Initial Investigation of Effective Teacher Professional Development among Experienced and Non-Experienced Engineering Teachers (Work in Progress)

Dr. Jennifer L Kouo, Towson University

Jennifer L. Kouo, is an Assistant Professor in the Department of Special Education at Towson University in Maryland. Dr. Kouo received her PhD in Special Education with an emphasis in severe disabilities and autism spectrum disorder (ASD) from the University of Maryland at College Park. She is passionate about both instructional and assistive technology, as well as Universal Design for Learning (UDL), and utilizing inclusive practices to support all students. Dr. Kouo is currently engaged in multiple research projects that involve multidisciplinary collaborations in the field of engineering, medicine, and education, as well as research on teacher preparation and the conducting of evidence-based interventions in school environments.

Dr. Medha Dalal, Arizona State University

Medha Dalal is a postdoctoral scholar at Arizona State University. With an educational journey that has spanned multiple disciplines including Electrical Engineering, Computer Science, and a doctorate in Education, Medha is interested in research at the intersections of engineering, technologies, and education. Three thrusts that define her research interests include, ways of thinking that address complex educational challenges, democratization of K-12 engineering education, and online/blended learning. Her research seeks to build capacity for engineering education stakeholders at the grassroots, while also informing policy.

Dr. Bruk T Berhane, Florida International University

Dr. Bruk T. Berhane received his bachelor's degree in electrical engineering from the University of Maryland in 2003. He then completed a master's degree in engineering management at George Washington University in 2007. In 2016, he earned a Ph.D. in the Minority and Urban Education Unit of the College of Education at the University of Maryland. Bruk worked at the Johns Hopkins University Applied Physics Laboratory, where he focused on nanotechnology, from 2003 to 2005. In 2005 he left JHU/APL for a fellowship with the National Academies where he conducted research on methods of increasing the number of women in engineering. After a brief stint teaching mathematics in Baltimore City following his departure from the National Academies, he began working for the Center for Minorities in Science and Engineering (CMSE) in the Clark School of Engineering at the University of Maryland. In 2011, he began working directly under the Office of the Dean in the Clark School, coordinating outreach and recruitment programs for the college. In 2016, he assumed the role of director of the Office of Undergraduate Recruitment and Scholarship Programs. His duties entailed working with prospective freshmen and transfer engineering students. In 2019, he transitioned to the role of Assistant Professor in the School of Universal Computing, Construction, and Engineering Education at Florida International University. His research interests transfer students who first enroll in community colleges, as well as developing broader and more nuanced engineering performance indicators.

Dr. Jumoke 'Kemi' Ladeji-Osias, Morgan State University

Dr. J. 'Kemi Ladeji-Osias is Professor and Associate Dean for Undergraduate Studies in the School of Engineering at Morgan State University in Baltimore. Dr. Ladeji-Osias earned a B.S. in electrical engineering from the University of Maryland, College Park and a joint Ph.D. in biomedical engineering from Rutgers University and UMDNJ. Dr. Ladeji-Osias' involvement in engineering curricular innovations includes adapting portal laboratory instrumentation into experiments from multiple STEM disciplines. She enjoys observing the intellectual and professional growth in students as they prepare for engineering careers.

Dr. Kenneth Reid, Virginia Polytechnic Institute and State University

Kenneth Reid is an Associate Professor in Engineering Education at Virginia Tech. He is active in engineering within K-12, serving on the TSA Board of Directors. He and his coauthors were awarded the William Elgin Wickenden award for 2014, recognizing the best paper in the Journal of Engineering Education. He was awarded an IEEE-USA Professional Achievement Award in 2013 for designing the nation's first BS degree in Engineering Education. He was named NETI Faculty Fellow for 2013-2014, and the Herbert F. Alter Chair of Engineering (Ohio Northern University) in 2010. His research interests include success in first-year engineering, engineering in K-12, introducing entrepreneurship into engineering, and international service and engineering. He has written texts in design, general engineering and digital electronics, including the text used by Project Lead the Way.

Prof. Cheryl Beauchamp, Regent University

Cheryl Beauchamp serves as the Engineering and Computer Science Department chair of Regent University's College of Arts and Sciences. She is a PhD student in the Engineering Education program at Virginia Tech. She earned her Master's of Science degree in Computer Science from George Mason University and her Master's of Education degree from Regent University. Her research interests include Computer Science education, STEM education, teamwork design, online learning, and cybersecurity.

