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Abstract

Engineering for US All (e4usa) is a National Science Foundation-funded first-of-its-kind initiative aimed at making engineering more inclusive and accessible to underrepresented populations. The "for us all" mission of e4usa encompasses both students and teachers. Paramount to the success of e4usa was the construction of professional development (PD) experiences to prepare and support teachers with different levels of engineering teaching experience as they implemented the e4usa yearlong course. The perspectives of nine teachers with varying degrees of engineering teaching experience were examined during two PD opportunities to compare experiences and dynamics between the teachers. Data sources consisting of focus groups and artifacts created during the PD were analyzed using inductive coding and the constant comparative method. The distinct themes that emerged included teachers redefining engineering, growing confidence to teach engineering, benefiting from the PD, receiving support from other teachers, experiencing imposter syndrome, and renewing a passion for engineering education. The results provide implications for how engineering education PD may be developed to allow for reciprocal support and mentoring that supports all teachers regardless of engineering teaching experience. The results also inform future e4usa efforts and aim to change the structure of high school engineering education.

Keywords

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Understanding the Impact of Professional Development for a Cohort of Teachers with Varying Prior Engineering Teaching Experience

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Abstract

Engineering for US All (e4usa) is a National Science Foundation-funded first-of-its-kind initiative aimed at making engineering more inclusive and accessible to underrepresented populations. The "*for us all*" mission of e4usa encompasses both students *and* teachers. Paramount to the success of e4usa was the construction of professional development (PD) experiences to prepare and support teachers with different levels of engineering teaching experience as they implemented the e4usa yearlong course. The perspectives of nine teachers with varying degrees of engineering teaching experience were examined during two PD opportunities to compare experiences and dynamics between the teachers. Data sources consisting of focus groups and artifacts created during the PD were analyzed using inductive coding and the constant comparative method. The distinct themes that emerged included teachers redefining engineering, growing confidence to teach engineering, benefiting from the PD, receiving support from other teachers, experiencing imposter syndrome, and renewing a passion for engineering education. The results provide implications for how engineering education PD may be developed to allow for reciprocal support and mentoring that supports all teachers regardless of engineering teaching experience. The results also inform future e4usa efforts and aim to change the structure of high school engineering education.

Keywords: engineering teachers, teacher experience, professional development, teacher change, collective participation

Introduction

Engineering offerings in pre-college classrooms provide opportunities for youth to learn about engineering, while boosting their learning of other science- and mathematics-based disciplines (Katehi et al., 2009; Yoon et al., 2018). These advantages have not led to widespread offerings of engineering, primarily due to the lack of qualified teachers and by association adequate teacher preparation (Daugherty, 2012; Duncan et al., 2011; Yoon et al., 2013a, 2018). The small number of in-service engineering professional development options and teacher preparation programs for engineering limits the pool of teachers capable of teaching such content (Katehi et al., 2009). Relying on practicing engineers to switch careers and enter teacher preparation programs has provided one source of qualified teachers but has been grossly insufficient for creating an adequate number of pre-college engineering teachers. This leads to schools relying on teachers already in the system who have no prior engineering education or experiences (Banilower et al., 2018; Porter, et al., 2019; Smith et al., 2021); only 3% of elementary school teachers, 10% of middle school teachers, and 13% of high school teachers have ever taken an engineering course in their own education. The lack of content experts is having a significant national impact on educating today's youth about the field of engineering.

Professional development (PD) for preparing in-service pre-college teachers to teach engineering is considered an essential mechanism that provides opportunities for teachers to acquire knowledge of new pedagogical approaches and engineering content (e.g., engineering design process) (Desimone, 2009; Yoon et al., 2013a). PD also supports teachers in developing a positive perspective toward engineering and increases confidence in teaching engineering (Katehi et al., 2009). Efforts to create, implement, and evaluate engineering-focused PD for pre-college teachers have increased over the last decade, with some initial studies in engineering education conducting comparisons with other science, technology, engineering, and mathematics (STEM) education disciplines (Wright et al., 2020; Yoon et al., 2018). There exist some challenges to improving pre-college engineering education with so few studies on engineering curricula PD models and limited knowledge on promising practices in the PD space (National Academies of Sciences, Engineering, and Medicine, 2020).

Some studies have reported positive impacts of engineering-focused PD on teachers (Autenrieth et al., 2017; Dare et al., 2014; Duncan et al., 2011; Klein-Gardner et al., 2012; Martin et al., 2015; Mesutoglu & Baran, 2021; Nugent et al., 2010; Utley et al., 2019; Yoon et al., 2013a, 2018), but the range in teachers' prior experiences with engineering has not been considered. The existing gap suggests a need to better understand how prior experience with engineering or engineering teaching influences learning in an engineering-focused PD. This necessary next step would have major impacts on the development of an effective, research-based PD in engineering education, while shedding light on our understanding of the unique impacts a PD experience can have on those with varying levels of prior experience. This knowledge is key to articulating how PD directly affects educators from diverse professional backgrounds.

This study aims to fill this gap through an exploration of a PD designed for Engineering for US All (e4usa), a National Science Foundation (NSF)-funded initiative designed to address the national need for demystifying engineering and democratizing engineering education for pre-college students and teachers. The first cohort of teachers participating in this program engaged in a PD experience designed to prepare and support their implementation of the yearlong e4usa curriculum (Kouo et al., 2020). A salient feature of the initial cohort was the diversity of prior engineering and teaching experiences brought to the PD by participating teachers. Teacher experiences during the PD along with dynamics between teachers were explored to better understand the impact of their prior experiences. We set the stage for our work by presenting extant PD literature within and outside engineering education and providing a theoretical lens to situate our approach within the e4usa PD.

