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NGSS-based teacher professional development to implement engineering practices in STEM instruction

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Abstract

Background: With widespread adoption of the Next Generation Science Standards (NGSS) in the USA (US), research is needed on how secondary science, technology, engineering, and mathematics (STEM) teachers conceptualize the integration of engineering knowledge and practices in traditional STEM classrooms. The present study explored the affective impacts of participation in an engineering education workshop for secondary STEM teachers as part of a 200-h professional development program. The workshop focused on the implementation of electrical engineering and biotechnology principles and design practices in disciplinary instruction, as well as training teachers to differentiate among engineering fields and advise on career pathways. The conceptual framework for the workshop design was based upon elements of the interconnected model of professional growth to identify influences contributing to engineering pedagogical self-efficacy and career awareness.

Results: The overarching research questions addressed how professional development in engineering education affected secondary STEM teachers' beliefs about the value of using engineering design to support learning, their self-efficacy regarding teaching engineering in their courses, perceived obstacles to effective STEM integration, and their confidence advising students about engineering post-secondary study and careers. The convergent parallel mixed methods design involved factor analysis, comparisons of means, and phenomenology with elements of grounded theory. The survey sample included 60 STEM teachers in the treatment group and 28 teachers in the control group. Six science teachers participated in interviews before and after the engineering workshops. Findings indicated that participating teachers significantly improved their confidence in engineering pedagogy, as well as their knowledge of engineering careers and precollege preparation for post-secondary engineering. Teachers expressed their views of engineering as a potentially powerful tool in developing students' critical thinking and problem-solving skills, particularly when integrating the practices of science and engineering with the instruction of disciplinary content.

(Continued on next page)

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Conclusions: The results from this study demonstrate that a university-based professional development workshop series, developed by engineering and science education faculty, is an effective first-step intervention to improve the engineering knowledge and skills of secondary STEM educators, ultimately facilitating NGSS adoption in classroom instruction. Educating teachers on engineering career pathways is another innovation for the promotion of more diverse participation in engineering fields.

Keywords: Engineering education, K-12 education, Mixed methods research, Precollege STEM preparation, Professional development, STEM integration

Introduction

There are significant educational challenges as many U.S. states transition their science standards to align with the *Next Generation Science Standards* ([NGSS] NGSS Lead States 2013; Singer et al. 2016). The primary goal of the standards is to empower all students with the requisite scientific and technological literacy to make informed personal and public decisions and to foster the motivation and requisite skills to pursue careers in science, technology, engineering, and mathematics (STEM) (National Research Council 2012). The standards intend to realize this goal through the integration of engineering practices with STEM disciplinary content (NGSS Lead States 2013). As of 2021, 40 states have planned adoptions of the standards or NGSS-like standards in an effort to reform science instruction through improvements in teacher education, curriculum, and assessment (Thompson 2019).

The integrative nature of NGSS presents a unique challenge for classroom teachers and teacher educators. One of the primary aims of NGSS is the integration of engineering practices with science content in a cohesive course of study (NGSS Lead States 2013), which reflects the inherent interconnectedness of STEM subjects in modern research and technological innovation (National Academy of Engineering 2009). A significant obstacle to the success of NGSS implementation is the inadequate preparation of secondary school teachers to address the engineering components of the standards (Banilower et al. 2018; Daugherty and Custer 2012; Smith 2020). Very few secondary science, mathematics, and technology educators have either educational or practical experience with engineering and many have significant misconceptions or a complete lack of knowledge of engineering (Bybee 2011; Cunningham et al. 2007). Without additional support, engineering practices may be avoided or misrepresented in the classroom (Purzer et al. 2014; Purzer and Quintana-Cifuentes 2019). A recent study indicated that just 29% of high school science classes emphasized real-life applications of science and engineering, 7% differentiated among science and engineering fields, and 5% instructed on how to do engineering (e.g., identifying constraints, optimizing solutions) (Smith 2020). Engineering learning has also been constrained when students have been taught mathematics and technology with non-contextualized or limited applications (Harris et al. 2015; Wang et al. 2011). Consequently, there is a need for professional development for STEM educators that will foster engineering literacy (Peters-Burton and Johnson 2018; Thatcher and Meyer 2017). Accessible and effective STEM teacher training that contributes to the development of engineering knowledge and practices may facilitate NGSS-aligned instruction (Darling-Hammond et al. 2017; Watkins et al. 2018; Yoon et al. 2007).

In response to the critical need for teacher training, this research examined the influence of an engineering professional development experience on STEM teachers' perceptions of the epistemological value of engineering in classroom instruction, as well as their perceived ability to teach engineering and advise on engineering post-secondary aspirations. Research has suggested the need for studies that iteratively contribute to the refinement of engineering professional development experiences (Peters-Burton and Johnson 2018), particularly in terms of engineering pedagogy, epistemology, and disciplinary practice (Purzer and Quintana-Cifuentes 2019). The current study investigated the involvement of STEM educators in a professional development workshop in engineering design practices, which was part of a 200-h professional development program. Several questions were explored, including: How does professional development in engineering design education affect: (a) secondary school STEM teachers' confidence in implementing epistemologically sound engineering design to support learning?; (b) STEM teachers' self-efficacy regarding teaching engineering design in their courses, and their perceived obstacles in doing so effectively?; and (c) STEM teachers' confidence in their ability to advise students about engineering post-secondary study and careers?

Review of literature

Science and engineering integration

The recent call for STEM education reform was based upon decades of research and reports illustrating the value of engineering in developing students' STEM knowledge and preparing them to contribute to the nation's economic stability and technological growth (American Association for the Advancement of Science 1990; National Academy of Engineering 2009; National Research Council 2012). The inclusion of the engineering performance expectations at every instructional level and across STEM disciplines ensures that all students are exposed to the engineering design process and engaged in related engineering practices (American Society for Engineering Education 2014; National Academy of Engineering 2009; National Research Council 2012; Peters-Burton and Johnson 2018). Research has shown that employing an engineering design protocol to support STEM instruction can improve student understanding and knowledge retention of related STEM content, as well as foster critical problem-solving skills and technological literacy (Guzey et al. 2019; McGowan et al. 2017; Mehalik et al. 2008).

There is ample evidence to support the positive impacts of embedding engineering instruction within science curricula (Fortus et al. 2004; Silk et al. 2009; Watkins et al. 2018). The synthesis of science and engineering instruction within NGSS provides a context for students to apply their developing science knowledge in practical and relevant real-world scenarios using engineering to enhance learning in both domains of understanding (NGSS Lead States 2013). Additionally, engaging students in engineering systems design tasks to create solutions for technical challenges has been shown to diminish the opportunity gap and subsequent performance disparities for traditionally underrepresented groups of students, including special education students, students of low socioeconomic status, and Hispanic and Black students (Cantrell et al. 2006; Mehalik et al. 2008; Silk et al. 2009). Despite these positive benefits, more research is needed in how teacher professional development opportunities in engineering may be expanded and optimized to increase meaningful STEM integration characterized by evidence-driven decision-making that contributes to positive societal outcomes (National Academy of Engineering 2009; Peters-Burton and Johnson 2018; Purzer and Quintana-Cifuentes 2019).

