2021 ASEE ANNUAL CONFERENCE
Virtual Meeting | July 26–29, 2021 | Pacific Daylight Time
Paper ID #32505

Enabling Factors and Barriers for Adopting Engineering Curricula in High Schools: School, District, and State Administrator Perspectives (Fundamental)

Dr. Medha Dalal, Arizona State University

Medha Dalal is a postdoctoral scholar in the Fulton Schools of Engineering at Arizona State University. She received her Ph. D. in Learning, Literacies, and Technologies with an emphasis on engineering education from the Arizona State University. Her research interests lie at the intersections of engineering, technologies, and education focusing on ways of thinking, online learning and democratization of K-12 engineering education.

Dr. Adam R. Carberry, Arizona State University

Dr. Adam Carberry is an associate professor at Arizona State University in the Fulton Schools of Engineering, The Polytechnic School. He earned a B.S. in Materials Science Engineering from Alfred University, and received his M.S. and Ph.D., both from Tufts University, in Chemistry and Engineering Education respectively. His research investigates the development of new classroom innovations, assessment techniques, and identifying new ways to empirically understand how engineering students and educators learn. He currently serves as the Graduate Program Chair for the Engineering Education Systems and Design Ph.D. program. He is also the immediate past chair of the Research in Engineering Education Network (REEN) and an associate editor for the Journal of Engineering Education (JEE). Prior to joining ASU he was a graduate student research assistant at the Tufts' Center for Engineering Education and Outreach.

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Abstract

Pre-college engineering education has been on a sharp rise in the United States. Numerous schools offer some variation of an engineering curricula, but challenges remain regarding socio-cultural perceptions of engineering, teacher training, curricular alignment with state standards, and policy decisions. Many past studies have examined students' and teachers' knowledge, perceptions, and beliefs regarding pre-college engineering instruction. Few studies have investigated the viewpoints of school administrators, or state and district personnel. This qualitative study investigated perspectives of three such administrators in a southwest US public high school. The school was one of nine pilot locations offering a new engineering course designed to 'demystify' engineering for high school students and teachers from all walks of life. Results converged around four major themes: 1) relevance and current state of pre-college engineering education, 2) teacher certification and professional development, 3) industry connections, and 4) expectations of pre-college engineering curricula. The resulting themes shed light on long standing issues affecting adoption of engineering at the pre-college level and highlight a few areas that upcoming pre-college engineering education programs could focus on.

Introduction

Engineering disciplines affect virtually every aspect of our society, yet few students encounter engineering-specific courses during their pre-college education. The general lack of engineering education experiences embedded in pre-college curricula means most students never gain a holistic understanding of engineering as a discipline.

Multiple reports over the past decade have discussed the importance of authentically introducing engineering to youth (National Academies of Sciences, Engineering, and Medicine, 2020; National Research Council, 2010, 2012). Many states have reacted by including engineering within their state K-12 science standards. Prior to 2011, only 11 states had explicit engineering standards (Carr, Bennett, and Strobel, 2012). This number increased to 12 in 2015 with an additional 24 states implicitly referencing engineering (Moore et al., 2015). As of 2018, 39 states have updated their science standards to include engineering with an additional four states planning to do so by 2021 (Lopez & Goodridge, 2018); 20 of these states have adopted the Next Generation Science Standards (or adopted them under a different, state-specific name with additional state-specific standards), which embeds engineering (Lopez & Goodridge, 2018).

Reports and state standards emphasizing the need to include engineering in P-12 education have not translated into a lot of action by districts and schools to incorporate engineering as a core subject in existing curricula. The blame for the lack of action cannot be fully placed on districts and schools. There has been limited common ground established to define pre-college engineering education nor engineering-specific curricula, instruction, and student outcomes (Moore et al.,

2014). This is due in part to engineering being incorporated into science, technology, engineering, and mathematics (STEM) as an integrated discipline instead of a standalone subject (Chabalengula et al., 2017). The grouping of engineering as part of STEM has essentially left the decision to teach engineering topics in pre-college setting up to science or technology teachers (Honey et al., 2014; NGSS Lead States, 2013).

If engineering is offered as its own course, it is typically included under the Career and Technical Education (CTE) electives (Lewis & Zuga, 2005). This option then leads to other challenges of meeting state CTE standards that tend to emphasize technology learning. The decision to lump engineering in with these other disciplines is also closely tied to the difficulties associated with finding teachers trained in engineering content areas. The majority of currently available pre-service teacher education does not cover engineering content or methods (Perkins Coppola, 2019). All these aspects of pre-college engineering education including teacher training, curricular alignment with state standards, and policy decisions are not simplified when you add the challenges that remain regarding socio-cultural perceptions of engineering. One program, Engineering for Us All (e4usa) funded by the National Science Foundation aims to address some of these issues.