Literature Review

Research on engineering-focused PD in the context of pre-college education has accelerated in the past decade, following educational reform in the United States involving the integration of engineering into pre-college curricula (Antink-Meyer & Brown, 2019; Daugherty, 2012). The relatively few studies focused on engineering PD are due in part to divergent perspectives on the utility of distinguishing engineering-focused PD experiences from those of other STEM disciplines (Bybee, 2014; Nadelson et al., 2013; Nathan et al., 2010). One prevalent notion posits that engineering can be subsumed under pre-college science education rather than being distinguished as a separate field. Such notions suggest that teachers receive PD to teach engineering through other STEM-focused PD. There has simultaneously been a growing body of literature in science and engineering education that criticizes the notion that engineering is subsumed by science. This work suggests an interdependent but distinct nature of science and engineering (Antink-Meyer & Meyer, 2016; Daugherty, 2012; Farmer et al., 2014; Reimers et al., 2015). These researchers contend that teachers must avoid oversimplification or misrepresentation of engineering as a subdomain of science, while considering the differences in the nature of science and engineering knowledge. Cunningham and Carlsen (2014) also argue that teaching students to solve engineering problems using science frameworks limits students' holistic understanding of engineering. These studies have coincided with the need for providing engineering-focused PD for teachers who have limited engineering knowledge and experience.

Venues have emerged to address the need for developing teachers' knowledge and capabilities to integrate engineering into pre-college curricula, including the NSF Research Experience for Teachers (RET) program and some pre-college PD initiatives (e.g., Engineering the Future [EtF] and Increasing Student Participation, Interest, and Recruitment in Engineering and Science [INSPIRES]) (Katehi et al., 2009). Researchers have investigated diverse aspects of PD offerings (e.g., teacher outcomes as a result of PD and factors influencing those outcomes) with a shared goal of developing an effective PD that elicits teacher change (Daugherty, 2012; Farmer et al., 2014; Reimers et al., 2015). The following sections provide a literature review focusing on teacher change resulting from participation in engineering-focused PD. Emphasis has been placed on collective participation, which has been shown to influence teachers' PD experiences.

Teacher Change from Engineering-Focused PD

A substantial body of literature in education has investigated teacher outcomes of PD using the concept of "teacher change" or the diverse changes that teachers encounter through PD activity (Clarke & Hollingsworth, 2002; Guskey, 1985). There are multiple perspectives and ways to view teacher change: (1) naturally occurring when experiencing PD, (2) attainable goals driven by the need for personal and professional development, and (3) learning and growth as a result of PD. Researchers investigating teacher change through these various lenses have shown its impact on teachers' knowledge, attitudes, and beliefs of their practice, which supports a significant goal of PD, i.e., improved student performance (Desimone, 2009).

Engineering education researchers have demonstrated the impact that engineering-focused PD can have on cognitive and affective domains of teacher change in the context of pre-college education (Mesutoglu & Baran, 2021). Cognitive domain changes include teacher knowledge of engineering content or pedagogical practice. Multiple studies of in-service teachers participating in summer PD to teach engineering have demonstrated increases in perceived engineering knowledge, recognition of engineering, and engineering content knowledge (Duncan et al., 2011; Nugent et al., 2010; Utley et al., 2019). Further work has demonstrated significant increases in teachers' knowledge of the engineering design process (Yoon et al., 2013a) and capability of using new pedagogical strategies (Autenrieth et al., 2017; Klein-Gardner et al., 2012; Yoon et al., 2013a). The majority of the research exploring teacher change in pedagogical practices due to PD has primarily focused on programs associated with the NSF RET program (Autenrieth et al., 2017; Klein-Gardner et al., 2012). Such work has highlighted the emerging integration of real-world contexts to expose students to engineering (Duncan et al., 2011; Klein-Gardner et al., 2012) and classroom lessons that regularly incorporate the engineering design process (Autenrieth et al., 2017).

Investigations of teacher change within affective domains have explored teacher attitudes, beliefs, and confidence in engineering or teaching engineering. Many of these studies have used a variety of methods to demonstrate increases in self-efficacy toward teaching engineering (Hardré et al., 2018; Ragusa & Mataric, 2016; Utley et al., 2019; Yoon et al., 2013a, 2013b, 2018). Changes were shown to be associated with positive, perceptual shifts of engineering, understanding engineering as a field, and engineering accessibility for students (Hardré et al., 2018). Additional work exploring teacher change in affective domains has gone beyond self-efficacy to explore motivation to use the knowledge gained from PD. Findings have revealed that most participants felt invigorated by the PD experience and the possibility of returning to participate in future PD opportunities (Autenrieth et al., 2017; Yoon et al., 2018).

Imposter syndrome is another affective phenomenon that has been observed in pre-college engineering-focused PD (Dalal et al., 2020; Kouo et al., 2020). The imposter phenomenon is characterized by feelings of low self-efficacy, self-doubt, and an inability to make someone feel like they are not as competent as others perceive them to be (Adams, 2020; Collins et al., 2020; Daquilanto, 2015; Nedegaard, 2017; Persky, 2018). This can lead to negative impacts on confidence in teaching competence and anxiety about lesson presentation, which can lead to imposter syndrome. Factors that help overcome imposter syndrome include being open to others' feedback and having the confidence to embrace feelings of vulnerability created by feedback (Nedegaard, 2017). Adams (2020) and Collins et al. (2020) each share autoethnographies of their own journeys as STEM educators and the imposter phenomenon they encountered as individuals identifying with underrepresented populations in STEM. Imposter syndrome resulted not only because they were new teachers, but also due to stereotypes and the chilly environment that is present in STEM fields. These findings highlight complexities in understanding this concept and a need to discuss imposter syndrome in STEM contexts like engineering-focused PD.

Teacher Experience and Collective Participation

Not all PD results in teacher change, so it is critical to understand the factors that contribute to teacher change in order to develop an effective PD (Whitworth & Chiu, 2015). Teachers who participate in pre-college engineering education PD can vary across individual factors (e.g., past experiences, motivation, and confidence) and contextual factors (e.g., school culture, school districts, and their policies and/or leadership styles) that can influence the overall impact of the PD experience (De Jong et al., 2019; Whitworth & Chiu, 2015). Teacher experience, i.e., years in the classroom, has been suggested as a critical factor for in-service teacher change that should be considered when developing an effective PD

(Whitworth & Chiu, 2015). This includes teachers' own academic and career backgrounds as well as length of participation in specific learning communities (Green et al., 2013). The influence of teacher experience has been explored by Luft et al. (2011) who revealed greater changes in beliefs than practice for beginning teachers compared to experienced teachers. What teachers seek to gain from PD also varies by teacher experience. Beginning teachers tend to focus their learning on new pedagogy and classroom management whereas experienced teachers generally seek to improve their content and pedagogical knowledge (Lewis et al., 1999).