The integrative nature of NGSS presents a unique challenge for classroom teachers and teacher educators. One of the primary aims of NGSS is the incorporation of engineering practices with science content and practices in a cohesive course (NGSS Lead States 2013). This involves STEM integration, or multidisciplinary approaches to analyzing and solving real-world problems with content and skills from science, technology, engineering, and mathematics (Wang et al. 2011). STEM integration is intended to promote STEM literacy, workforce readiness, and student engagement and interest in STEM; this necessitates preparing teachers with adequate STEM competence (Peters-Burton and Johnson 2018).

The goals of STEM integration may be limited by inadequate teacher content knowledge, pedagogical content knowledge, and lack of self-efficacy, which have been associated with a general reluctance to teach about engineering (National Academy of Engineering and National Research Council 2014). Very few science educators have either educational or practical experience with engineering and many have significant misconceptions or a complete lack of knowledge of engineering (Christian et al. 2018; Bybee 2011; Kimmel et al. 2007). A recent study indicated few secondary science teachers felt prepared to teach engineering principles related to defining engineering problems, developing possible solutions to technological problems, and optimizing design (Smith 2020). It is essential for teachers to incorporate open-ended engineering design challenges in their instruction to effectively integrate engineering with science, mathematics, and technology content (Porter et al. 2019). Consequently, there is a need for professional development for science educators that will foster participants' engineering literacy.

Fostering STEM preparation and aspirations

The academic experiences of students before college often influence their career aspirations and how they make choices to reach these goals (Aschbacher et al. 2014; Ashford et al. 2016). High school academic course selection is an important consideration in engineering admissions, since post-secondary success in engineering study has often been linked to precollege course preparation in advanced mathematics and science (May and Chubin 2003; Tyson 2011). However, access to such courses has been inequitable in terms of ethnicity and socioeconomic status (Kelly and Sheppard 2009, 2010, 2019; Krakehl et al. 2020; National Center for Science and Engineering Statistics 2018; Padwa et al. 2019; Sheppard et al. 2020). Teachers may be influenced by latent biases concerning which students are best suited for engineering (Nathan et al. 2010). To achieve the goal of a larger and more diversified engineering workforce, informed secondary STEM educators are well positioned to promote post-secondary engineering study, particularly in terms of guiding students to select the appropriate coursework for equitable access to this vocational choice (Hall et al. 2011).

Knowledge of the preparation for and tasks involved in various engineering disciplines is another consideration in precollege career advisement. Both students and teachers may have a lack of knowledge or misconceptions regarding the nature of engineering subdisciplines, for example, researchers have found confusion in how students differentiate among computing disciplines (Anthony 2003) as well as weak understandings of engineering in general (Montfort et al. 2013). Engineering career choice is often predicated upon whether students believe that choice is consistent with their personal identities and values (Bugallo and Kelly 2014; Kolmos et al. 2013; Matusovich et al. 2010); therefore, it is important that students be able to differentiate among engineering careers and have awareness of the mathematics and science gateway coursework (Fouad 1995). Limited formal STEM career advisement typically occurs with school counselors (Gibbons et al. 2003), yet STEM teachers may be better positioned to influence students through informal conversations, encouragement, and classroom-based instructional strategies (Packard and Jeffers 2013).

University-based STEM teacher professional development

The adoption of NGSS has necessitated high quality cost- and time-effective professional development for the majority of STEM teachers who are not adequately prepared to teach engineering (Banilower et al. 2018). Research has identified several aspects of STEM teacher professional development that may improve teachers' knowledge of science and engineering principles, as well as affective domains related to pedagogical confidence (Astor-Jack et al. 2007). These aspects include collective participation, focus on disciplinary content knowledge, active teacher learning, and coherence through an overall program of teacher learning and ongoing communication (Garet et al. 2001). In the context of STEM professional development, promising programs have focused on situated engineering design experiences, using data to make evidence-based decisions, and implementing open-ended investigations to iteratively revise prototypes (Cunningham et al. 2007; Porter et al. 2019).

University-based professional development programs have similarities with those provided by informal science institutions, which often provide short-term collaborative experiences that serve as a catalyst for future professional learning, ultimately improving pedagogical practice (Yerrick and Beatty-Adler 2011). Such opportunities have facilitated teachers' understandings about scientists and how their work is related to everyday concepts (Avraamidou 2015). Although teachers' pedagogical change has often been measured through classroom observations in conjunction with self-reported data (Williams et al. 2019), changes in teachers' beliefs and approaches to learning provide valuable insights into their intentions as a first step in assessing training effectiveness (Garet et al. 2001).

Conceptual framework

The development of effective teaching practice is a complex process, occurring through teacher training and experiences in various contexts. The *interconnected model of professional growth* attempts to characterize the influences contributing to the growth of a teacher's pedagogical competencies (Clarke and Hollingsworth 2002). This model describes several domains of teacher change and their interrelationships, three of which are applied to the present study. The external domain describes the stimuli for professional change and the sources of instructional support that influence a teacher's practice, such as state standards and professional development experiences. These stimuli may be more motivational in the context of a community of inquiry with other STEM teachers (Al-Balushi and Al-Abdali 2015). This external domain has a direct influence on teachers' perceptions and awareness of the target growth area, as well as their behaviors in the classroom. The personal domain identifies attitudes toward the intended instructional innovation and knowledge associated with the instructional practice. Finally, the domain of consequence describes the teacher's conclusions regarding the progression of professional change (Clarke and Hollingsworth 2002), in the present case, their attitudinal shifts regarding engineering pedagogical practice and career advisement.

The ongoing interaction among these domains occurs through modeled practice, collective participation, and reflection. Teachers continuously use their experience and knowledge from one domain to influence their teaching philosophy through the other domains (Clarke and Peter 1993). Additionally, the model acknowledges the influence of environmental factors on teacher growth, such as school expectations and resources, guiding standards and curriculum, and interactions with colleagues (Clarke and Hollingsworth 2002). The conceptual framework of this study is represented in Fig. 1.