The e4usa project, led by five US universities, began in 2018 with the goal of creating an all-inclusive high school level engineering curriculum. An introductory course was designed and developed to introduce engineering to high school students with an eye toward providing students with college credit for completing the course. The course was intentionally designed to emphasize the idea of thinking like an engineer and developing students' professional and design skills through team-based engineering design experiences. The course was piloted during the 2019-2020 academic school year in nine schools across the nation.

This qualitative study investigated perspectives of three administrators co-located in one southwest US school district where one of the nine pilot teachers was teaching the new e4usa course. Past studies have examined students' and teachers' knowledge, perceptions, and beliefs regarding pre-college engineering instruction (Hotaling et al., 2012; Hsu et al., 2011; Lachapelle, & Cunningham, 2007). Few studies have investigated the viewpoints of school administrators, or state and district personnel (e.g., principals, vice-principals, or CTE personnel) (Shields, 2007). The rise and growth of pre-college engineering education makes it critical that we gain an understanding of what it means to provide meaningful engineering experiences to students. Data supporting the implementation of such courses will be the primary means of educating and convincing administrators that such offerings are necessary. This includes understanding:

1. What do administrators and policy makers look for when selecting curricula and teacher training?
2. What issues do administrators confront when making decisions?

The current study explores these questions and aims to contribute to the literature by examining the first-hand perspectives of administrators.

Methods

This study was conducted as part of the e4usa program, purposefully selecting one public high school in the southwestern United States. The high school is one of five in the school district. Three other high schools in the district have had some form of engineering curricula, including teacher designed courses and three-year sequences of pre-college engineering design offered through dual enrollment with a local state university. The school selected for this study decided to offer an engineering course in the 2019-20 academic year, which was the pilot year for the e4usa. The decision was driven by a few factors such as the withering robotics club, parental demands, and a desire to stay competitive with other schools in the district (Reid, Dalal, & Beauchamp, 2020). The school administration signed up to offer the e4usa introductory engineering course.

Three administrators from the selected school, school district, and the state department of education were interviewed at the concussion of the academic year. The participants included the school vice-principal of education services, the district director of the CTE department, and the CTE program specialist from the state department of education. All three participants happened to be females, two White and one Asian American. Two of them had prior engineering experience; one had worked in production and machining with a degree in mechanical technology and the other had an undergraduate degree in computer science and engineering. The third participant had multiple degrees in teacher education, school counseling and educational leadership and administration. Here onwards, we will use the terms 'administrators', 'officials' and 'participants' interchangeably.

The three administrators were invited to participate in semi-structured interview sessions that lasted approximately one hour. The interview questions were formulated to understand participants' perspectives of pre-college engineering education, particularly focusing on the enabling factors and barriers for adopting engineering curricula in high schools. The interview data was analyzed inductively using a two-cycle coding approach (Saldaña, 2009) with constant comparison (Corbin & Strauss, 2015). Two members of the research team coded transcripts together and established common meaning units, codes, definitions, and interpretations. Results converged around four major themes as described in the next section.

Findings

Four themes emerged from the interview data that illustrate the often intertwined enabling factors and barriers for schools and school districts to adopt engineering curricula. The four themes include: 1) relevance and current state of pre-college engineering education, 2) teacher certification and professional development, 3) industry connections, and 4) expectations from pre-college

engineering curricula. We report on these themes with embedded participant quotes for contextual understanding.

Relevance and Current State of Pre-College Engineering Education

Administrators recognized the importance and relevance of engineering education for high school students as a means to obtain the skills needed for higher education and the job market. They explained that they want and are seeking out ways to offer an engineering track in the high school curriculum so more students can take advantage of the opportunity. They felt that pre-college engineering experiences provide a "great foundation" and a "powerful [mechanism] for students to figure out" if they like engineering and want to pursue it in future. An added incentive was mentioned that students could receive an industry certification for computer-assisted design (CAD) as the state mandates an exam for CTE courses. Participants conveyed that all high schools should have an engineering elective course as evident from this quote:

> *In this day and age, we need to have engineering at every high school. It is, you know, CTE prides itself on being able to prepare students for careers that are high demand and high wage - engineering is, it's right there.*

Participants also voiced the need for a "marketing campaign" to "get the word out" and inform parents and students about engineering programs. They mentioned that CTE is still interpreted by many as "vocational, trade-related education that is not meant for every kid" and "most kids get scared when they hear the word engineering."

