Title: High school teachers' conceptualizations of engineering teaching

Word Count: 1970.

Abstract

Stakeholders of engineering education have recognized the need for engineering instruction in K-12 classrooms, especially at the high school level. However, lack of engineering-specific standards and varied conceptions of engineering teaching create challenges for high school teachers to teach engineering courses. This paper explores high school teachers' conceptions of engineering teaching in the context of an engineering education professional development (PD) workshop. We use Social Cognitive Career Theory (SCCT) to examine participants' conceptions during two focus groups conducted as part of the PD; particularly focusing on teachers' goals, interests, challenges, and expected outcomes of teaching a high school level engineering course. Results highlight the need for social support for teachers to sustain engineering teaching.

Keywords: Engineering education, social cognitive career theory, teacher professional development.

Introduction

Over the years, there has been limited common ground regarding a clear meaning of K-12 engineering education as it relates to curriculum, instruction, and student outcomes (Moore et al., 2014). The absence of this clarity is reflected in what is designed and offered to instructors in professional development (PD) programs, how the instructors understand the PDs, and translate the information to their students (Luft, et al., 2016). This qualitative study sought to understand high school teachers' conceptions of engineering teaching, specifically in the context of a PD organized under the Engineering for Us All (e4usa) initiative. This will allow for the design of more effective PD for K-12 engineering teachers and promote improved teacher practice, which correlates with increased students' performance (Reimers, et al., 2015).

E4usa is a National Science Foundation (NSF) funded project to create a high school engineering curriculum aimed at addressing the nation's need for increasing the number of engineers. To that end, the program aims to: 1) introduce engineering to any student; 2) develop engineering-centric skills, such as problem-solving, design thinking, and collaboration that cross-

cut a broad range of fields and prepare students for 21st-century careers; 3) create a bridge course for students who may want to select engineering majors in universities; and 4) make engineering more inclusive and accessible to secondary school educators and students, particularly those from underrepresented populations. With these goals, an introductory e4usa course was developed around four threads, *Discovering Engineering*, *Engineering in Society*, *Engineering Professional Skills*, and *Engineering Design*, and in-person PD for teachers was conducted in the summer of 2019. Under this context, the specific research question addressed by this study is:

How do high school teachers, who participated in e4usa professional development, conceptualize engineering teaching?

Literature Review: Conceptions of Engineering Teaching

Conceptualizations of engineering teaching at the school level vary in the literature (Breiner et al. 2012). There are several definitions ranging from simple to integrated pedagogical visions (Kloser, et al., 2018). The study of Tsupros et al. (2009), defined engineering education instructionally as: ''an interdisciplinary approach to learning where rigorous academic concepts are coupled with real-world lessons in contexts that make connections between school, community, work, and the global enterprise'' (p. 2). Merrill (2009) defined engineering education as ''a standards-based, meta-discipline residing at the school level where discipline-specific content is not divided, but addressed and treated as one dynamic, fluid study''(para.8). Radloff and Guzey (2016) conceptualized teaching of engineering as infusing the practices of technological, scientific inquiry, and interdisciplinary skills. These perspectives view engineering as an integrated discipline within STEM subject areas (Honey et al., 2014) and emphasize the development of critical thinking skills instead of the traditional focus on content. While engineering concepts could be integrated into science and mathematics, teaching stand-

alone engineering course(s) creates challenges for teachers who may not be engineers by training or did not learn engineering education instructional methods during their teacher preparation programs. Lack of engineering-specific standards and varied conceptions of engineering pedagogy exacerbate the situation for teachers who strive to provide early engineering learning experiences to students in order to prepare them for higher education STEM and career pathways (Honey et al., 2014).

Theoretical Framework

We used the Social Cognitive Career Theory (SCCT) as a guiding framework to understand teachers' conceptions of engineering teaching. SCCT is used to describe the development of vocational and academic interests, people's choice quest of career-relevant decisions, their persistence and performance in professional, educational and occupational fields (Inda et al., 2013; Lent & Brown, 2006; Lent et al., 1994, 2000). SCCT suggests that environmental contextual elements combined with learning experiences impact outcome expectations and self-efficacy, which then help advance an individual's intents and decisions as shown in Figure 1 (Kantamneni, et al., 2018). Our focus on conceptions of engineering education is intended to understand teachers' goals, interests, and challenges associated with providing high school students with early engineering learning experiences and the SCCT made an apt choice as a guiding framework, particularly focusing on the social support, barriers, and teachers' interests and intent.

