham, R. (2006). *Multivariate data analysis* (6th ed.). Pearson Prentice Hall.
Hammack, R., & Ivey, T. (2017). Examining elementary teachers' engineering self-efficacy and engineering teacher efficacy. *School Science and Mathematics, 117*(1–2), 52–62. https://doi.org/10.1111/ssm.12205
Hammack, R., & Yeter, I. H. (2022). Exploring pre-service elementary teachers' engineering teaching efficacy beliefs: A confirmatory analysis study (fundamental). In *2022 ASEE Annual Conference & Exposition*.
Hammack, R., & Ivey, T. (2019). Elementary teachers' perceptions of K-5 engineering education and perceived barriers to implementation. *Journal of Engineering Education, 108*(4), 503–522. https://doi.org/10.1002/jee.20289
Hammack, R., Gannon, P., Foreman, C., & Meyer, E. (2020). Impacts of professional development focused on teaching engineering applications of mathematics and science. *School Science and Mathematics, 120*(7), 413–424. https://doi.org/10.1111/ssm.12430
Hechter, R. P. (2011). Changes in preservice elementary teachers' personal science teaching efficacy and science teaching outcome expectancies: The influence of context. *Journal of Science Teacher Education, 22*(2), 187–202. https://doi.org/10.1007/s10972-010-9199-7
Henson, R. K. (2001). *Teacher self-efficacy: Substantive implications and measurement dilemmas* [Paper presentation]. Annual Meeting of the Educational Research Exchange. College Station, TX.
Hodges, C., Moore, S., Lockee, B., Trust, T., & Bond, A. (2020). *The difference between emergency remote teaching and online learning.* EDUCASE. https://er.educause.edu/articles/2020/3/the-difference-between-emergency-remote-teaching-and-online-learning
Kaya, E., Newley, A., Yesilyurt, E., & Deniz, H. (2019). Improving preservice elementary teachers' engineering teaching efficacy beliefs with 3D design and printing. *Journal of College Science Teaching, 48*(5), 76–83.
Lawrent, G. (2022). Sources of teacher efficacy related attributes alongside Bandura's perspectives. *Journal of Education*. https://doi.org/10.1177/00220574221094238
Lederman, D. (2018). *Who is studying online (and where).* Inside Higher Ed. https://www.insidehighered.com/digital-learning/article/2018/01/05/new-us-data-show-continued-growth-college-students-studying
Lewis-Moreno, B. (2007). Shared responsibility: Achieving success with English-language learners. *Phi Delta Kappan, 88*(10), 772–775. https://doi.org/10.1177/003172170708801016
Mukhtar, K., Javed, K., Arooj, M., & Sethi, A. (2020). Advantages, limitations and recommendations for online learning during COVID-19 pandemic era. *Pakistan Journal of Medical Sciences, 36*(4), 27–31. https://doi.org/10.12669/pjms.36.COVID19-S4.2785
Mulholland, J., Dorman, J., & Odgers, B. (2004). Assessment of science teaching efficacy of preservice teachers in an Australian university. *Journal of Science Teacher Education, 15*(4), 313–331.
National Academies of Sciences, Engineering, & Medicine [NASEM]. (2020). *Building capacity for teaching engineering in K-12 education*. The National Academies Press. https://doi.org/10.17226/25612
National Center for Education Statistics. (2022). *Postbaccalaureate enrollment. Condition of education.* U.S. Department of Education, Institute of Education Sciences. https://nces.ed.gov/programs/coe/indicator/chb.
National Research Council. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. USA: National Academies Press.