The district and state officials explained that most of the engineering programs that they have previously implemented have all come from modeling other existing programs around the country. All participants recognized that while the programs and district processes do not have to be the same, standards would help bring in synergy across various programs and offerings. The district administrator described her challenge:

> *I have engineering at four of five high schools, including the offering from e4usa. And I will be very honest, that all four of them are doing something very different. So, to me that is one area we have to work on. That is something that we are going to be audited on and that's the conversation we've already started with our engineering instructors.*

School and district officials expressed the desire to have curriculum standards that are found in popular K-12 engineering programs to be incorporated into the state standards of schools for an easier transition for students and teachers. They further indicated that they "would have liked to be able to hire a new educator, or bring in an already employed teacher, and give them a class with

the engineering curriculum that aligned with the industry trends and the standards already incorporated into it."

Teacher Certification and Professional Development

All participants expressed difficulty in finding willing and qualified instructors to teach engineering classes. For example, one administrator explained,

> *I think some of the struggles that schools face is finding qualified teachers that want to teach engineering. As you know, out in the field, engineers are going to make significantly more. And so coming to work in a high school or middle school to teach engineering is, you know, that's a calling.*

Engineering does fall under the CTE umbrella for this school district, so instructors do need a CTE certification or a lengthy work history in industry to qualify for teaching. Participants expressed that often math and science teachers have the breadth of knowledge required to help students with the math and science components of engineering courses, but do not have the CTE certification.

All participants agreed that a potential solution was the incorporation of certified personal development (PD) for teachers that express an interest in teaching engineering courses. This approach not only allows teachers to gain the content knowledge needed to instruct engineering courses, but also provides certification to take with them for future endeavors and teaching opportunities. One participant mentioned,

> *I think we have teachers that also feel that way, that they wouldn't be able to have that background knowledge or be able to teach engineering when actually a lot of them really could. They really could with some professional development and working alongside engineers, I think that a lot of our teachers could really scale up to be able to teach engineering.*

Participants also expressed their disappointment with the lack of engineering PD programs as evident from this quote:

> *When I kind of put feelers out of you know, what are you doing for engineering and you know, what's - where's professional development that you sent your, your engineering teachers. The only thing I got back was Project Lead the Way, so there's just not a lot of opportunity that I've seen for training for our engineering teachers. [Project Lead the way] comes at a fee and a cost that I think probably is why districts can be apprehensive to buy in. It's quite costly so they do certainly offer training if you, go in that direction, however, I couldn't just send my engineering teacher to their training and not do their curriculum and program.*

Industry Connections

Another key theme that emerged was the strong desire for industry connections. Administrators noted the extreme difficulty they had in finding industry connections that would be actively involved in the high schools. This task was viewed as just as hard or even harder than finding qualified instructors for engineering courses. The participants wanted to see programs like e4usa try to bridge the gap between schools and industry by reaching out and making connections. Administrators believed that having industry professionals involved in the learning process would provide students with a real-world example of how their learning can be applied to future careers and pursuits and elevate student engagement and learning, especially when "the majority of the teachers are not trained engineers." One participant elaborated:

> *...that connection to industry helps us in our schools immensely so that they know, we know, what's the latest software? What are the skills that our students really need to have that would help us as well? That connection to industry is always kind of a challenge for us to get you know, you're only probably getting the voice of maybe one or two people when we need the voice of that industry.*

Some of the suggestions made to strengthen industry-academia opportunities include but were not limited to, making connections with industry professionals for guest lectures and project guidance; providing students with industry internships/work shadowing opportunities; certification opportunities; and "Train to hire" opportunities where industry professionals would work with recent high school graduates in completing their degree/certification on the condition that they have a job offer lined up for the student.

Expectations from Pre-college Engineering Curricula

This theme covers what the participants described as their expectations from a high school engineering education program. All participants emphasized the need for programs to be a minimum of two-years. The reason being:

> *The challenge that [engineering education has] sometimes within CTE is the requirement that our programs are two years, and I understand. I believe our programs should be two years, you need that time to really, if you're really going to develop and go deep into learning some skills, you can't do that in an academic school year, 45 minutes a day, we just - you need the two years.*

Programs implemented in this district also needed to meet the state CTE standards and bring in the latest industry trends. A few other elements mentioned as necessary in an engineering curriculum included group-based hands-on projects, relevant and authentic experiences, and thoroughness to meet the state requirements of fluency in computer-assisted design (CAD). There was an expectation from programs such as e4usa to bring practicing engineers to the classrooms.