Methods

Research design

A convergent parallel triangulation design informed the three research questions, providing cross-validation of qualitative and quantitative results (Creswell et al. 2003). This design was selected to present a more comprehensive analysis of survey data and teacher's self-reported professional views and experiences. Triangulation improves the external validity of findings by comparing qualitative and quantitative data to identify congruent phenomena (Jick 1979). This mixed methods approach resulted in a more complete depiction of STEM teacher attitudes than a solely quantitative or qualitative analysis (Creswell et al. 2003), and captured a more holistic perspective of the impact of participation in professional development (Jick 1979). Triangulation between methodologies not only increased confidence in the study findings but also illuminated elements of teacher

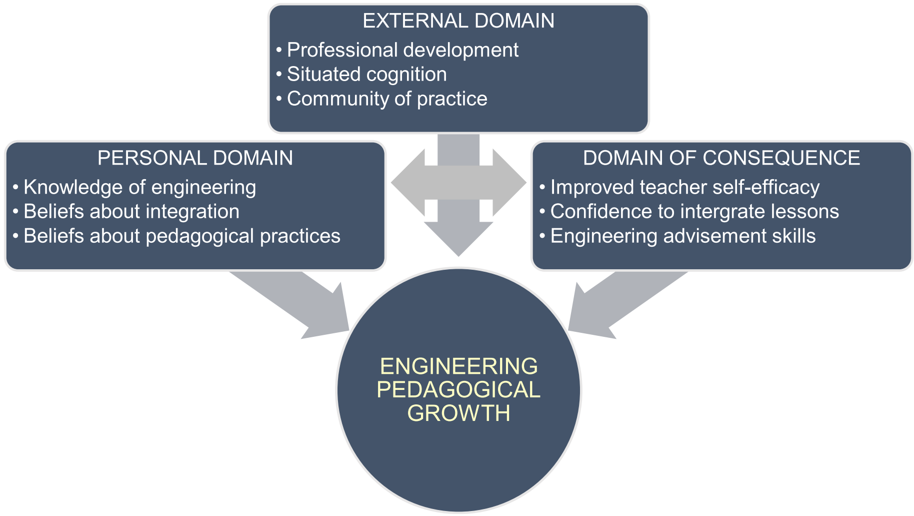

Fig. 1 Integrated model of pedagogical growth in engineering education (adapted from Clarke and Hollingsworth 2002)

attitudes that did not fit the a priori conceptual model (Jick 1979). In addition, limitations in the descriptive value of the survey instruments were addressed with interview questions that allowed for a deeper investigation of individuals' self-efficacy (Creswell et al. 2003).

The convergent parallel triangulation design involved a self-selected treatment group of secondary STEM teachers (*N*=60), as well as a randomly selected control group of science teachers from similar schools (*N*=28). The self-selected participants in the treatment group were involved in a state-sponsored Master Teacher Program, requiring teachers to participate in 50 h of professional development per year for 4 years, for a total of 200 professional development hours. For STEM teachers, the 200 h of professional development in the program were continuously aligned with NGSS disciplinary core ideas, crosscutting concepts, and science and engineering practices. The teachers had many options for various professional development workshops during each of their 4 years in the program. Participants were secondary teachers who were actively teaching biology (*n*=12), chemistry (*n*=6), computer science (*n*=8), Earth science (*n*=9), engineering (*n*=13), physics (*n*=9), mathematics (*n*=8), and/or technology (*n*=25) in various school districts. Some participants taught more than one subject. Four teachers attended both workshops and they were not included in the data analysis. The control group was selected and surveyed to establish relative equivalence in baseline responses with the treatment group, since self-selection into the treatment may have introduced bias in the research design. The control group was from secondary schools in the same region in the state and included teachers with similar disciplinary backgrounds as the treatment group. However, this district had slightly higher income families than the average schools employing participants in the treatment (New York State Education Department 2018).

The study included teachers from science, mathematics, and technology to foster interdisciplinary discussions in the professional development workshops; this inclusive approach was intended to broaden teachers' conceptions of how science, mathematics, and technology constructs could be integrated to support students' understanding of engineering content and design. NGSS had been adopted in a modified form in the state and officially implemented starting in the 2019-2020 academic year. The standards diminish traditional disciplinary boundaries and articulate stronger integration among all STEM disciplines (NGSS Lead States 2013), consequently, the inclusion of instructors from multiple disciplines was intended to facilitate horizontal curricular collaboration.

The design was mixed methods and convergent parallel since qualitative and quantitative data were collected both before and after the treatment. Six science teachers, each working in a different school district, consented to participate in interviews both before and after the engineering workshop series. The science teachers were most likely to have immediate plans to implement STEM integrated lessons since they would be held accountable for NGSS-based instruction. Two teachers worked in diverse high need schools with the majority of students considered economically disadvantaged. The rest of the districts were relatively homogeneous. All of the interview participants had at least 11 years of classroom teaching experience. Interviewed teachers and their school characteristics are summarized in Table 1.

Workshop structure

The workshops were taught and developed collaboratively among university science education, biology,

Table 1 Teacher interview participants (NYSED 2018)

Teacher	Primary teaching content area and level	Years of teaching experience	School district demographics							
			District enrollment (2017-2018)		Enrollment by ethnicity					
			English language learners	Economically disadvantaged students	Black or African American	Hispanic or Latino	Asian/Native Hawaiian/ Pacific Islander	American Indian/ Alaskan Native	White	Multiracial
New York State			***2,622,879***		***17%***	***27%***	***10%***	***1%***	***43%***	***2%***
			9%	***58%***						
Interviewed electrical engineering workshop participants										
Pedro	Earth Science MS	16+	6131		3%	6%	10%	0%	80%	2%
			1%	10%						
Joseph	Physics HS	11-15	4933		0%	6%	21%	0%	71%	1%
			2%	9%						
Jack	Physics HS	11-15	6144		1%	8%	8%	0%	81%	2%
			1%	12%						
Lydia	Biology MS	11-15	8657		14%	32%	3%	0%	46%	5%
			6%	65%						
Interviewed biotechnology engineering workshop participants										
Sophie	Biology HS	16+	18,903		9%	84%	2%	0%	3%	0%
			33%	89%						
Richard	Biology HS	16+	3373		2%	7%	1%	0%	88%	1%
			2%	20%						

physics, and engineering faculty. The workshops focused specifically on the engineering design principles emphasized throughout the NGSS and American Society for Engineering Education standards (American Society for Engineering Education 2014; NGSS Lead States 2013). To maximize broader impacts, workshops were presented in two modules: (1) electrical engineering co-instructed with physics education faculty (6 h); and (2) biotechnology co-instructed with biology education faculty (4 h). Each module addressed disciplinary core ideas, crosscutting concepts, and science and engineering practices through theory-based instruction and discussions, hands-on tasks, and collaborative assessment design. Consistent with NGSS, the workshop activities were framed for identifying problems, applying design thinking through a scientific approach, and defining limitations and criteria for technological solutions (NGSS Lead States 2013). Teachers built several devices, including a home security system (Krayem et al. 2018), a night light (Stuart et al. 2021), and a biofuel cell, and they optimized solutions through the cost analysis associated with their designs (NGSS Lead States 2013). They modified the functionality of their devices and tested them before taking them back to their classrooms. Teachers also attended sessions that focused on developing student assessments and preparing and advising students on engineering career pathways. The objectives of each course are summarized in Table 2.

Study participants voluntarily enrolled in one or both of the two multi-session professional development workshop series. The content of the series varied as one course focused on applications of electrical/computer engineering aligned to secondary physics curricula and the second focused on biotechnology aligned to secondary biology curricula. The courses were based upon recent literature regarding high quality teacher professional development, which emphasized engineering design experiences, support from engineering professionals, and explicit connections to science content (Bybee 2011; Darling-Hammond et al. 2017). Numerous opportunities throughout the course allowed teachers to collaborate with peers and science and engineering researchers to draw connections between engineering and relevant STEM principles. Previous studies have shown that this model for engineering professional development increases program efficacy (Hardré et al. 2010; Nugent et al. 2010).

