Broadening the Pool of Precollege Engineering Teachers: The Path Experienced by a Music Teacher

Medha Dalal, Adam R. Carberry, and Richard Maxwell

Abstract*—*Contribution: **This single case study represents a unique attempt to examine a music teacher's experiences as he took on the challenge of teaching a high school level engineering course. The study contributes to the growing body of research and conversations around science, technology, engineering, and mathematics (STEM) versus non-STEM beliefs, perceptions, and practices in precollege education. This work informs future teacher professional development (PD) and hiring efforts to broaden the pool of teachers capable of teaching precollege engineering classes.**

Background: **Engineering education is growing in precollege settings but recruiting willing and qualified teachers has been a continuous challenge. Teacher PD programs should consider a broader and inclusive approach that builds confidence and empowers teachers from all disciplinary backgrounds (STEM and non-STEM) to teach precollege engineering classes. Such opportunities are not always made available to non-STEM teachers.**

Research Questions: **1) How does a high school music teacher with a non-STEM background experience teaching an introductory engineering course? 2) What are the necessary preconditions that could help bridge non-STEM content areas to engineering, specifically for teacher PD efforts?**

Methodology: **Multiple interviews, teacher reflection entries, and classroom observations were open coded using a two-cycle coding approach that resulted in six themes.**

Findings: **Results highlight the necessary preconditions and processes involved in bridging seemingly disparate subject areas that could lead to confidence building and empowerment of non-STEM teachers.**

***Index Terms*—Engineering education, precollege programs.**

I. Introduction

PRECOLLEGE engineering education is continually growing as a topic of study in the United States (U.S.) and is also finding its way into international discussions [1], [2]. The growth is largely due to the ever-increasing need for trained science, technology, engineering, and mathematics (STEM) professionals around the world [3]. The STEM workforce demands in the U.S. increased by 175% from 1980 to 2008 and continue to rise [4]. According to the Bureau of Statistics, the U.S. needs to increase the number of STEM degree recipients by 34% on an annual basis to meet the projected demands of industry [5].

Of particular concern is the field of engineering. The total number of students receiving degrees in engineering has increased in the last decade, but the numbers are not adequate to meet the projected growth rate of the engineering sector [6], [7]. Efforts in higher education provide one approach to addressing the demand, but such efforts may be too late in students' formal education. Capacity needs to be established early in formal education to educate and excite youth about STEM careers before they have chosen alternative pathways [8]. This places the onus on primary and secondary schools to appropriately inform students about STEM disciplines, especially the vast number of engineering subdisciplines and associated careers.

Precollege engineering education is still figuring out how and what to teach. Engineering as a subject that all students should have some exposure to during their school education has only recently emerged as a requirement in some locations [9], [10]. The lack of a "common curriculum" has been exacerbated by the fact that very few primary and secondary teachers have engineering backgrounds, and very few engineering-specific teacher preparation programs exist. This reality has led many schools to take a default approach to lean on teachers who teach other science, technology, and mathematics subjects, such as physics, mathematics, or computer science [11]. This approach assumes that engineering is completely technical and concerns only the application of science, technology, and mathematics.

There is an argument to be made that schools should consider broadening the diversity of potential engineering teachers by considering all kinds of content backgrounds (STEM and non-STEM). Such broadening expands the pool of potential candidates and supports the interdisciplinary nature of the engineering field. Enacting a broader and inclusive approach to selecting teachers requires that teachers be supported as emerging engineering educators. This could be accomplished through inclusive teacher professional development (PD) programs that build confidence and empower teachers from all backgrounds to teach precollege engineering classes [12]–[14].

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Such opportunities are not always made available to teachers [1], [10], which has resulted in the dearth of scholarship regarding non-STEM teachers' experiences teaching STEM content [14], [15].

This single case study investigated a music teacher's experience teaching engineering content for the first time. The aim was to understand his experience by exploring what prompted the journey, what he discovered along the way, and how he gained the confidence needed to teach engineering. It should be noted that this study does not intend to examine teacher change in terms of knowledge, beliefs, and perceptions; nor does it aim to evaluate teaching or teaching approaches. The purpose of the study was to explore how a music teacher experienced teaching a high school level engineering course while overcoming outward assumptions about whether non-STEM teachers should be teaching engineering courses.

This examination of a music teacher's experience teaching engineering content aims to contribute to the growing body of research and conversations around STEM versus non-STEM beliefs, perceptions, and practices in precollege education. The intent is to highlight the necessary preconditions for bridging non-STEM content areas to engineering that could very well inform future efforts to broaden the pool of teachers capable of teaching precollege engineering classes. This research effort is framed to address the following research questions: 1) How does a high school music teacher with a non-STEM background experience teaching an introductory engineering course? and 2) What are the necessary preconditions that could help bridge non-STEM content areas to engineering, specifically for teacher PD efforts?