Dr. Adam R Carberry, Arizona State University

Dr. Adam Carberry is an associate professor at Arizona State University in the Fulton Schools of Engineering 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 is currently the chair of the Research in Engineering Education Network (REEN) and an associate editor for the Journal of Engineering Educaiton (JEE). Prior to joining ASU he was a graduate student research assistant at the Tufts' Center for Engineering Education and Outreach.

Dr. Stacy S Klein-Gardner, Vanderbilt University

Dr. Stacy Klein-Gardner serves as an Adjunct Professor of Biomedical Engineering at Vanderbilt University. She is the external evaluator for the Engineering For Us All (E4USA) project. She chairs the ASEE P12 Committee and is a Fellow of the society.

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Jennifer Kouo, Medha Dalal, Bruk Berhane, Olushola Emiola, Kemi Ladeji-Osias, Ken Reid, Cheryl Beauchamp, Adam Carberry, Stacy Klein-Gardner, Matt Miller, and Briana O'Neal

Experts have identified an urgent need over the past decade to increase the number of professionals in STEM disciplines [1, 2]. According to the Bureau of Statistics, the U.S. needs to increase the number of STEM degree recipients by 34% on an annual basis [1]. The need for STEM *educators* in K-12 education is highlighted as a particular population of STEM professionals that are in high demand due to the paucity of their numbers. Within K-12 *engineering* education specifically, scholars note that improvements are difficult because there are no clearly defined engineering curricula [3]. These same scholars note that most educators are unprepared to advise students in K-12 about engineering careers, let alone introduce K-12 skills and knowledge in engineering into their classrooms [3]. Engineering is often perceived as esoteric among early elementary education instructors, which can lead adults to be wary about adapting engineering curricula [4]. It is worth considering whether or to what extent middle or high school educators perceive engineering in similar ways.

Engineering for US All (E4USA): A National Pilot Program for High School Engineering Course and Database is a National Science Foundation-funded initiative designed to address this national need. The E4USA project aims to make engineering more inclusive and accessible to high school educators and students, particularly those from underrepresented populations. This paper describes the experiences of a sample of high school educators that comprise the inaugural cohort of nine E4USA educators. The educators' reflective responses to professional development (PD), which they received as preparation for this course prior to the start of the 2019-20 academic year are particularly illuminated.

Literature Review

A review of extant scholarship reveals several themes regarding the teaching of engineering in K-12 settings. One theme is a tendency among some K-12 scholars and practitioners to not distinguish *engineering* education as a distinct field within the STEM disciplines. Nadelson, Callahan, Pyke, Hay, Dance, and Pfiester [5] suggest that the affective responses that educators have to STEM fields in general are similar to the responses that they have to engineering in particular. Nathan, Tran, Atwood, Prevost, and Phelps [6] similarly state that few articles have been documented that explore educator beliefs related to pre-college engineering. Instead, the majority of this body of literature focuses on science or math-related perspectives [6]. Bybee [7] addresses the question of whether or not to distinguish engineering amongst STEM fields by suggesting that there is no need for a separate course that introduces students to engineering. Bybee [7] further suggests that the objective of introducing children to engineering can be accomplished by science coursework.

Scholars who contend that engineering can be subsumed under science education might also advocate for teachers to receive engineering PD through science departments. By contrast, Cunningham and Carlsen [8] criticize the notion that engineering can simply be added as a type of addendum to science courses. They posit that such an approach would limit students' understanding of the entirety of engineering. The authors suggest educators should present a more holistic view of engineering that allows students to solve problems using engineering frameworks rather than science frameworks. These scholars would likely be in favor of a PD that focuses more exclusively on engineering.

Engineering education training exists in a variety of modalities. Using case study analysis, Daugherty [9] analyzes PD for educators across several different types of initiatives. The author describes educators who have received training through in-person workshops, online modules, self-assessment training, as well as summer training institutes. The overall analysis [9] indicates that some of the programs have been designed as a means of promoting technological literacy for all students, regardless of their academic or career path; this has included students who might enter the workforce directly after high school. The author describes other cases as designed for increasing skills for post-secondary engineering education [9]. Among the educator PD programs are initiatives designed for educators to be self-guided in their instructional models, along with others that have encouraged more scaffolded problem solving [9]. The article also points out that some PD cases involve project leaders (e.g., professors from institutions of higher education), master educators, or some combination of both [9]. Some educators referenced in the article have more computing/technology/pre-engineering backgrounds than science backgrounds, while others are more science-oriented based on their academic discipline [9]. Ultimately, this paper illustrates through multiple cases the differences in how educators are trained, their backgrounds, and the emphasis of the engineering education programs.