As the literature has suggested, professional development has been most effective when it modeled the intended teaching practice (Knapp 2003; Putnam and Borko 2000). As such, the course was designed to engage teachers in the engineering design process through a

Table 2 Engineering professional development workshop objectives

Electrical/computer engineering workshop series (3 sessions of 2 h each)	
Objectives	• Review the NGSS format and relevant standards
	• Introduce the engineering design process
	• Engage participants in two electrical/computer engineering projects (designing a night light and a home security system)
	• Discuss classroom implementation and design assessments
	• Differentiate engineering disciplines and careers
	• Encourage collaboration among participants with support from engineering and science education faculty
Biotechnology workshop series (2 sessions of 2 h each)	
Objectives	• Review the relevant NGSS
	• Introduce and review the engineering design process
	• Engage teachers in the design and optimization of a bacterial fuel cell
	• Discuss classroom implementation and design assessments
	• Encourage collaboration among participants with support from science and science education faculty

number of content specific activities. Using the interconnected model of professional growth (Clarke and Hollingsworth 2002), the courses were designed to foster teachers' knowledge of engineering by calling upon their pre-existing knowledge of science and mathematics to develop their self-efficacy in integrating STEM in their classrooms.

Data collection

Quantitative data analysis

The *Master Teacher Engineering Professional Development Survey* (Table 2) was used to measure various aspects of participants' familiarity with engineering and their self-efficacy in teaching engineering. The survey was modified from two validated, reliable questionnaires—the *Teaching Engineering Self-Efficacy Scale* (Yoon et al. 2014) and the *Familiarity with Design, Engineering & Technology (DET) Survey* (Yaşar et al. 2006). Construct validity of items selected from the two surveys, in addition to new items related to standards alignment and engineering advisement, was evaluated by two experts in science and engineering education using Messick's framework for interpretive inference (Messick 1989).

Survey items were selected and constructed to measure epistemological confidence related to engineering, self-efficacy in teaching engineering, and confidence in advising about engineering study and careers. Epistemologically sound beliefs about engineering practices were related to teachers' recognition of engineering as an interdisciplinary practice; this involves the application of science and mathematics concepts to real-world contexts, technological innovation, and building models for prototyping and testing (Cunningham and Kelly 2017; Purzer and Quintana-Cifuentes 2019). Self-efficacy has been defined by as a contextual construct that reflects teachers' perceptions of their ability to teach engineering effectively and facilitate student achievement (Yoon et al. 2014); questions also addressed self-efficacy in standards aligned instruction. New questions were constructed to address confidence in engineering advisement; this was in response to prior research that suggested teachers may be well situated to inform students of engineering pathways (Packard and Jeffers 2013).

Survey responses were collected from participants at the start of the workshop and immediately afterwards—some responses were electronic and others were submitted on paper. The survey was administered once prior to the study to a control group of demographically similar science teachers from the same geographic area. The surveys administered prior to the workshop were also used to collect background information about teacher education, certification, teaching experience, and prior professional development in engineering. The 20-question Likert inventory used in both the pre- and post-professional development surveys had a high internal consistency (Cronbach's α = 0.97). Teachers responded on a six-point Likert-scale (1=strongly disagree to 6=strongly agree), self-assessing their ability to accomplish the tasks described in Table 2. Pre- and post-experience within-group and between-group differences were analyzed with inferential statistics. The comparisons of means identified any significant differences between the responses of the control group and the pre-experience survey responses of teacher participants (independent-samples t tests), while also comparing pre- and post-experience responses of the participants (paired-samples t tests).

A subsequent exploratory factor analysis with Varimax rotation was performed to identify thematic subscales in the survey. The sample size for factor analysis met the criterion proposed by Mundfrom et al. (2005). In terms of model fit, the Kaiser-Meyer-Olkin measure of sampling adequacy was 0.86, above the minimum threshold of 0.6, and Bartlett's test of sphericity was significant ($\chi^2(190)=1390.09$, $p<.001$). The minimum primary factor loading was 0.58, exceeding the suggested threshold of 0.4 (Stevens 2012). The communalities were all ≥ .38, indicating shared variance among items. Each factor had at least three items, which is considered adequate representation (Fabrigar et al. 1999), and the instrument explained 70% of the variance. Given these parameters, exploratory factor analysis was suitable for all 20 survey items.

Qualitative data analysis

Using a phenomenological perspective, the qualitative analysis aimed to elicit responses regarding the changes in teacher attitudes toward teaching engineering skills and career awareness in their courses. Interview questions were designed to explore teachers' epistemologically sound beliefs about engineering, self-efficacy in teaching engineering and perceived obstacles, and confidence in engineering advisement. Six teachers were recruited and agreed to participate in two 45-min interviews, one before and one after the workshops. The first interviews took place within the 2 weeks preceding the first workshop. The second interviews occurred several weeks after the final workshop session but within 3 months of the pre-workshop interview. Semi-structured interview protocols are included in the Supplemental Materials.

With concurrent triangulation mixed methods design in mind, a magnitude coding technique was applied in analyzing responses (Creswell et al. 2003; Saldaña 2009). Preliminary structural codes were anticipated to include the perceived epistemic value of engineering, teaching engineering design self-efficacy, and STEM integration self-efficacy. The structural coding technique allowed for indexing responses into categories related to a number of possible factors inhibiting teachers' successful integration of engineering into their courses (Saldaña 2009). Based on prior research, it was anticipated that several themes would emerge as obstacles, including resources and course expectations (Darling-Hammond et al. 2017). These themes were also considerations in the survey design and quantitative analysis. Magnitude coding further differentiated responses along scales of value and self-efficacy (Creswell et al. 2003). Coded interview responses related to self-efficacy were compared to survey responses for added validity (Saldaña 2009). Two researchers initially interpreted and open-coded transcripts until a clear coding scheme were developed. The researchers independently coded transcripts and later compared results for agreement in coded passages and attributed axial codes, or groupings of open codes in related categories. Discrepancies in coding were resolved through negotiated agreement to maximize reliability (Campbell et al. 2013). In the final coding stage, thematic codes were identified to present explanatory constructs for the teachers' experiences in the study. Reliability of the qualitative component of this research was established by reaching 90% interrater agreement on open codes, and the researchers collaborated on the identification of axial and thematic codes through independent analysis followed by extensive discussions. Through this iterative evaluation process, developing themes were confirmed and further explored through subsequent interviews (Morse et al. 2002).