Most PD experiences will involve a mix of teachers with varying degrees of prior teaching experience, which provides an opportunity for collective participation. Collective participation refers to collaboration that occurs between teachers from the same discipline, school, or grade level as they engage in PD (Chong & Kong, 2012; Garet et al., 2001; Van Driel et al., 2012; Zwart et al., 2009). Such collaboration has been shown to be one of the core features of effective PD activities (Garet et al., 2001). Desimone (2009) offered collective participation as a powerful structure for teacher learning when considering the potential interactions and discourses created by the structure. Professional communities resulting from collective participation were pointed out as the network that supports teachers' continued growth after the PD activity, i.e., professional learning, which contributes to teachers' continued growth (Garet et al., 2001; Klein-Gardner et al., 2012). Research exploring the influence of dynamics between teachers with varied experiences on teacher change in diverse contexts of collaborative learning (e.g., community of practice, team-based PD, reciprocal peer coaching, and peer mentoring) has revealed that heterogeneity in terms of teacher experience benefits all teachers as more experienced and less experienced teachers learn from one another (Blanton & Stylianou, 2009; Gast et al., 2017; Green et al., 2013; Jin et al., 2019; Zwart et al., 2009). Interactions between more experienced and less experienced teachers in mentoring were also reported as an important factor influencing less experienced teachers' professional identity and retention (Jin et al., 2019).

Teacher experience and collective participation have been frequently considered in PD research within education and other STEM education settings. Few previous explorations in engineering education have primarily compared teacher changes between teachers with varied demographic or individual factors, including prior STEM content knowledge (Nadelson et al., 2013). Findings suggest that older pre-college teachers or those with more STEM content knowledge felt more comfortable teaching engineering material than those who were younger or had less STEM content knowledge after their participation in engineering PD. The one exception is Yoon et al.'s (2013b) study which provides insights on the potential impact of interactions within a team consisting of more and less experienced teachers on teachers' motivation. The findings collectively indicate that teacher change is influenced by the factors associated with teacher experience (e.g., teachers' content knowledge, age, interactions between more and less experienced teachers). This study aims to build on Yoon et al.'s work by filling the void in the literature regarding the potential impact of engineering teaching experience on teacher change and the dynamics between teachers with varying degrees of experience within collaborative working environments created by engineering-focused PD.

Standards and Theoretical Perspectives Guiding the Formation of the PD Program

The e4usa PD was designed to adhere to a set of standards created to inform the preparation and professional development of pre-college engineering teachers (Reimers et al., 2015), while leveraging the theoretical value embedded in the use of communities of practice (CoPs; Lave & Wenger, 1999; Wenger, 1998). Reimers et al. suggest a set of five standards that should be used to inform the creation of engineering PD:

- Standard A emphasizes that PD for teachers of engineering should address the fundamental nature, content, and practices of engineering to promote engineering content knowledge.
- Standard B states that PD should emphasize engineering pedagogical content knowledge.
- Standard C places emphasis on how engineering design and problem solving offer a context for teaching standards of learning in science, mathematics, language arts, reading, and other subjects.
- Standard D highlights the need for PD to empower teachers to identify appropriate curriculum, instructional materials, and assessment methods.
- Standard E outlines the importance of PD for teachers of engineering to be aligned to current educational research and student learning standards.

A matrix developed by Farmer and Klein-Gardner (2014) to demonstrate how an engineering-focused PD might address elements of the five standards with high, moderate, or low emphasis was used in the design of the e4usa PD. The e4usa PD subsequently includes teachers' participation in multiple engineering design challenges found in the curriculum, reflections upon connections between 21st-century skills with engineering design challenges, and making connections in science, technology, and mathematics.

CoPs additionally informed and shaped the e4usa PD. According to Wenger (1998), CoPs have been common throughout history, and are defined by the following three aspects: (1) there is a *joint enterprise* shaping the CoP mission, which is understood and regularly reshaped by members of the community; (2) the members work together through *mutual engagement* in particular activities, which can include formal engagements (e.g., academic) or informal activities (e.g., hobbies); and (3) the community has a *shared repertoire* of resources that are readily available to all members. Lave and Wenger (1999) build on this by introducing the concept of *legitimate peripheral participation*, which is a way of unpacking how new and more established members of the community relate and interact with one another. They also advance the idea of *situated learning*, which recognizes the production of knowledge that is developed and fostered within CoPs (Lave & Wenger, 1999). These theoretical perspectives suggest that learning develops between members of the community, and by extension relationships are critical to the success of CoPs. Finally, Lave and Wenger (1999) suggest that in the context of education, CoPs are not restricted to formal instructors, but to a broader set of stakeholders (e.g., teachers and students). The e4usa PD was situated within a CoP that included high school instructors as well as college/university faculty as a means of furthering teacher change and collective participation.

Purpose of the Study

Part of the e4usa pilot-year mission was to welcome teachers with different academic backgrounds, school contexts, and varied prior work or teaching experiences. Paramount to e4usa was the construction of PD experiences that would prepare and support teachers with varying degrees of engineering instructional training as they implemented the yearlong engineering course.

The purpose of this study was to examine the perspectives of nine e4usa teachers during these PD experiences to highlight its impact on teachers who came to the program with varying degrees of experience with engineering and teaching engineering. The following research questions guided the study:

1. What impact did the PD have on teachers with varying degrees of expertise toward teaching engineering?
2. What, if any, unique experiences were had by those with and without prior engineering teaching or engineering industry experience?