II. Literature Review

Embedding engineering into precollege classrooms is still a relatively new endeavor for educators. There has been limited common ground regarding the clear meaning of precollege engineering education as it relates to curriculum and instruction [16]. It is important to understand how engineering offerings in precollege education efforts have evolved over time and what is their current status that prompted this research.

A. Precollege Engineering Teaching

Engineering as a domain of knowledge encompasses many different disciplines, each with its own content knowledge as it relates to the discipline, skills, and prevalent practices. Engineering content is also perceived as esoteric requiring discipline-specific specialization to teach [17]. The vast nature of engineering makes it logical that precollege engineering curricula should focus on cross-disciplinary, general topics like engineering design. The committee for the Standards for K–12 Engineering Education recommended integrating engineering design concepts into standards for other disciplines, such as science or technology [18]. This was enacted in the U.S. as part of the Next Generation Science Standards (NGSS), which formally included engineering practices that emphasize the importance of engineering design and problem solving [19].

The incorporation of engineering practices in the NGSS led to a sharp rise in STEM PD programs for U.S. teachers and associated research. Such efforts particularly aimed to develop teachers' knowledge of engineering and engineering design, while exploring teacher beliefs regarding engineering teaching [20]. These studies have largely reported an increase in cognitive understanding and positive attitudes toward teaching engineering content.

There is simultaneously a growing body of literature disapproving the integrated pedagogical vision. For example, Lewis [21] argued that when engineering and science are integrated, engineering design is often reduced to generic inquiry procedures. Scientific inquiry and engineering design are conceptually comparable but differ in ways of implementation. Teaching engineering design requires a strong base of subject matter content knowledge [14], [22]–[24]. For example, Hynes [14] conducted observations as middle school teachers taught a unit on using the engineering design process and found that teachers holistically understand the purpose and context of the engineering design process but could use a better understanding of the individual stages of the design process. Included in this understanding is a clear sense of what failure means, which is often equated by teachers to making a mistake [23]. The integrated science and engineering practices also pose another challenge for teachers, many of whom see the integration as science versus engineering as opposed to science and engineering [24], [25]. The "teachers' knowledge and beliefs about engineering may be at odds with the disciplinary practices" of engineering [24, p. 26] complicating the teacher's role as a design coach. Hynes [22] concluded that the subject matter content knowledge for precollege engineering teachers includes, but is not limited to, knowledge of the engineering design process; basic concepts of engineering and technologies from various fields (e.g., mechanics, electrical circuits, manufacturing and construction, and computer programming); materials (e.g., advantages/disadvantages of metals, plastics/polymers, ceramics, or organic materials); the engineering profession and what engineers do; and fundamental math and physics/science concepts.

Others have pointed out that science and engineering are two related, yet distinct domains of knowledge and practice [12], [26]–[29]. Teaching engineering skills and practices as a piecemeal approach under science subject matter limits students' understanding and appreciation of engineering concepts [29]. Such limitations are exacerbated by the lack of emphasis given to engineering in adopted state science standards, science textbooks failing to include activities that allow students to apply engineering principles, science teachers' limited likelihood to change their teaching practices to meet the needs of engineering activities, and negligence of engineering as a subject area in state assessments [30]–[32].

Recent precollege engineering education efforts geared toward the development of frameworks and standards suggest that engineering should be established as its own subject in precollege curricula [16], [33]. These efforts advocate for the inclusion of engineering as either a course that is central to all students' educational experience or as a sequence of optional courses for students interested in pursuing engineering careers [9]. Finding teachers trained in STEM topics, specifically, engineering content areas, has been an ongoing struggle for schools and districts [34], [35]. The majority of currently available preservice teacher education programs do not cover engineering content or methods [35]. The shortage of trained teachers makes offering engineering as a stand-alone subject challenging. Hiring teachers from non-STEM backgrounds to teach engineering could alleviate concerns regarding the shortage of STEM teachers while helping students discover the broader scope and applicability of the engineering field [11], [15]. Asking teachers to teach subject matter that they are not trained to teach could also lead to interesting negative consequences for both teachers and students [35].