Results

Quantitative results

The quantitative results are based upon pre- and post-survey responses by teachers in the treatment group, as well as responses from a control group of similar teachers. Composite scores for the *Engineering Professional Development Survey* were generated by totaling Likert responses for the overall survey and the individual sub-constructs. To improve external validity, the pre-survey composite scores of the treatment group were compared to a control group. A priori power analysis (G*Power 3.1, Faul et al. 2007) indicated a combined sample size of 42 was required to detect a large effect in means comparisons with 80% power. An independent-samples t test indicated no differences between the treatment and control groups in terms of engineering knowledge and skills, pedagogical content knowledge, and ability to differentiate engineering disciplines (t=0.495, df=97, p=.622) on the pre-survey (M_{control}=83.86, SD= 16.59; $M_{\text{treatment}}$=86.17, SD= 22.37), suggesting similarities between the groups in self-efficacy related to engineering education.

A paired-samples t test was conducted with the treatment group (n=60) to compare mean composite survey scores before and after the workshop. The teachers significantly improved their self-assessed engineering knowledge and skills (t=6.760, df=59, p<.001, 95% CI [11.52, 21.21]) from pre-survey (M=86.83, SD=23.77) to post-survey (M=103.20, SD=13.74), with a large effect size (d=0.84). The teachers improved their self-assessed ability to teach engineering, modify their curricula to comply with NGSS, and advise students on preparing for engineering study and careers, as indicated in Table 3.

Results from the exploratory factor analysis suggested the presence of two constructs. These two subscales—(1) engineering pedagogical confidence (α=0.97), and (2) engineering career awareness and advisement confidence (α=0.87)—accounted for 48% and 22% of the factor variance, respectively.

Paired-samples t-tests were analyzed to determine within-group differences on these two specific scales. For factor 1, teachers significantly improved their engineering pedagogical confidence (t=6.262, df=59, p<.001, 95% CI [8.89, 17.24]) from pre-survey (M=74.38, SD=20.29) to post-survey (M=87.45, SD=12.27), with a large effect size (d=0.78). For factor 2, teachers significantly improved their engineering career awareness and advisement confidence (t=4.495, df=59, p<.001, 95% CI [2.10, 4.49]) from pre-survey (M=12.45, SD=4.99) to post-survey (M=15.75, SD=2.31), with a large effect size (d=0.85).

Qualitative findings

The pre- and post-workshop interviews with select participant teachers provided more nuanced insights

Table 3 Engineering professional development survey results

In my role as a teacher, I am able to…	Pre-survey mean (*SD*)	Post-survey mean (*SD*)	Primary factor loading	Cross loading	Communalities η^2
Construct 1: Engineering pedagogical confidence					
1. Explain engineering concepts well enough to be effective in teaching engineering.	3.96 (1.67)	4.78 (1.22)	.81	.27	.69
2. Assess students' engineering products.	4.02 (1.61)	4.73 (1.18)	.70	.46	.61
3. Employ engineering activities in my classroom effectively.	4.18 (1.56)	4.96 (1.02)	.87	.27	.75
4. Explain the ways engineering is used in the world.	4.57 (1.40)	5.33 (0.65)	.68	.56	.71
5. Describe the process of engineering design.	4.20 (1.67)	4.94 (0.97)	.78	.37	.78
6. Create engineering activities at the appropriate level for my students.	4.08 (1.62)	4.90 (1.15)	.89	.22	.80
7. Select appropriate materials for engineering activities.	4.02 (1.58)	4.84 (1.16)	.79	.38	.68
8. Recognize and appreciate the engineering concepts in my subject area.	4.53 (1.47)	5.22 (0.83)	.82	.29	.55
9. Guide my students' solution development in learning the engineering design process.	4.22 (1.63)	4.98 (1.09)	.80	.34	.66
10. Increase students' interest in learning engineering.	4.59 (1.40)	5.37 (0.63)	.62	.47	.38
11. Help students apply their engineering knowledge to real world situations.	4.29 (1.40)	5.25 (0.80)	.75	.41	.49
12. Promote a positive attitude toward engineering learning in my students.	4.90 (1.32)	5.59 (0.54)	.58	.38	.48
13. Encourage my students to think creatively during engineering activities and lessons.	4.80 (1.36)	5.49 (0.67)	.73	.41	.70
14. Encourage my students to think critically when practicing engineering.	4.67 (1.35)	5.37 (0.77)	.74	.38	.61
15. Encourage my students to interact with each other when participating in engineering activities.	4.86 (1.34)	5.49 (0.70)	.59	.52	.48
16. Modify my curriculum to comply with the Next Generation Science Standards (NGSS) and/or the New York State Science Learning Standards (NYSSLS).	4.24 (1.29)	5.06 (0.88)	.75	.06	.60
17. Acquire the resources for implementing NGSS and/or NYSSLS.	4.25 (1.29)	5.08 (0.91)	.71	.12	.53
Construct 2: Engineering career awareness and advising confidence					
18. Inform my students about engineering careers.	4.53 (1.53)	5.41 (0.64)	.85	.32	.76
19. Differentiate among engineering disciplines.	4.12 (1.61)	5.16 (0.88)	.85	.17	.87
20. Recommend relevant high school courses to students interested in pursuing engineering.	4.59 (1.50)	5.39 (0.83)	.84	.18	.71
Overall composite***	**86.83 (23.77)**	**103.20 (13.74)**			

***$p<.001$

into their attitudes regarding the epistemic value of engineering instruction, their pedagogical self-efficacy and perceived obstacles, and their confidence in advising about engineering study. Through the process of coding and convergent analysis of the quantitative responses, two distinct themes emerged: (1) teachers' pedagogical motivation and confidence in integrating engineering, along with their perceived obstacles for achieving integration effectively, and (2) teachers' awareness of engineering futures and precollege preparation.

Motivation and confidence to integrate engineering instruction

One of the main goals of the workshop series was to increase teachers' motivation for and confidence in engineering instruction. As earlier research has shown, increased self-efficacy often leads to successful STEM integration in the classroom (Kelley et al. 2020). Principally based on the situative perspective of learning (Putnam and Borko 2000), the workshops allowed teachers to participate in the same modeled engineering tasks intended for their students. As a central element of the workshops, these projects meant to engage teachers in the engineering design process to improve confidence and motivation. Following the workshops, interviewed teachers had all demonstrated a transition in their vision of how this process could be used in their classrooms, which was consistent with the overall trends in the survey responses of the treatment group.

Some teachers identified engineering as a potentially powerful tool in developing students' critical thinking and problem-solving skills, particularly when integrating the practices of science and engineering with the instruction of disciplinary content in real-world contexts. This focus on engineering skills development presented a novel challenge for teachers as these practices were not explicit in previous standards and reform efforts (American Association for the Advancement of Science 1994; National Research Council 1996; New York State Education Department 1996), and many inservice teachers have struggled with the pedagogical, epistemological, and methodological challenges of teaching STEM integrated content (Christian et al. 2018; Daugherty and Custer 2012; New York State Education Department 2016; Purzer and Quintana-Cifuentes 2019). The participants discussed their improved confidence in teaching specific science skills that would be supported with engineering instruction, such as asking questions, developing and using models, planning and carrying out investigations, and constructing explanations from evidence.