Methods

Context and Participants

In 2019, the first year of the e4usa project, nine high school teachers were recruited to teach the e4usa course in local high schools across the nation. Each teacher attended one of two, five-day PD workshops at a large U.S. university during the summer of 2019. Participants for

this study include five teachers who all had taught engineering classes before and attended the second PD workshop. The five participants included two White males, one African-American male, one White female, and one African-American female. They are currently teaching the e4usa course in public high schools located in Maryland, Washington, D.C., Virginia, and Pennsylvania.

Data Gathering

Data sources included two focused group discussions, lasting 60 to 75 minutes, once before the PD (pre-PD) and another at the completion of the PD (post-PD). The focus group protocol was designed to elicit teachers' conceptualizations of engineering teaching. The teachers were asked to describe what engineering meant to them, how they taught engineering prior to the e4usa PD, how they will teach the e4usa curriculum, and the challenges they foresee.

Data Analysis

Qualitative data analysis followed an inductive approach (Tracy, 2013) in conjunction with the SCCT framework. In the first cycle, data units were open-coded by two members of the research team based on the concepts underscored by participants during focus groups (Tracy, 2013). In the second cycle, the constant comparative method was used to develop a common set of repeated themes informed by the SCCT. These themes pertained to meaning, self-efficacy, ways, intent, perceived support, and challenges associated with teaching a high school level engineering course.

Results

Results converged around eight themes including, (a) definition of engineering; (b) confidence in teaching engineering; (c) perceived goal of engineering teaching; (d) outcome expectations; (e) challenges; (f) benefits of the e4usa PD; (g) renewed passion; and (h) future

plans of teaching engineering. Table 1 presents these themes with definitions, sample quotes, and related SCCT constructs.

Definition of engineering: Most of the teachers defined engineering in the pre-PD focus group as a "creative application of math and science" that "goes about solving problems". However, at the end of the PD, the participants agreed that this was a narrow perspective focused on math and science requirements. They acknowledged that engineering "is a way of life" and it should be related to "everyday experiences of [their] students". A participant summarized this change as, "having more depth than the initial definition, having more pieces to tie together, recognizing that everything is a result of engineering, in short, everything has an engineering piece to it . . . there's the community piece . . . I think all those pieces are, equally valuable and worth mentioning". With the changed definition of engineering, teachers conceptualized engineering teaching as a means to relate to student's interests and making connections to the community.

Confidence in teaching engineering: Teachers described post-PD that they felt confident to teach the e4usa course. The PD experience improved their confidence in teaching engineering "knowing that you are on the right track". The reinforcement in confidence was evident when one teacher said, "I always felt confident in teaching engineering, just because I've done it for a while. But I think what's been added sort of a level of depth to get to that, is your colleagues [in the PD] you get to see their perspectives, how they would do it, their thought process on it".

Perceived goal of engineering teaching: When teachers described their goals of teaching the e4usa course post-PD, we related this theme to the 'intent' portion of the SCCT. To some extent, this theme encompasses the essence of engineering teaching for the teachers as evident from this quote, "teachers come from all different backgrounds. We're not necessarily engineers, we've been in state and into tech education, pick it up from there and try to move but not necessarily have a degree in engineering. So I'm always learning when I'm in the company of degreed

engineers, I'm always trying to learn as much as I can from them, so I can take back to my students…teachers' strategy is always how do we get this to the students".

Outcome expectations: This theme is linked to the 'outcome expectation' of SCCT as the teachers describe engineering teaching outcomes as obscure. A female teacher mentioned that she is in this because she is trying to be "the face of the program" with an expectation of "bring[ing] in more girls and minorities". However, she wasn't sure if she would see the outcome soon enough. For others, it was the personal satisfaction of providing "employability skills" to their students.