Positionality Statement

Secules et al. (2021) note that when researchers establish their positionality, it affords them the chance to “interrogate their own motivations, worldviews, [and] beliefs” (p. 20). They add that positionality statements are especially relevant in engineering education research because engineering as a field traditionally conceives of data as separate from the researcher. The authors of this paper include tenured and tenure-track faculty, research professors, and postdoctoral researchers associated with e4usa. The team includes researchers representing materials, biomedical, and electrical engineering, as well as computer science and education. The team also includes current or former elementary school, middle school, and high school instructors. Several of the team’s engineers have had overlapping careers in both engineering and pre-college instruction, with three authors in particular having taught high school STEM courses. Most team members also hold expertise in leading or co-facilitating engineering outreach initiatives (e.g., summer or weekend academies).

We have a shared and invested interest in the success and effectiveness of the PD created specifically in alignment with an engineering curriculum developed in parallel. The team is dedicated to supporting teachers in order to achieve the greater programmatic mission of an inclusive, nationwide engineering curriculum that demystifies engineering and democratizes engineering education for all. Team members served in multiple roles as part of this study, including developing the curriculum and PD, facilitating the PD, and conducting research. The vast number of authors is due in part to a conscious effort to ensure impartiality when reporting results and to provide research opportunities for all interested members of the e4usa project team.

Methods

Context

This study is situated in e4usa, a pre-college engineering initiative in the United States established in 2018. Two key components of the project include: (1) design and development of an engineering course for high school students of all grade levels and (2) teacher PD to ensure fidelity in curriculum implementation and to support adoption efforts. The curriculum was developed by a team of experts in engineering education through a series of workshops, including an initial workshop with engineering educators, high school teachers, university administrators, and other stakeholders. Follow-up working sessions were used to develop and design a curriculum to impart engineering design and professional skills (e.g., teamwork, effective communication, critical thinking, an interdisciplinary approach to problem solving) rather than a course meant to train students in discipline-specific skills. The first iteration of the curriculum was a hands-on, project-based model, originally based on the first-year engineering classification scheme (Reid et al., 2018). The course is designed to introduce and explore engineering through engineering design rather than teaching engineering as a set of sub-disciplines.

The course objectives are framed by four areas, or threads: Connect with Engineering, Engineering in Society, Engineering Professional Skills, and Engineering Design. These four threads are embedded across eight units and imparted to students through a project-based approach. Unit 1 introduces students to "engineering" as a discipline that influences almost everything we do in our daily lives. Unit 2 introduces the engineering design process. Units 3 and 4 engage students in selecting and prototyping a solution to solve a local problem, typically within the school and with the help of the teacher in identifying the stakeholders. Units 5 and 6 focus on a design solution for a more global issue such as housing, clean water, or electricity. In Unit 7, students examine their day-to-day lives and find a problem that could be tackled by a small team. Unit 8 concludes the course with an opportunity to reflect. Students enrolled in the course progressively experience larger and more self-directed hands-on projects, each created to focus on solving a problem through engineering. Students and teachers have greater agency in the focus and scope of the problems addressed and solutions developed as the course progresses. Each analysis and design problem is not only based on the engineering design process, but societal and professional implications and reflection on students' engineering identities (Pleasants & Olson, 2019; Reid et al., 2018, 2020).

High school teachers were recruited through a nationwide open call to teach the introductory e4usa course during the 2019–2020 school year. Nine teachers who were teaching in public high schools within the United States were selected for the first cohort. Each teacher attended one of two five-day in-person PD workshops hosted by a large U.S. university during the summer of 2019. The summer PD primarily led the teachers through the curriculum threads, the first four units of the e4usa curriculum, and a scoring rubric for engineering design portfolios. The sessions involved hands-on activities to explore, plan, and teach components of the e4usa curriculum, as well as inclusive pedagogy, reflective exercises, and opportunities to build collaborative relationships with peers. All nine teachers gathered as a cohort for three days in winter 2019 for another short mid-year PD session. The winter session focused on familiarizing the teachers with the remaining four units. Teachers were also supported throughout the year via an online CoP that included university faculty and practicing engineers. The online community discussions took place on a learning management platform and teachers were invited to share their classroom experiences and lesson plans. The e4usa team members were available to answer any questions regarding the curriculum and its implementation and helped facilitate guest lectures with practicing engineers.

PD instructors were university professors and graduate students, some of whom were also former pre-college teachers. The on-site summer e4usa PD involved hands-on activities to explore, plan, teach, and reflect on components of the e4usa curriculum, opportunities to build collaborative relationships, and engage in focus groups.

Participants

Participants included nine high school teachers from the United States with varying degrees of engineering expertise. Seven teachers had experience in engineering education, while two teachers had no STEM background or engineering teaching experience; one had a teaching background in history and the other had a teaching background in music. Three of the seven participants with engineering education experience had undergraduate degrees in engineering or engineering technology and had been teaching high school engineering classes for four or more years. The remaining four teachers did not have formal engineering education but did have STEM backgrounds and/or some experience teaching high school engineering classes.

Six of the teachers were male and three teachers were female. Three of the teachers were African American and the remaining teachers were European American. Table 1 provides additional details on the participants, including the student demographic composition within the teachers' classroom and school, which was collected via surveys. Privacy and confidentiality of the teacher participants was a prime ethical concern due to the small sample. We addressed this concern by not sharing the geographical location (city/state) in Table 1 in order to protect participant confidentiality. It is noted here that such details are valuable and have undergirded much of our overall approach to the broader evaluation of e4usa, but this specific effort did not consider PD experiences across *student* demographic groups. These themes, as well as other aspects of diversity, are explored in other published and planned manuscripts of e4usa.

Table 1
Participant background and demographic information.