Nesmith, S. M., & Cooper, S. (2021). Connecting engineering design and inquiry cycles: Impact on elementary preservice teachers' engineering efficacy and perspectives toward teaching engineering. *School Science and Mathematics, 121*(5), 251–262. https://doi.org/10.1111/ssm.12469
NGSS Lead States. (2013). *Next generation science standards: For states, by states*. The National Academies Press. https://doi.org/10.17226/18290
Palmer, D. (2006). Sources of self-efficacy in a science methods course for primary teacher education students. *Research in Science Education, 36*(4), 337–353. https://doi.org/10.1007/s11165-005-9007-0
Palvia, S., Aeron, P., Gupta, P., Mahapatra, D., Parida, R., Rosner, R., & Sindhi, S. (2018). Online education: Worldwide status, challenges, trends, and implications. *Journal of Global Information Technology Management, 21*(4), 233–241. https://doi.org/10.1080/1097198X.2018.1542262
Perkins Coppola, M. (2019). Preparing preservice elementary teachers to teach engineering: Impact on self-efficacy and outcome expectancy. *School*

Science and Mathematics, 119(3), 161–170. https://doi.org/10.1111/ssm.12327
Plourde, L. (2002). The influence of student teaching on preservice elementary teachers science self-efficacy and outcome expectancy beliefs. *Journal of Instructional Psychology, 29*(4), 245–254.
Putman, S. M. (2012). Investigating teacher efficacy: Comparing preservice and inservice teachers with different levels of experience. *Action in Teacher Education, 34*(1), 26–40. https://doi.org/10.1080/01626620.2012.642285
Riggs, I. (1988). *The development of an elementary teachers' science teaching efficacy belief instrument*. Kansas State University.
Ross, J., Cousins, J., & Gadalla, T. (1996). Within-teacher predictors of teacher efficacy. *Teaching and Teacher Education, 12*(4), 385–400. https://doi.org/10.1016/0742-051X(95)00046-M
Savran, A., & Çakıroğlu, J. (2003). Differences between elementary and secondary preservice science teachers' perceived efficacy beliefs and their classroom management beliefs. *Turkish Online Journal of Educational Technology, 2*, 15–20.
Swackhamer, L. E., Koellner, K., Basile, C., & Kimbrough, D. (2009). Increasing the self-efficacy of inservice teachers through content knowledge. *Teacher Education Quarterly, 36*(2), 63–78.
Taber, K. S. (2018). The use of cronbach's alpha when developing and reporting research instruments in science education. *Research in Science Education, 48*, 1273–1296. https://doi.org/10.1007/s11165-016-9602-2
Tosun, T. (2000a). The beliefs of preservice elementary teachers toward science and science teaching. *School Science and Mathematics, 100*(7), 374–379. https://doi.org/10.1111/j.1949-8594.2000.tb18179.x
Tosun, T. (2000b). The impact of prior science course experience and achievement on the science teaching self-efficacy of preservice elementary teachers. *Journal of Elementary Science Education, 12*(2), 21–31. https://doi.org/10.1007/BF03173597
Tschannen-Moran, M., & Hoy, A. W. (2001). Teacher efficacy: Capturing an elusive construct. *Teaching and Teacher Education, 17*(7), 783–805. https://doi.org/10.1016/s0742051x(01)00036-1
Unfried, A., Rachmatullah, A., Alexander, A., & Wiebe, E. (2022). An alternative to STEBI-A: Validation of the T-STEM science scale. *International Journal of STEM Education, 9*(24), 1–14. https://doi.org/10.1186/s40594-022-00339-x
Ward, G., Dixon, H., & Withy, H. (2020). Primary science teachers' self-efficacy and outcome expectancy: A case study. *Australian Journal of Teacher Education (online), 45*(9), 79–91. https://doi.org/10.14221/ajte.2020v45n9.5
Watters, J. J., & Ginns, I. S. (1995). *Origins of, and changes in preservice teachers' science teaching self efficacy* [Paper presentation]. Annual Meeting of the National Association for Research in Science Teaching. San Francisco, CA.
Yesilyirt, E., Deniz, H., & Kaya, E. (2021). Exploring sources of engineering teaching self-efficacy for pre-service elementary teachers. *International Journal of STEM Education*. https://doi.org/10.1186/s40594-021-00299-8
Yoon Yoon, S., Evans, M., & Strobel, J. (2014). Validation of the teaching engineering self-efficacy scale for K-12 teachers: A structural equation modeling approach. *Journal of Engineering Education, 103*(3), 463–485. https://doi.org/10.1002/jee.20049
Zee, M., & Koomen, H. M. Y. (2016). Teacher self-efficacy and its effects on classroom processes, student academic adjustment, and teacher well-being: A synthesis of 40 years of research. *Review of Educational Research, 86*(4), 981–1015. https://doi.org/10.3102/0034654315626801

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