After his experience in the biology workshop, Richard demonstrated a more refined understanding of the engineering design process, as well as a more definitive connection to specific science skills, such as communication, collaboration, analysis, and asking questions:

> It's going to allow kids to be just better thinkers. It's going to help them become more active and engaged in the learning process. When you start bringing in these engineering processes, and like you say, have this analysis, and you have this whole process of optimizing and doing all of that, I think kids become more engaged with each other. I think there's more conversation in the classroom. I think there's more interaction. I think it also allows them to think a little bit more openly… Getting them up and moving around and doing more on their own, versus me being the sole source of information.

Other teachers also felt they gained confidence as hands-on participants in these workshops. The engineering design challenges were framed by a situative perspective to model a typical secondary science classroom. A brief introduction to the problem and necessary content knowledge was provided, then teachers collaborated in pairs to construct, test, and optimize their products, just as their students might do in an engineering-based lesson. Most of the teachers had very little experience in engineering prior to the workshops, which was likely to be true of their students (Smith 2020). Jack described the value of this format from the perspective of his confidence in teaching STEM integrated lessons:

> Looking at it from the point of view that this is something we could be having students do, actually doing it myself, that I think helps showcase places where students are going to falter. You can anticipate what parts of a project are going to be more difficult, which need to be explained more, or what parts you can let them do because it's going to make sense, it's not dangerous, things like that.

Providing teachers with a sense of the student learning experience made them more sensitive to their students' potential responses to learning engineering design.

A central element of the workshops included projects meant to engage teachers in the engineering design process. Each activity was framed as a practical problem to which teachers were challenged to devise a solution within certain constraints and trade-offs. The microbial fuel cell, a design task in the biotechnology workshop, was presented in the context of a discussion about human dependence on fossil fuels. Participants were challenged to engineer the most efficient fuel cell by testing variables associated with the soil and environment and collaborating to share the results of their experiments. In evaluating the fuel cell activity specifically, Richard captured the focus on optimization:

> I felt like, okay, if you have everything set up beforehand and you give them the options, they'll go set it up, try different things, and then again, if they don't get the success or the results they expected, you can go back and say 'All right, let's retool. Let's figure out how you maximize it.' Even if they do get good results, it's how can they – how do you take the results you have now? Let's try to improve upon it. I think what I've learned is that even if you have success or don't have success, everybody still needs to maximize what they've done… It's not like, 'Okay, we did it. It's done.' It's 'Okay, we did it. Now how do you make it better? How can we scale it up?' I never really thought about that in bio.

Richard identified how this activity could be used in his classroom but also considered the broader applications of the engineering design protocol, which involved solution development in the engineering design process. He made specific connections to his own students and curriculum, suggesting his intentions to follow through with implementing engineering instruction. This was consistent with survey responses that indicated teachers were intending to apply NGSS principles in their classrooms.

Despite the growth in engineering knowledge and confidence that teachers did experience, continued gaps in understanding were identified in post-workshop interviews. It was apparent that some teachers still wavered in their confidence about the design process, particularly with regard to optimization. Some of the teachers felt the format of the activities restricted the optimization process with limited variables to manipulate in the design, making the projects feel "a little bit like a cookbook lab," "very guided," and "very rules-driven." Jack said of the electrical engineering projects,

> We didn't have much control over what we were doing. It was neat that we were able to change the color I think by tweaking RGB so that was kind of cool and that related to the science lesson. But the control that we had over the project seemed very minimal. Again, I don't know how we could do something so technically rigorous and also be able to tweak it.

The recognition of this limitation is positive, in that it demonstrates that teachers had sufficient awareness of the engineering process to identify its iterative nature. Lydia and Sophie seemed disappointed that the optimization phase of design was not emphasized in the activities, particularly due to the potential cost associated with having adequate materials for this purpose. Based on their reflections following the workshops, it seemed that some teachers would struggle with how to incorporate this element of the design process into their own engineering lessons.

Perceived obstacles to integrating engineering

Despite their motivation to implement engineering practices in their classrooms, the teacher participants were concerned about potential obstacles to implementation. Three themes emerged from conversations with the six teacher participants regarding obstacles, which centered on time, materials and resources, and congruency with standardized assessments. With the limited time that had elapsed between pre- and post-workshop interviews, there was little change in teachers' expectations with regard to these obstacles for the duration of this study.

Time Every teacher identified time as a limiting factor in enacting change in the classroom. Many already felt pressure to complete their curricula and prepare students for the associated standardized state science assessments. They worried that adding additional standards onto their already rigorous content would prevent their students from attaining the STEM learning objectives students were expected to demonstrate by the year's end. Throughout the professional development experience, some teachers maintained their concerns that the integration of engineering into their courses would require a sacrifice in the coverage of science content central to their course. After the workshops, Pedro expressed his reservations:

> There are very few lab activities that have the flexibility and that design in [college preparatory] level classes where you have a core curriculum to get through. And time is kind of a precious resource. The time allowing a kid to—it comes at a compromise. That's one of the things we all discover when we are pushing other activities into it. You can take from somewhere else, you can't get everything put in or you get behind in timing, and eventually something else drops.

He recognized that his existing curriculum had not provided the opportunity for frequent NGSS-aligned engineering activities. While time limitations were a concern for many teachers, Pedro's justification suggested a continued misconception that engineering engagement would be tangential to the science content rather than integral.

Materials and resources Some teachers expected accessibility to resources to be an additional obstacle to utilizing engineering activities in the classroom. However, these concerns varied considerably between teachers in different school districts. This was not revealed by the aggregate survey responses, which showed a general increase in teachers' confidence to acquire materials after workshop participation. Lydia and Sophie taught in districts with more limited financial resources than the other participants. Sophie described how restrictive the science materials budget was in her district, "We don't have a lot of resources. We have probably more than 20 biology teachers. Our budget for those teachers is $3,000 for the year." With the limited available funds, she and her colleagues felt pressure to invest wisely in materials that could be utilized for a large number of students over many years. She explained that many teachers in her district purchased materials for classroom use with their own money without reimbursement from the school. Sophie worried that doing projects like the fuel cell that was constructed in the biotechnology engineering workshop would not be accessible to her and her colleagues because of the cost of materials.

In addition to accessibility to supplies, Lydia found it difficult to implement some NGSS-aligned engineering lessons because of the lack of technology in her school:

> We have no access to technology. So they weren't able to research a design, really – either they did it at home or they were just literally brainstorming by using pictures from a textbook, which is difficult. But they need to see something working first. It's hard for me, quite frankly, to get a 13-year-old who doesn't have exposure to that stuff in the past to try and just get it out of nowhere. So technology is a huge obstacle for us.

With limited accessibility to computers and digital information, she felt she would not be able to sufficiently contextualize the engineering tasks she expected her students to complete, potentially inhibiting STEM integration and standards-based learning.