Continuing education and PD for teachers were mentioned as other desirable elements. The school administrator explained,

> *To get some PD credit, or even college credits under their belt, how to teach and train. What is it about, so teachers aren't scared off. [So] increasing their depth of knowledge [beyond just what the standard says] I think will only help us more.*

Finally, the participants also emphasized the thoroughness they would like to see in terms of math and physics knowledge from students and teachers in engineering classrooms. All participants emphasized the importance of math and science numerous times during the conversation as evident from this quote, "...to be ready for the college, they have to keep in mind, they need physics. They need math, as much math as possible and we tell the CTE teachers, the same thing." Math specifically was considered a non-negotiable pillar that all students taking an engineering course need to be successful in college and later in their careers. There was a consensus that "by the time many students reach the high school level, their math skills are underdeveloped" and that "hinders their ability to do well when the students are otherwise, very capable."

Discussion, Conclusions, and Future Work

The results from the three interviews conducted with school administrators not only speak to the known, long standing issues affecting adoption of engineering at the pre-college level, but also highlight a few areas that upcoming pre-college engineering education programs could strive toward.

It was interesting that while parental demands were one of the factors that led the school to offer an engineering class in the first place, participants still felt the need to change perceptions of engineering among the local community. Prior reports and studies have shown that engineering is often perceived as an esoteric discipline, immersed heavily in math and science (Nathan et al., 2010; National Academy of Engineering, 2008). These perceptions then overshadow other engineering-centric knowledge, skills, and abilities such as design thinking, interdisciplinary thinking, teaming, and communication that cut across various disciplines and 21st century careers. Programs such as e4usa that are designed with all students and teachers in mind to create engineering literacy could make a difference in changing such perceptions.

The idea of standardization is well-established, and the need has persisted since the inception of pre-college engineering education (Chandler et al., 2011). The field currently lacks an adequate number of programs to learn from. Engineering often gets lost either as an integrated discipline under science standards or as a topic under technology education. The question is whether engineering belongs embedded within science or technology education. The recent release of the *Framework for P-12 Engineering Learning* is a strong foundational step toward future standardization efforts of engineering-specific education (AEEE & ASEE, 2020). The framework should lead toward generating and implementing a cohesive engineering curriculum in alignment

with state requirements rather than the piecemeal utilization of different engineering activities in science classrooms.

A dearth of willing and qualified teachers is another issue that has recently been recognized as a barrier to mass adoption of pre-college engineering education (Dalal, Carberry, Warmington, & Maxwell, 2020; Biagiati et al., 2010). There is scarcity of STEM qualified teachers across the country, but vocational and arts programs are struggling to get the enrollment numbers needed to be sustained (Gray, 2004; Shaw 2018). The time might be now for empowering teachers from non-STEM backgrounds with appropriate PD to teach introductory engineering classes (Kouo et al., 2020; Carberry, Dalal, Nagda, & McCarthy, 2021) Changing the perception of engineering and exciting diverse groups of students to pursue engineering requires a diverse group of teachers to teach pre-college engineering classes, beyond the mathematics, physics, and computer science groups (Katehi et al., 2009). Therein lies an opportunity for researchers to design relevant PD opportunities that build capacity for pre-college engineering educators. The American Society for Engineering Education standards provide a comprehensive description of the professional preparation and development to fully prepare engineering teachers to create and assess the P-12 engineering knowledge (Reimers, Farmer, & Klein-Gardner, 2015).

It should be noted that this study worked with a small group of administrators in one school district and the extent to which the findings are generalizable is limited. Interviews with a larger group of administrators in other school districts and states may reveal different and additional themes. We also interviewed administrators who had adopted an engineering education program in their school/district. It would be interesting to conduct similar interviews with school administrators who do not already have an engineering offering to further illuminate the barriers in adoption.

The issues and barriers described have persisted for a long time. The pace of change has been slow, despite the collective agreement from the pre-college engineering education community and numerous calls for change. These conversations and actions to enact change in pre-college engineering education must continue. Our work adds to the conversation by providing direct evidence of school, district, and state administrators' perspectives. We will continue to engage in multiple reflections and discussions with administrators across the nation in the coming years as the e4usa scales up to create district-level partnerships. The study has implications for how school and district partnerships may be developed to allow for reciprocal support as pre-college engineering education continues to grow.

Acknowledgements

This material is based upon work primarily supported by the National Science Foundation (NSF) under NSF Award Number EEC-1849430. Any opinions, findings and conclusions, or recommendations expressed in this material are those of the author(s), and do not necessarily reflect those of the NSF. The authors acknowledge the support of the project team.

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