Challenges: Teachers mentioned multiple challenges of teaching engineering classes such as "kids that come in with the mindset that, this is just robotics", "taking a student who is not necessarily interested in engineering [and] introducing them to a subject area or field in a way that they could enjoy", getting the school district "to upgrade the CAD software", having "an overt or direct curriculum that directly addresses engineering-specific skills". Participants conveyed that the biggest issues were "not having a professional support group" of engineering teachers which could help them overcome some of these challenges.

Benefits of the e4usa PD: Teachers mentioned several benefits of e4usa PD to them with one of them saying, "I'm excited that my students, through this partnership will be able to get college credit". And "I've got that contact to reach out to now at Vanderbilt University that can speak with my students, and give them a better idea of what that field's about". Another said that "the way it is set up is geared to solidify students' understanding of the design process so that we can make application on it with a sense of ease, as well as to solve problems in order to generate problems that they can have multiple solutions for". This theme resonates with the SCCT construct of 'social support', as participants identified the PD itself as the much needed social support. As one teacher mentioned, "the networking side is great, because we can learn from

each other about how to do things a little bit differently, or to add to what we're doing in our classrooms already".

Renewed passion: This theme is connected to the SCCT construct of 'interest', as the teacher participants described a renewed interest in teaching engineering. At the end of the PD, one teacher said, "I think it's teaching engineering, to the full definition of an engineer. And not just, you know, engineering design in isolation, or whatnot. But looking at the big picture, I am excited".

Future Plans of teaching engineering: Participants talked about teaching the e4usa curriculum, teamwork, and making connections to what they were taught in the PD. This theme is linked with 'intent' under SCCT constructs. Teachers indicated their intent to teach e4usa course using hands-on learning experiences, team-based design projects, and making connections for students. A teacher described teamwork saying "working on the lessons together was awesome, because we got to see all kinds of different perspectives" Another described making connections as "I may do additional design project based on the year what I just got to kind of figure out what the timeline is".

Conclusion

The use of SCCT to explore teachers' conceptualization of engineering teaching highlights several themes that can be used to improve the design of engineering PD efforts. Specifically, PD activities including interacting with engineers and other engineering teachers evolved the teachers' definition of engineering, increased confidence and passion for teaching, and emphasized the need for social support through sustained PD efforts that create learning communities of practice. During the presentation, we will discuss the e4usa course design, this study, and the lessons learned during the e4usa PD within the context of current challenges in the K-12 engineering education landscape.

Acknowledgements

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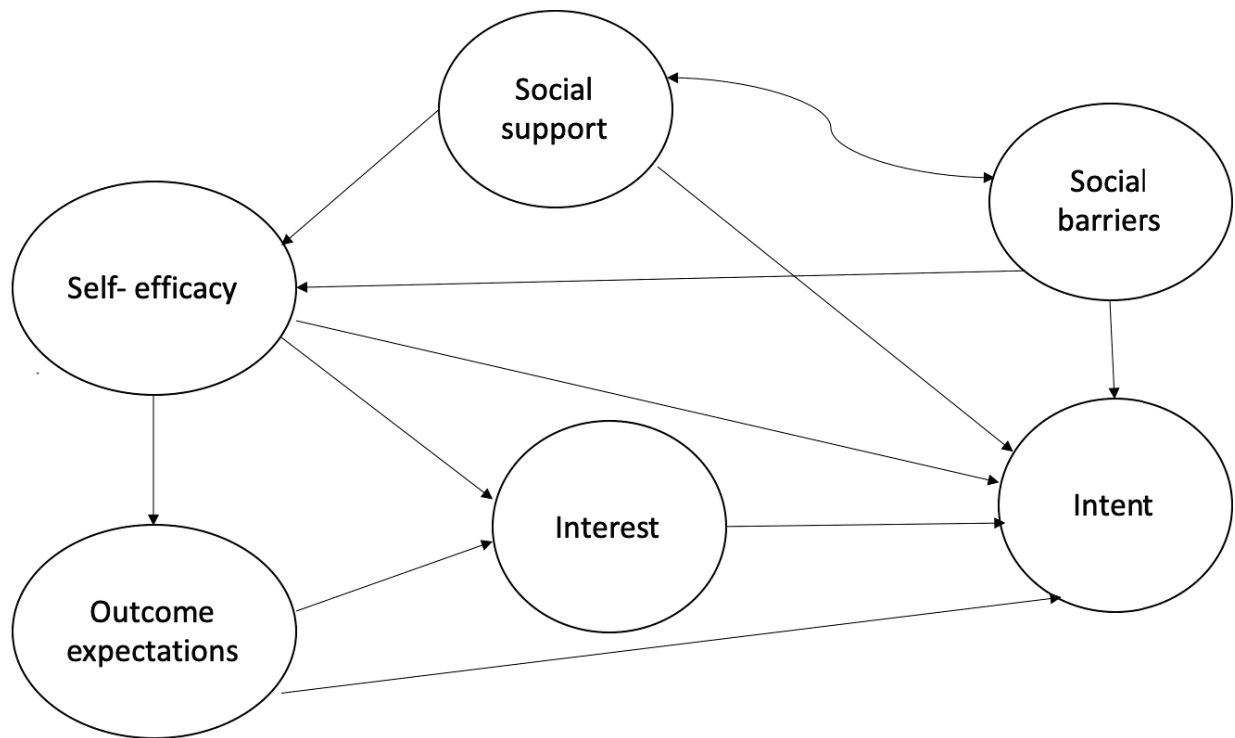*Figure 1, SCCT diagram Replicated from Aure, et al., (2019).*