Congruence with standardized assessments When New York State adopted NGSS in 2016, no immediate changes were made to the existing standardized state assessments in science, which were aligned to the previous standards. The state anticipated administering updated science assessments at the elementary and middle levels beginning in 2022 and revised high school assessments, called Regents exams, in 2023 (New York State Education Department 2019). Prior to NGSS adoption, students were not accountable for demonstrating competency in engineering practices. Therefore, at the time of this study, teachers were expected to align their instruction to standards that were different than those assessed on state standardized exams. Several teachers commented on the incongruence between teaching expectations and assessment objectives as a challenge to classroom reform.

Many teachers found it difficult to justify the investment in engineering instruction as long as it was not being assessed on end of course examinations. One teacher said his primary focus was "getting the curriculum done and gearing the class toward the Regents [exam]." Jack expressed the same concerns:

> I think if I wasn't teaching a Regents class with that assessment at the end, I think I would be able to figure out how to teach a physics course with lots of engineering. Now with the Regents based on the old standards and trying to incorporate the practices of the new standards, I had to teach two months' worth of physics [in one month] because I did too much science and engineering practices in September through December. So doing that on top of everything seems like a big challenge.

Jack worried that he had committed too much time to addressing the new standards related to student practices and in doing so had compromised his students' preparation in some of the content that would be assessed on their exit exam. This attitude may have inhibited NGSS implementation prior to the planned testing modifications. This finding identified an accountability constraint that was not measured on the survey instrument.

Encouraging engineering futures

During one of the workshops, teacher participants were provided with information and had discussions about engineering courses of study and precollege advisement for students intending to pursue engineering. The teachers responded positively to this component of the workshop, acknowledging that it was a novel concept that had not been addressed in other professional development activities. Two themes emerged during the interviews in terms of student preparation for engineering futures. Teachers reflected on their ability to help students prepare for future engineering fields of study through precollege course advisement, as well as their ability to direct students toward specific engineering fields based on students' interests.

Preparation for engineering study All of the teachers acknowledged having students express an interest in engineering as a career option. Of the interviewed participants, the physics teachers more often identified having students approach them about engineering than the biology teachers; this differentiation among teachers was not evident from the aggregate survey responses. Prior to the workshops, most teachers admitted they lacked confidence in their ability to provide reasonable guidance for students considering engineering career paths. Some teachers said they would refer interested students to their school counselors or other teachers for advice. After the workshops, most teachers said they felt more prepared to help students devise plans for pursuing engineering. This included making recommendations for other high school coursework and guiding students toward a particular engineering field of study. Richard said, "I think that discussion we had, getting a better sense of it, is definitely going to help me guide kids. I think I have a much better handle on it."

One of the goals of NGSS is to make science and engineering careers more accessible to a broader spectrum of students than those who have traditionally pursued those pathways (NGSS Lead States 2013). For students considering engineering futures, many of the high school science teachers said they would advise more students to enroll in advanced-level science and mathematics classes, specifically physics, chemistry, and calculus.

Additionally, Joseph and Richard suggested students develop programming experience by taking a computer science or coding course offered at their school. Joseph placed significant emphasis on this saying, “The number one thing you can do for yourself before going to engineering school is take a computer science class.”

Engineering career awareness In response to discussions regarding engineering career pathways, teachers demonstrated growth based on their assessment of their own ability to explain the diversity of engineering fields and related careers. Those teachers with little awareness prior to the workshops reported feeling more confident about educating students regarding career options than they did in pre-workshop interviews. Teachers were appreciative of the informative posters they received in the workshop and most had hung them in their classrooms, encouraging student questions and conversations about engineering fields. Joseph said of the posters, “I hung up all those posters that you gave us in our classroom and kids go up to them, they read them, and they’re interested, and they ask – it’s a conversation-starter.” Some of the teachers expressed interest in receiving even more instruction on the engineering disciplines to acquire resources to share with their students in the classroom.

Discussion

Researchers have suggested the need for studies that examine how teachers conceptualize the value of STEM integration (Purzer and Quintana-Cifuentes 2019), how professional development might be aligned to promote the integration of science inquiry and engineering design (National Academy of Engineering 2009), and how short-term professional development might be a first step toward sustained pedagogical shifts (Lauer et al. 2014). The findings from the present study suggest a university-based professional development program in STEM integration had immediate affective impacts with regard to engineering epistemologically sound beliefs, pedagogical self-efficacy, and advisement and career awareness. Qualitative findings also indicated participants had sustained affective impacts several months after the workshops. The interconnected model for professional development provided the framework for the analysis of teachers’ responses to their involvement in this engineering training experience (Clarke and Hollingsworth 2002). Findings and results showed evidence of the influence of the collaborative workshops, as the external domain, on teachers’ personal domain. The resulting change in teachers’ attitudes toward engineering integration in the STEM classroom, within the domain of consequence, provided a means of reinforcement for teachers as they reflected on their workshop experience and reconceptualized engineering instruction and career preparation through newly acquired pedagogical skills and strategies. Findings are discussed in terms of affective impacts on pedagogical growth and awareness of engineering coursework preparation and careers, with a specific focus on themes elicited from both the quantitative and qualitative analyses.

Affective impacts on pedagogical growth

The university-based engineering training served as an external influence contributing to science teachers’ self-efficacy and pedagogical knowledge. Surveyed teachers reported improved confidence in explaining engineering concepts and design, implementing activities with appropriate materials and resources, applying content principles to engineering, assessing student work in engineering, and promoting student interaction, interest, and positive attitudes toward engineering. Interviewed teachers provided more nuanced perspectives, reporting increased confidence in teaching through questions and addressing student responses, using models during investigations, and emphasizing optimization and the iterative nature of engineering. These pedagogical skills allow teachers to foster students’ ability to plan and carry out investigations (Duschl and Bybee 2014; Peters-Burton and Johnson 2018). It also became apparent that while teachers showed growth in their perceived ability to develop NGSS-aligned engineering lessons, more attention should be paid to open-ended design and cost effectiveness in future workshop sessions, which is consistent with prior research (Haag and Megowan-Romanowicz 2015; Shernoff et al. 2017).

Based on the existing research on teacher professional development, the experience addressed a pre-existing gap in teachers’ awareness of the engineering-related standards through collaborative engagement in the engineering design process facilitated by university faculty in engineering, science, and science education departments, consistent with recommendations from prior research (Darling-Hammond et al. 2017). This builds on the existing research on the situative perspective of cognition, providing evidence of the value of engaging science teachers in the engineering design process as they prepare to address the engineering practices (Putnam and Borko 2000). While much research supports professional development through sustained long-term experiences (Yoon et al. 2007), this study provided triangulated quantitative and qualitative evidence of the positive impact of this short-term (4- to 6-h) model of in-service training on teacher pedagogical growth, grounded within a 2-h professional development program that emphasized NGSS. In a time when widespread inservice teacher training is required for fidelity of NGSS implementation, particularly with respect to engineering disciplinary practices (Daugherty and Custer 2012;

National Academy of Engineering 2009; Peters-Burton and Johnson 2018), the present workshop design provided teachers with opportunities to practice complex tasks and learn transferable design skills while improving their pedagogical self-efficacy and epistemic values. These characteristics have shown promise in contributing to long-term teacher and student outcomes (Lauer et al. 2014).