Teacher[a]	Engineering teaching experience/total teaching experience	Other STEM subjects taught	School/ student context	Demographic composition of class as reported by teacher	Percentage of class identified as Black, Indigenous and People of Color (BIPOC)[b]	Percentage of school identified as (BIPOC)	Percentage of class identified as female	Percentage of school identified as female	Percentage of school identified as economically disadvantaged
Limited experience in engineering teaching									
Alex	0 years teaching engineering/ 23 years teaching		Public, suburban	3 African American, 2 Asian,14 Caucasian, 16 Hispanic, 1 Middle-Eastern, 2 Mixed race	50%	43%	21%	50%	37%
Blake	0 years teaching engineering/ 5 years teaching		Charter, suburban	6 African and/or African American, 4 Caucasian, 4 Hispanic, 2 Middle-Eastern	63%	82%	26%	51%	32%
Experienced in engineering teaching									
Taylor	3 years teaching engineering/13 years	Technology, manufacturing	Public, rural	1 African American, 1 Asian, 57 Caucasian, 1 Pacific Islander	3%	<1%	27%	48%	68%
Jordan	4 years teaching engineering/20 years teaching	Physics	Public, suburban	4 Asian, 17 Caucasian, 2 Hispanic	9%	6%	13%	50%	1%
Carey	5 years teaching engineering/23 years teaching	Research	Public, suburban	Not provided	Not provided	74%	51%	52%	36%
Sam	5 years teaching engineering/24 years teaching	Physics, biology, chemistry, physiology, earth and environmental science	Public, urban	6 African American	100%	99%	27%	44%	Not available
Evan	12 years teaching engineering/14 years teaching	Technology design, robotics	Public, suburban	Not provided	Not provided	86%	17%	53%	40%
Jamie	13 years teaching engineering/24 years teaching	Introduction to engineering, engineering foundations	Public, suburban	2 African American, 3 Asian, 9 Caucasian, 1 Indian	13%	15%	33%	48%	15%
Parker	20 years teaching engineering/26 years teaching	Engineering design & development, digital electronics, robotics, computer science	Public, urban	2 African and/or African American, 9 Hispanic	100%	91%	27%	42%	50%

[a]Pseudonyms are used for all teachers. [b]BIPOC information is provided rather than specific underrepresented racial/ethnic data because the participating teachers self-reported race/ethnicity data on their classes. These data did not always reflect reporting conventions used by agencies such as the U.S. Census. For our specific purposes, BIPOC racial/ethnic data collectively refer to groups that have historically been underrepresented in engineering and other STEM fields, specifically African American, Asian, Hispanic, Pacific Islander and mixed race.

Data Collection and Analysis

Primary data sources included pre- and post-focus groups conducted during the summer and winter PD sessions. Focus group questions attempted to unpack different aspects of participants' PD experience. Pre-focus group questions during the summer PD were designed to capture participants' perceptions and prior experiences with engineering education while post-focus group questions attempted to assess participants' experiences in the PD and impact on confidence toward teaching the e4usa curriculum. Some of the questions included, *What does engineering mean to you?* or *How confident do you feel to teach the e4usa course having completed the professional development?* Pre-focus group questions posed during the winter PD focused on teachers' experiences implementing the e4usa curriculum and post-focus group questions focused on understanding the value of the PD and support structures for the teachers. Some of the questions included, *What barriers did you encounter in implementing the course so far?* or *What would you say has changed regarding your own beliefs and perceptions, if any, regarding engineering teaching because of teaching the e4usa course?* All focus groups were audio-recorded and transcribed. An additional data source used were letters written at the end of the summer PD by the nine teachers to the next e4usa teacher cohort. The writing of letters was an intentionally included PD activity. Teachers were asked to type their response to the following prompt: *Write a letter to next year's cohort and share with them inspiration and advice that will support them as they become an e4usa teacher*. These letters were used as a secondary data source to further explore the themes identified from the analysis of the focus groups.

Data were analyzed using Dedoose (2018), a collaborative qualitative data analysis platform. Dedoose was used to organize and code the data. The analysis focused on the experiences of the teachers and the resulting impact of the PD. An inductive coding approach (Saldaña, 2011) was applied by the lead author for thematic analysis. Data units were open-coded based on the concepts underscored by participants. The codes and categories were reviewed by two other members of the research team to ensure a robust analysis. Differences were resolved over online meetings and discussions to ensure 100% agreement at the end. The revised coding scheme was then used to re-code the transcripts to establish trustworthiness in the lead author's coding efficacy.

The constant comparative method (Corbin & Strauss, 2015) was used throughout the iterative process of coding wherein the lead researcher looked for similarities and differences in data, grouping data that were similar under a category. Each data unit was compared to previous data and sorted into the most relevant category. Finally, the categories were reviewed and collapsed as necessary to ultimately develop a common set of repeated themes. Letters were then analyzed using the same themes while also capturing new emergent themes. The intention was to triangulate multiple participants' perspectives across all data sources as well as categories of experience to ensure reliability (Lincoln & Guba, 1985).

Validity and reliability of analysis

The entire research team engaged in several discussions about the analysis procedures, data, interpretations, and resulting themes to ensure trustworthiness. For example, the team had a conversation on how to group participants on a range of experiences. A sub-group of authors often discussed common themes across participants to ensure there was enough backing across datasets. Themes with enough backing were then presented to the rest of the team for further critique and validation. For example, the coding categories acknowledging *peer contribution*, *benefit of peer collaboration*, *praise for peer support*, and *advice received/given from and to peers* were discussed as similar enough to be potentially grouped under one theme. Transcripts were re-examined for context and dynamics between teachers. A decision was then reached unanimously to group these categories under one theme of *receiving support from other teachers.* Likewise, the categories of *lack of confidence*, *apprehension*, *inexperience*, and *inadequate comfort level* clearly emerged among the participants with limited engineering education experience. Extensive discussions took place among team members to confirm that these categories were really reflective of *experiencing imposter syndrome.* Disagreements or differences were discussed until consensus was reached. The team also relied on three specific team members who had conducted the majority of the PD sessions to arbitrate using observations and informal conversations they had with teachers during the PD. The lead researcher re-coded the transcripts after such discussions and consensus on the scheme to establish trustworthiness in the coding efficacy. Finally, member-checking took place by sharing a draft of this paper with the participants to confirm interpretations and results (Creswell, 2013).

Results and Discussion

Our examination of the experiences that teachers had as they engaged in the e4usa PD is a focused effort to better understand the ways in which teachers learn or change through PD. It is important to recognize that theories designed to understand the act of learning help us frame the mechanisms in which learning occurs (e.g., socially or experientially) by examining the ways we think (e.g., cognition) and act (e.g., behaviors) in a particular situation (Schunk, 2020).