Other articles published in recent years reference similar, but not necessarily identical, types of engineering education PD to those that Daugherty [9] discusses. Nadelson et al. [5], for example, outline a summer PD for mostly female and all White instructors, which emphasizes manipulatives like LEGO blocks. A cohort consisting of older participants felt more favorable about teaching engineering than a second cohort of younger participants. Additionally, educators with more STEM content knowledge felt more comfortable teaching engineering material than those with less content knowledge. The authors noted that educators' confidence in teaching STEM was highly correlated with educators' *efficacy* for teaching STEM.

These articles indicate the breadth of PD that may exist (e.g., online, in-person, hybrid) as well as the types of educator measures that can be analyzed (e.g., confidence, knowledge, other professional background, etc.). Educator demographics can also become part of the data that is included in such studies. To date, there has been no clear articulation of a consistent set of data points that scholars seek to generate, leading perhaps to broad and varied approaches to designing studies around engineering K-12 PD, and to potentially inconsistent tools for administering engineering K-12 PD. Much work is needed to develop consistent goals and outcomes across studies, while also determining an evidence-based approach to developing PD modules.

Purpose of the Study

Part of the E4USA pilot year mission has been to welcome educators with varying degrees of experience in industry and teaching. Paramount to E4USA was the construction of PD experiences that would prepare and support educators with varying degrees of engineering instructional training as they implemented the yearlong engineering course. One component of this was a weeklong, intensive E4USA PD. The PD involved focus groups, hands-on opportunities to explore, plan, and teach components of the E4USA Curriculum, and build collaborative relationships. The purpose of this study was to examine the perspectives of four pilot E4USA educators during this PD. The sample of eductors includes novice and experienced engineering educators. 'Novice' in this instance was defined as having less than a year of experience teaching engineering, while 'veteran' was defined as having more than three years of experience. This study aimed to highlight the impact of the E4USA PD on both novice and veteran engineering educators. The study also intends to emphasize how the inclusion of

educators with varying experiences with engineering education may increase educators' empathy towards students who may be equally hesitant about engaging engineering.

Methodology and Analytic Approach

Participants

Participants consisted of two novice and two veteran engineering educators. The first novice educator has been teaching music for the past 22 years and has a background in symphony orchestra. The second has been teaching history, but initially majored in engineering as a college student before changing his academic pathway halfway through. Both were going to teach an engineering class for the first time. The remaining two educators were deemed 'veterans' with a total of 15 years of experience as engineers and more than 20 years as high school engineering educators. Table 1 below shows further participant details.

Table 1. *Participant Background and Demographic Information*

Educator	Sex	Race/ Ethnicity	Content area	Engineering Education	Engineering Experience	School Context
1	M	Caucasian	Physics	B.S. (Chemical Eng)	4 years teaching high school Eng classes	Public, suburban
2	M	Caucasian	Music	None	None	Public, suburban
3	F	African American	Engineering and Technology	B.S. (Electronics Eng Technology)	10 years in the industry as senior quality assurance engineer followed by 20 years teaching high school engineering and technology classes	Public, urban
4	M	Caucasian	History	1.5 years in Eng school before transferring to another major	None	Charter, suburban

Data Collection and Analysis

Data sources included focus groups and letters written to future cohorts of E4USA educators. Participant focus groups were conducted at the beginning and the end of the PD week. Participants also wrote welcome letters to the next cohort of educators who would be engaging in the E4USA PD. Pre and post focus group data and letters were analyzed by two members of the research team using inductive coding and the constant comparative method [10]. Emergent themes represent the past experience or inexperience of educators with engineering.

Results

Analysis of the collected data resulted in the identification of six themes. The themes depict the transformative impact of the PD on the educators in redefining engineering, strengthening their confidence, and renewing their passion for teaching engineering. The themes, definitions, sub-themes, and representative excerpts are presented in Table 2.