Table 1: Operational definitions for themes and sample excerpts.

Theme	Description	Example Extract	SCCT Construct
Definitions of engineering	Teachers describing the meaning of engineering before and after the PD	"Engineering is all about understanding how things work and why they work the way they do this to know what we can improve on".	n/a
Confidence in teaching engineering	Teachers are confident in their ability to teach engineering after the PD	"…very confident in being able to teach the lesson starting this fall, I was really worried coming in, especially with the student project side of things but I feel very confident now that I'll be able to easily incorporate all".	Self-efficacy
Perceived goal of engineering teaching	Teachers describing the goal of teaching engineering education (e4usa curriculum)	"We're looking at them for possibly two years minimum of engineering education. How do we make them good? I've always said the purpose of my courses, one to kind of educate you on what engineering is. But the second course is to prepare them for university in a way that improves their statistics for success".	Intent
Outcome expectations	Teachers describe the outcomes of engineering teaching as a high hanging fruit	"I think you also need to go with this with the understanding that this is a process and you're working with these kids that are building skills. They might not be evident during that time that you have them. But when you look at this kid two years later … and you see how they grow. And	Outcome expectations

that's where you can see where these skills come into play.

Challenges	The challenges that teachers identify specific to engineering teaching	'to have a kind of professional support group in some ways that that can mean anything in terms of whether it's rubric development, whether it's, you know, developing a project for integrating different things. As engineering teachers, I think you're often isolated in a school … I still need people like me to kind of give me critical feedback on things that I develop or do".	Social barriers
Benefits of the E4USA PD	Teachers describe the benefits of the PD in terms of the needed social support	"I had been teaching engineering, the last couple of years after switching over from science. I was okay with that, you know, I don't mind getting out of my comfort zone, [but] collaborating with other people, that's been great. It gave us a chance to learn from each other and I thought working on the lessons together was awesome, because we got to see all kinds of different perspectives and it made everything meaningful".	Social support
Renewed passion	Teachers showing renewed passion and interest in engineering teaching after the PD.	I think going to the course this week is like looking at the design process, you really recognize that everything really is engineering. And then for this to be engineering for all is like helping to translate that to students so	Interest

that they can see it and get the spark, and then run with it as well.

| Future plans of teaching engineering | How teachers plan to teach the e4usa curriculum. | "I'm also, you know, looking forward to, when, when Adam was talking about, like, I think it was even unit seven more, we're, we're identifying the problem. And, you know, it's looking at your opportunities for my students to do project that way. You know, I've been trying to incorporate stuff like that with my classes, where they, you know, I did a STEM challenge with my students and, and, you know, not only doing that, but adding a global component where they collaborate with a students from another country. And, you know, thinking, Okay, I have seen, that's the direction I want to go. And that's offering for some cool opportunities". | Intent |