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Analysis of the collected data resulted in the identification of six themes across our two research questions that connect back to theories of learning and teacher change. The themes depict the transformative impact of the PD opportunities and provide insights into changes experienced by all teachers—redefining engineering, growing confidence to teach engineering, benefiting from the PD, and receiving support from other teachers—as well as unique experiences for those with—renewing a passion for engineering education—and without—experiencing imposter syndrome—prior engineering teaching or engineering industry experience. These findings are the result of a PD designed to support and benefit all teachers regardless of their previous experiences with engineering (Blanton & Stylianou, 2009). The themes, definitions, sub-themes, and illustrative quotes are presented in Table 2 and are organized according to the guiding research questions.

Research Question 1: What Impact did the PD have on Teachers with Varying Degrees of Expertise Toward Teaching Engineering?

Redefining the meaning of engineering

An important element to the PD and a key theme connecting other themes was the redefinition of engineering to broaden its access and inclusivity. Teacher views of engineering became more expansive. Jamie, a more experienced teacher stated, "Going back to the definition, I think it's teaching engineering, to the full definition of engineer. And not just, you know, engineering design in isolation, or what not. But looking at the big picture." A teacher with limited engineering experience also captured this shift when Blake wrote in their letter that the stereotypical perceptions of engineers, as men with strengths in math and science seated behind computers, was false. In actuality, "Engineers work in many fields globally to help solve problems. Highlighting the work engineers do for the world allows students to see that engineers serve humanity."

Teachers also began to see the application of engineering in tackling everyday issues, and a direct connection to their daily instructional practices. As an experienced engineering teacher, Jordan realized that the iterative process of improving upon instruction aligned with the concepts of engineering. They stated:

> *When we look at our lesson plans, and we look at that and go, 'Well, this worked, this part didn't. How do I switch this up?' Do we see ourselves as engineers at that moment? And I think the answer to that is traditionally, 'No.' Are we fulfilling at least some of those concepts of what an engineer does in that moment? I would say, 'Yes.'*

This change in perspective caused Alex to begin to see engineering in everything and is in full alignment with the literature on teacher change (Clarke & Hollingsworth, 2002; Guskey, 1985). Parker also saw this broadened understanding of engineering as a way to build confidence in students:

> *As long [as] students are using any methodical process design and engineering process, problem solving process, whatever you want to call it, iterative process, to make something, evaluate, analyze, make it better. There's never one way to solve something. That's what it means to me. To describe it now—it's in everything. Most people are afraid of the word engineering, they're afraid of the word STEM.*

Experiencing this redefining of engineering also led teachers to help students see the broad definition and impact of engineering, which ties back to the ultimate goal of improving student performance (Desimone, 2009). Taylor shared during the winter PD focus group that the e4usa helped students understand how their daily lives, such as playing video games, riding a bike, or driving down a road, are a direct result of engineers. Teachers also helped students see a connection between their professional aspirations to engineering.

Growing confidence to teach engineering

The structure and approach taken by e4usa naturally led to an initial cohort of teachers with diverse backgrounds and experiences with engineering all going through PD together. Collective participation and an opportunity to learn through collaboration (Fullan, 1995; Hargreaves, 1998) and first-hand experiences (Schön, 1983; Wilson et al., 1987) led to growth in all teachers' confidence to teach engineering. We observed an increase in confidence across all teachers following both the summer and winter PDs. As a teacher with less experience in engineering, Blake shared "I feel much more confident [for] not being an engineering teacher, I was very nervous about my ability to work with the content coming in." Taylor, who had more experience, shared that they were initially worried, especially with regard to guiding students' engineering projects. The PD opportunities were essential in addressing the less experienced teachers' feelings of being an imposter, another theme, as well as supporting more experienced teachers as they, too, navigated a new curriculum and revisited their past pedagogical practices when teaching engineering. During the winter PD focus group, teachers also expressed increased confidence in teaching the curriculum and an eagerness to continue teaching the curriculum year after year to further build

Table 2
Identified themes from data sources collected from the engineering teachers.

Theme	Definition	Sub-themes	*Illustrative quotes*	*Teacher*
Research question 1: What impact did the PD have on teachers with varying degrees of expertise toward teaching engineering?				
Redefining the meaning of engineering	Transformation of a stereotypical or restricted definition of engineering	Inclusiveness, cultural shift	*Prepare yourself for the direct confrontation of any misconceptions you may still have about the role of engineering (engineering is for everyone).*	*Jordan*
			It's much bigger. Engineering is something much bigger than just a single defined element …it's much more about identifying problems or situations and then developing solutions for them. That will, not to sound cliché, but they can help society or help a community or you know, resolve a situation that needs to be resolved in some capacity and that that can stretch across and I'm starting to see now literally including my own in the entertainment world, for the most part, but in any field or any industry.	*Alex*
			It has to do with employing a skill set and utilizing a process to go about solving problems, finding solutions to these problems, and developing systems and prototypes.	*Carey*
Growing confidence to teach engineering	Teachers feeling assured about their abilities to teach engineering		*It was a very productive and worthwhile professional development. I feel much more confident in my ability to deliver the e4usa content to students.*	*Blake*
			I think I was, you know, I always felt confident in teaching engineering, just because I've done it for a while. But I think what's been added [is] sort of a level of depth to get to that.	*Jamie*
Benefiting from the PD	The role of the PD in supporting both limited experienced and experienced teachers	Activities of the PD, leaders of the PD	*I thought actually working with the lessons like the work we did, end of the day, Wednesday and yesterday, taking some of the lessons and kind of pre-work and how we would do it in the classroom. That type of stuff is always great. So hands-on experience of working with the stuff, just the overall reviews of the units and things like that.*	*Blake*
			What else [was] said that helped as well…? You know [finding out] what the learning outcomes really are. I also thought with the video reviews we did [were] really helpful to see some of the classroom interaction to kind of discuss with you guys.	*Blake*
			This entire week has not just inspired me, it has motivated me.	*Alex*
			I'll add another adjective on it, which is passionate, and I think that comes out as well. It's very clear that all of you have a very innate and passionate interest in this program and its success.	*Jordan*
Receiving support from other teachers	The differing experiences of teachers leading to support and encouragement of one another	Acknowledgement, praise, advice	*You will feel overwhelmed the first night—do not give into that pressure. Lean in on your teammates to get support, ideas, encouragement, and advice.*	*Jordan*
			Part of the reason why I think this worked was because we were operating not only in a small group, but we were…continually coming back to each other. It wasn't just that it was in small groups. It was a group that became that team that was able to constantly reflect in like a macro micro way. I think that's part of it.	*Alex*
			I think one of the things that I'm actually most proud of is that I feel like I was able to lend my voice to the conversations this week. I see it now that…I was a resource for you that I did not anticipate being at all. I don't see that bragging in any kind of arrogant way.	*Alex*