As presented in the extracts, the educators were apprehensive prior to the PD, and the novice educators saw themselves as imposters. However, their confidence increased, as well as their personal identification with engineering. As one educator 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." In particular, novice educators identified factors that supported their confidence in teaching the E4USA curriculum. The PD aided the educators in altering their viewpoints on engineering. In a letter aimed to impart wisdom to a future cohort of educators, one educator 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.

Another contributing factor to supporting the confidence of the novice educators were the efforts to redefine engineering and broaden its access and inclusivity. In his letter, a novice educator

Table 2. *Identified Themes from Data Sources Collected from the Engineering Educators*

Theme	Definition	Sub-themes	Example Extracts
Imposter Syndrome	Novice educators 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.*
Growing Confidence	Novice educators feeling assured about their abilities to teach engineering.		*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.* *It was a very productive and worthwhile professional development. I feel much more confident in my ability to deliver the E4USA content to students.*
Renewing Passion for Engineering Education	Veteran engineering educators 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.* *Engineering, designing, building, testing. That's what it used to, after this week of PD, and the big idea of discovery 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 it needs to be discovered.*
Redefining 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).* *It's a much bigger engineering is something much bigger than just a single defined element that it's much more about identifying problems or situations and then developing solutions for them. That will, not to sound cliche, 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, it's not this.*
Impact of the PD	The role of the PD in supporting both veteran and novice educators.	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.* *What else is said that helped as well just to get us an idea and understanding what the goals of the course are, what each unit is heading towards? You know what the learning outcomes really are. I also thought with the video reviews, we did really helpful to see some of the classroom interaction to kind of discuss with you guys.* *This entire week has not just inspired me, it has motivated me.*
Support from Educators	The differing experiences of educators leading to support and encouragement of one another.	Acknowledge-ment, 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.* *Part of the reason why I think this worked was because we were operating not only in a small group, but we were able 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.* *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 it was an 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.*

captured this shift. He wrote that the stereotypical perceptions of engineers, as men with strengths in math and science seated behind computers, was false. In actuality, the educator wrote, "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." Furthermore, educators began to see the application of engineering in tackling everyday issues, and a direct connection to their daily instructional practices. One educator realized that the iterative process of improving upon instruction aligned with the concepts of engineering. The educators also aimed to share this redefinition with others, including school counselors, who may support students' understanding of the applicability of engineering.

The support structures made available through the provision of the PD and support from the team of engineering educators leading the activities were identified by the educators as essential in building both confidence and enthusiasm. A novice educator 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 are 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.*

Discussion and Implications

The goal of the E4USA project is to promote engineering 'for all', which includes both students and educators. The literature shows that educators with greater content knowledge demonstrate greater comfort with PD in engineering as a discipline. This is not surprising because developing PD for educators with content knowledge allows the developers of that PD to focus on discipline-specific content. Involving educators with little to no experience in engineering introduces issues of lower self-efficacy and differing level of empathy to students who will be in their classrooms. Educators with less experience were more apprehensive when faced with content with which they had little experience, but our analysis of letters shows that the week-long PD and the involvement of both experienced and novice educators had a positive effect on *all* of the educators, including those with little experience and content knowledge. These positive effects should translate to the students in the classroom as well. This is, in essence, the mission of the E4USA project.

The introduction of engineering in the context of 'for all' had a positive effect on the educators. The team-based PD allowed more experienced educators to serve as mentors for those with less practical experience and a greater measure of imposter syndrome. The PD allowed the imposter syndrome present among the educators to decrease, and the appreciation of stereotype threat and necessary empathy in the classroom to be highly visible. The inclusion of educators with varying levels of experience appears to build confidence and a sense of belonging among those varying levels of experience. This we believe is achieving our goal of 'for all'.

The weeklong PD is one component of the professional learning the educators will receive as they teach the E4USA Curriculum during the academic year. A community of practice, which was initiated during the PD, will be further cultivated through reflection posts, webinars, and additional PD. Since these educators are still completing the pilot year, information will be continuously gathered through focus groups and surveys to further examine the success of the PD and make improvements for the following cohort of engineering educators. Additionally, the hope is to continue to engage the pilot year educators in redesigning the PD, implementing it, and providing mentorship to subsequent engineering educators of E4USA.

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