This study also offers unique insight into the experience of STEM teachers learning engineering content, practices, and pedagogy in alignment with NGSS. The majority of analyses on engineering professional development have focused on programs designed for technology or engineering teachers or training for specific curriculum programming or resources (Daugherty 2010; Singer et al. 2016); more research is needed supporting the integration of science and engineering for all STEM teachers, particularly in terms of the nature of engineering and the unique disciplinary practices associated with engineering applications and design (Purzer and Quintana-Cifuentes 2019).

The ongoing concerns of participating teachers in this study echo previously identified issues for teachers attempting to adopt curricular changes. All schools are influenced by their inherent culture, practices, and policies, and integrated STEM instruction will have a higher likelihood of success if school leaders optimize the conditions for reform-based instruction (National Academy of Engineering and National Research Council 2014; Purzer and Quintana-Cifuentes 2019). Preparation and classroom time, access to resources and training, and alignment with standardized testing are often impediments to classroom change (Haag and Megowan-Romanowicz 2015; Shernoff et al. 2017). The need for reconceptualizing instructional time, while securing school-level financial commitments to purchase materials, would alleviate participants' frequently cited limitations to implementation. This is particularly important given the complexities of the engineering design process and the difficulty of integrating engineering knowledge and pedagogy in traditional science, mathematics, and technology instruction (Cunningham et al. 2007; Porter et al. 2019).

Teachers' articulated obstacles to engineering integration should also be considered while designing iterative improvements to professional development workshop structures. Teachers may have viewed time as an impediment because they still considered teaching engineering as a separate pursuit from teaching disciplinary content, rather than viewing STEM integration as a methodologically rich approach to solving technological problems with science and mathematics applications (Purzer and Quintana-Cifuentes 2019). Increased emphasis on the complementary nature of the integrated teaching and learning of the STEM disciplines should be considered for future professional development. Furthermore, the findings of this study underscore the need for clarity in defining learning and assessment expectations from local and state policy makers and support from district administration to enable teachers to follow through on reform at the instructional level.

Affective impacts on engineering preparation and careers

Teachers in this study were introduced to new information about engineering careers and precollege engineering advisement for students. While it is known that teacher influence is a contributing factor in student post-secondary study and career choice (Moore 2006), targeting engineering career awareness during science teacher professional development has not been well documented in the literature, even though fewer than 10% of high school teachers emphasize the nature of science and engineering disciplines and careers (Smith 2020). This study provides evidence that STEM teachers can benefit from specific instruction about engineering courses of study and careers. Teacher participants improved their confidence in informing students about engineering careers, precollege preparatory coursework, and differentiating among engineering disciplines. This may be consequential for students since STEM career advisement has often been lacking with school counselors (Gearns et al. 2018; Gibbons et al. 2003), and STEM teachers may be influential through serendipitous conversations, personal encouragement, and an increased emphasis on the relevance of engineering in devising technological solutions (Packard and Jeffers 2013).

Conclusions

There are several implications from the results of this study. Initially, the STEM teachers expressed a lack of awareness of the NGSS engineering practices and their relationship to the STEM content, supporting the need for this type of teacher learning experience (Bybee 2011). Research has suggested that teachers' commitment to integrate STEM has been fostered by their perceived value of these learning experiences for their students (Brand 2020; Purzer and Quintana-Cifuentes 2019), consequently, the quantitative results and qualitative findings suggest that professional development was lead driver in their shifting pedagogical philosophies which have positive implications for their students. This study provides evidence that the model for professional development employed here may positively influence engineering self-efficacy and awareness in STEM teachers regardless of their content area specialization. Also, as state-recognized Master Teachers, the participants in this study had previously been identified as teacher leaders in their schools. Having already established themselves in this role, the participants were in an ideal position to support the development of engineering confidence and awareness in other educators. This may be an effective means of broadening teacher change with limited resources and time. Another implication is the importance of university-based professional development as a resource for reformed pedagogy and information on post-secondary opportunities for engineering study, careers, and research. University researchers are uniquely positioned to educate K-12 teachers on expectations and impacts related to engineering work, and how STEM principles are foundational to engineering design and practices.

Limitations and future research

There are limits to the generalizability of these findings. The study participants were Master Teachers and had self-selected into the professional development workshops; consequently, they were already fairly confident and motivated to improve their practice. The sample size for the quantitative results was relatively small though adequate for statistical purposes. Due to logistical constraints, the control group only completed the pre-test survey to establish a baseline comparison with the treatment group. Although the control group was from secondary schools in the same region in New York State as the treatment group and included teachers with similar disciplinary backgrounds, this district had slightly higher income families than the average schools employing teachers in the study. This disparity was not viewed as a major limitation since there was no difference in pre-treatment scores between the treatment and control groups.

The sample for the qualitative segment was also small, yet the emerging themes reached saturation when interview data were analyzed (Guest et al. 2006). The interviewed participants were also science teachers who were responsible for implementing NGSS in their instruction. Although this sample did not include mathematics and technology teachers, the science perspective provided nuanced understandings of immediate pedagogical beliefs and constraints. Two of the researchers, one current and one former high school science teacher, may have been biased in their interpretations of the participants' experiences and attitudes, although they took time to acknowledge and bracket their biases through prolonged discussion and iterative case-by-case analysis (Fischer 2009). The time elapsed from pre- to post-measures was of relatively short duration. Despite these limitations, this study provides evidence for the value of this model for engineering professional development in secondary educational settings and provides a foundation for continuing research.

Future research in science and engineering curricular integration is required to develop ways for teachers to implement engineering practices and awareness in STEM instruction. Since few teachers are confident in their ability to teach engineering in the context of core disciplinary ideas (Banilower et al. 2018; Christian et al. 2018), more training and research in implementing engineering practices in STEM would be beneficial. Longitudinal studies may shed light upon long-term impacts of professional development, particularly in terms of how teachers' increased self-efficacy may translate to pedagogical practice. Observations of classroom practice would provide more direct evidence of engineering integration. More intensive professional development that involves 50-80 h of engineering education specific training (Supovitz and Turner 2000) may have even more pronounced impacts upon teacher confidence and intentions. The evidence presented in this study provides support for future university-based partnerships between science and engineering faculty and K-12 schools to promote engineering knowledge, design practices, and increased interest and diversity in engineering careers.

Abbreviations

NGSS: Next Generation Science Standards; U.S.: United States; STEM: Science, technology, engineering, and mathematics

Supplementary Information

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Additional file 1. Interview protocol.

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Authors' contributions

KBC and AMK collected and analyzed the participant data, and were major contributors in writing the manuscript. MFB and AMK made substantial contributions to the conception, design, and implementation of the intervention. All authors read and approved the final manuscript.

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Availability of data and materials
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Declarations

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

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