Continued on next page

Table 2
(Continued)

Theme	Definition	Sub-themes	*Illustrative quotes*	*Teacher*
Research question 2: What unique experiences were had by those with and without prior engineering teaching or engineering industry experience?				
Experiencing imposter syndrome	Teachers hesitant about teaching engineering	Inexperience, apprehension	*I do have a little prior knowledge in engineering but it was close to 20 years ago that I studied engineering as an undergrad. Coming into this week I was very concerned [about] my abilities to teach the content.*	*Blake*
Renewing passion for engineering education	Experienced engineering teachers revitalized to teach		*I came into this wanting to do more about this team-building process that was kind of my going in. That's the area that I want to focus on. And I really feel like I was given training.*	*Jordan*

that confidence. These results align with the literature (Duncan et al., 2011; Nugent et al., 2010; Yoon et al., 2013a) examining collective participation across backgrounds and previous experience, while expanding our understanding of how to effectively structure such opportunities using a CoP approach to prepare teachers to teach pre-college engineering.

Benefiting from the PD

The support structures made available through both the summer and winter PDs and support from the e4usa team leading the activities were identified as essential in supporting all participating teachers. Blake stated in their letter:

> *Through the PD you will work with lessons from several units. The lessons are very thoroughly planned but do allow flexibility to make lessons more authentic for your students. The e4usa team is very accommodating and relaxed. It was a very productive and worthwhile professional development. I feel much more confident in my ability to deliver the e4usa content to students.*

The teachers' authentic experiences with the engineering design process through interactive and hands-on PD were impactful. Many teachers lauded the passion and support of the e4usa team and believed it to be a unique experience that helped them to teach the curriculum. Evan, an experienced engineering teacher, shared in their letter, "The people you meet will enhance your participation. The program coordinators are truly special, and 'yes,' professionally efficient. As a teacher, I know you have participated in many PD workshops. However, this is by far one of the best."

An important component to the summer PD was also the co-planning and co-teaching of a lesson. Many teachers expressed their appreciation of this activity. For example, Taylor stated, "It has inspired me to think of student-led engineering projects in a different way. Also, seeing what the other group of teachers did in presenting their lesson was a helpful part of reassuring me that there is a lot of flexibility in working with the projects." The sum of these benefits speaks to the collaboration embedded in the PD through collective participation across numerous stakeholders (Garet et al., 2001).

Receiving support from other teachers

The shared perspectives of the teachers revealed an evolving dynamic between the teachers with varying amounts of engineering experience. This dynamic developed into a supportive community. Teachers were praiseworthy of one another and provided encouragement throughout the PD opportunities. The teachers relished the opportunities to discuss, learn from one another, and gather a variety of different perspectives. As an experienced engineering teacher, Sam shared in their letter, "As you navigate through the week, the people who are currently strangers will become your team/network community." In their letter, Jamie shared the following:

> *Learn from your colleagues. I've learned much from the formal program, but I've also learned from my peers as they've shared stories and perspectives from their classrooms and their lives. By the time you read this, my colleagues and I will have implemented the curriculum for the first time. Reach out to us. I look forward to seeing you in our community of learning.*

These findings highlight the importance of providing teachers with opportunities to receive support from other teachers who possess different backgrounds and experiences, so that insights from teachers with limited engineering experience (e.g., empathy for new engineering learners) and teachers with more experience (e.g., understanding being an engineer) can be translated to all students (Jin et al., 2019; Yoon et al., 2013b). This creates a CoP through collective participation that provides a mechanism for sustained teacher change beyond the PD experience (Teague & Anfara, 2012). The environment created suggests a need to go beyond the content and standards (e.g., Reimers et al., 2015) of engineering-specific PD by focusing on the structure of the PD itself. This includes embedding a CoP approach and examining the approaches taken within a PD experience to bring together diverse engineering perspectives, especially teachers with existing content knowledge who tend to demonstrate increased comfort with discipline-specific PD, engineering being no exception (Nadelson et al., 2013).

Research Question 2: What Unique Experiences were had by Those With and Without Prior Engineering Teaching or Engineering Industry Experience?

Experiencing imposter syndrome

Most teachers asked to teach engineering lack an engineering background or training, i.e., they have never had the chance to learn about the discipline of engineering or how to teach engineering. Such situations can introduce the potential for lower self-efficacy, differing levels of empathy toward students, and imposter syndrome (Adams, 2020; Banilower et al., 2018; Collins et al., 2020; Daquilanto, 2015; Katehi et al., 2009; Nedegaard, 2017; Persky, 2018). The illustrative quotes suggest that many teachers were initially apprehensive about piloting and teaching a new engineering curriculum. The two teachers with limited experience in engineering education especially saw themselves as imposters prior to the summer e4usa PD. They made it very transparent in how they communicated their content area expertise as being in non-STEM fields. The teachers' personal identification with engineering changed as they progressed through the PD experience. Alex stated, "I am realizing that my lack of identifying with that moniker [engineer] had nothing to do with engineering. It had entirely to do with me." These two teachers particularly identified factors that supported their personal connection to teaching the e4usa curriculum and in essence redefined their understanding of engineering, which was an impact of the PD experienced by all teachers. The PD aided the teachers in altering their viewpoints on engineering, but also alleviated feelings of being an imposter as evidenced by another quote from Alex:

> *In so many ways, this is about a perspective shift. Or perhaps, more accurately, a perspective addition. I can only speak from my experience in all this, and I can tell you that I came into this uncertain to say the least. Feeling as though I was an imposter. As though in so many ways I do not belong. After just a week of PD—really this was so clear to me within less than a day—I am an engineer. Not superficially just to make this work for me to be part of the e4usa project, but because, it would seem, I actually am.*

In a letter aimed to impart wisdom to a future cohort of teachers, Alex also stated the following:

> *Run towards e4usa. Embrace it. All the things that you might be feeling are liabilities, big, small, or even unknown, regarding your experience—even your perspective—are not liabilities at all. They are in fact, resources. And not even just tangential—make you feel better about yourself resources—they are truly of tremendous benefit to both you and your students.*

As the teachers progressed through the academic year, teachers associated their limited, but growing, experience as an asset. Experiencing imposter syndrome appeared to fade away as there was limited discussion in the focus groups conducted during the winter PD. Teachers continued to see a personal connection to engineering, and how they too were going through the engineering design process as they taught the e4usa curriculum. This connection to engineering was evident when they recognized an engineering project was not limited to building bridges or tower structures but could also be applied to a need in their disciplines. Alex started to see connections between the engineering project manager role and their more traditional role in their discipline:

> *I'm already seeing connections to what I do, like within less than 24 hours [of PD], like very direct, it also uses very direct connections. I'm actually fascinated. Somebody said something this morning about giving the students a project to do something or other that related to, I can't remember what you suggested, but I thought to myself, you know, we have, like, you look at our facility that I'm using, but like our studios don't have really good isolation. And we've always struggled with that. And I started thinking, you know, would it be interesting at some point to be able to have some of my engineering students address that specific issue [studio sound isolation], and then actually implement it. Like, here is the budget from the grant that I got for us to solve this. Here are the criteria, here are all these things that we've been talking about and maybe, I have, you know, I treat it like I do with other things that I do. In general where I'm like, sort of like the executive producer, I get veto power. I'm the project manager, if you will, or the executive project manager, because I love to have a student project manager, obviously.*

Early on, Alex was already transferring what was gained from the PD regarding engineering and the design process. The result was that they experienced decreasing amounts of imposter syndrome. Alex was able to make the connection to the application of engineering in their own discipline.

Renewing passion for engineering education

Participating in the PD experiences resulted in numerous different types of teacher change, including opportunities for more experienced engineering teachers to "discover engineering all over again," as Parker stated in their letter. Redefining engineering was also associated with a renewed passion for engineering education. As a more experienced engineering teacher, Parker also shared, "Engineering, designing, building, and testing, that's what it used to be, after this week of PD, and the big idea of discovering engineering was most important for me. You can see it from all perspectives. You don't have to be an engineer to engineer. So that's what needs to be discovered." Jordan shared a similar take-away regarding engineering skills and their relevance in other fields:

> *I like how it [curriculum] tackles not just the hard skills, but the soft skills of not just being an engineer [but] of just being a student, of being a person in a culture where you have to communicate with other people, it doesn't matter [whether] you are my cashier at Walmart, just to pick two things, or whether you are the head PI of a research grant, you have to be able to communicate with other people.*

Taylor shared, "I am thankful for the opportunities and presentation materials I was a part of this week. After a long (but fun) week of training, I feel confident and excited to begin using the e4usa curriculum lessons in my class this year." The renewed passion demonstrated by these experienced teachers aligns with findings that have shown teachers to become reinvigorated by a PD experience (Autenrieth et al., 2017; Yoon et al., 2018), while also suggesting that experienced teachers gain just as much as beginner teachers when collective participation is part of the PD experience (Garet et al., 2001).

Implications, Limitations, and Future Work

This study provides a glimpse into the PD experiences of teachers with and without prior engineering teaching experience. Development of PD to teach engineering for similar programs should consider a number of factors beyond guiding standards, including diverse backgrounds, prior engineering training, prior engineering experiences, and prior engineering teaching. We found our sample of teachers to have a mix of backgrounds ranging from teachers who had no experience to teachers with prior engineering teaching experience and/or industry experience as an engineer. We believe this program has been successful in using the prior training and experiences of teachers to benefit the overall cohort through collective participation. Incorporating structured PD activities that encourage further teacher interaction and collaboration between teachers with varying previous experience are recommended. Additionally, explicit activities to foster teamwork, particularly when exploring lesson planning, would help enhance community building among the participating teachers.

Those developing PD programs should be sure to appreciate the initial existence of imposter syndrome. Recognition that those participating in the program may experience imposter syndrome will help participants understand and begin to overcome this perception. Highlighting this explicitly will also allow teachers to help students do the same.

The lessons learned from this work cannot be generalized but should be informative to similar efforts to design engineering-focused PD experiences. It is important to explicitly note two limiting factors that influence our results. First, we recognize that our results were from a small cohort of instructors and suggest that a larger cohort may see additional variability in experience, attitudes, and perceptions. Second, the team responsible for the development of the PD also developed the accompanying curriculum. This combined effort gave additional insight into the curriculum, which is a benefit that other programs may not have.

Future work to develop the emergent results presented in this paper would require a series of longitudinal case studies to ensure that differences across experiences have been mitigated and positive impacts are sustained. Ongoing and upcoming research for the e4usa team will examine the effectiveness of all professional learning aspects offered by this project, including revisions to the in-person PD opportunities and integrating online offerings, additional teacher supports provided by coaches and liaisons from institutions of higher education and industry, and the CoP. Future insights will continue to inform modifications to the e4usa professional learning to ensure all teachers have the necessary resources needed to teach engineering to any student. Every step taken further advances the goal of education reform that provides engineering "*for us all*" and highlights the importance and value of providing engineering-specific, in-service teacher to all regardless of background or previous experience.

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