Studies suggest that appropriate PD and buy-in from school administration can provide the necessary support for teachers from all backgrounds to make the transition to teaching engineering curricula [12], [35], [36]. Nadelson *et al.* [36] implemented and assessed a STEM PD for elementary teachers that particularly targeted teachers who did not have STEM backgrounds. Their study revealed two major findings: 1) PD that attends to STEM knowledge may be needed by teachers at multiple stages in their career regardless of their backgrounds and teaching experience and 2) significant correlations exist between attitude toward engineering and knowledge of STEM. Preliminary work emerging from the current project has shown that appropriate PD, social support, and personal drive can lead to the successful implementation of an engineering course by non-STEM teachers, including teachers with backgrounds in subjects like music that are seen at face value to have no connection to engineering [15], [37]. The unique contribution of this article is to offer insights into the necessary preconditions that could help teachers, administrators, and PD providers bridge non-STEM content areas to engineering.

B. Arts and Engineering

A sizable body of education literature presented over the past couple of decades has investigated the relationship between arts and engineering. Explorations examining this relationship have occurred at both the higher education and precollege education levels. These efforts can be broadly classified as: 1) interdisciplinary undergraduate degree programs at the intersection of arts and engineering and 2) precollege science, technology, engineering, arts, and mathematics (STEAM) education.

Undergraduate arts and engineering students share many common traits, including a penchant for considering aesthetics, using creativity, and seeking novel experiences in fluidly structured and/or focused learning environments [38]. Both disciplines require an ability to problem solve and leverage creativity to go beyond conventional norms and challenge incumbent thinking [38]. Overlapping characteristics have led to the creation of interdisciplinary degree programs in higher education specifically at the intersections of performing arts (e.g., music) and engineering over the past two decades [39], [40]. These programs are often created through interdisciplinary collaborations between arts and engineering units to provide students from both programs with access to hands-on opportunities that encourage lateral and creative thinking [39]–[42]. Topics covered by such interdisciplinary offerings between music and engineering include the physics of musical instruments [40], [41], tools and techniques for constructing musical instruments [40], creative music composition from an engineering systems perspective [41], and computational modeling of music processes [42]. Researchers have investigated students' experiences and outcomes in these "engineering meets music" courses and concluded that students appropriately apply engineering and music content learned from the courses and develop lateral thinking [41], [42]. For example, students use creativity and innovation to construct new musical instruments or uniquely modified existing instrument prototypes [40]. Engineering students were shown to recognize the importance of going beyond a conventional process and being creative and experimental, while music students built an appreciation for feedback from others in their creative process [40]–[42]. These efforts provide an exemplar of impactful cross-disciplinary activity.

Similar efforts in precollege education have advocated for the integration of arts topics into traditional STEM subjects to enhance overall student learning [43]–[47]. The justification for expanding STEM to include the arts, i.e., STEAM, focuses on opportunities for students to enhance teamwork, communication, creative thinking, and innovation through cross-disciplinary education [43]–[48]. Watson and Watson [43] argued that "The inclusion of the arts in teaching STEM, therefore, does not minimize any aspect of the STEM disciplines; it makes them stronger, more engaging, relevant to students" and exposes "students to a different way of seeing the world" [p. 3]. The natural hands-on learning and production embedded across STEAM disciplines provide unique opportunities for teachers to combine different content areas that allow students to "explore, question, research, discover, and exercise innovative building skills" [44, p. 1]. Such efforts require flexibility in planning and pacing but allow for effective implementation of STEAM activities into precollege education [45].

The work being conducted at both levels highlights the arts as a means to bring elements of creativity, imagination, and ingenuity to the student learning experience in STEM classrooms. Engineering and science projects situated within arts contexts often lead to more engaging experiences and new understandings for students [46], [47]. Careful infusion of these disciplines creates a transdisciplinary space that goes beyond what each can accomplish alone while providing a platform to explore important social and societal issues [47], [48].

Studies examining various interdisciplinary arts and engineering efforts have primarily focused on the curriculum design or students' engagement, outcomes, and experiences. Studies examining the experiences of teachers are very limited in number. Previous work from this project is one instance that examined a music teacher's experience embracing the teaching of computer-assisted engineering design [15]. The study concluded that appropriate PD, encouragement from administrators, and personal drive can empower teachers from non-STEM disciplines to teach engineering content. This study aims to build upon these initial findings to explore how a music teacher experienced teaching an introductory precollege engineering course while illuminating the preconditions that could help bridge non-STEM content areas to engineering.

III. Methods

A. Research Design

A single case research design [49] was selected to document and analyze a music teacher's detailed experiences teaching an introductory engineering course for the first time. This approach was used to exemplify the unique qualities of the case under investigation [50], [51]. Critics have questioned the value of a single case study, but scholars like Flyvbjerg [50], have responded to the criticism addressing many misconceptions about case study research. Flyvbjerg [50, p. 220] wrote, "the conventional wisdom of case-study research, which, if not directly wrong, is so oversimplified as to be grossly misleading." The real-world situations and the wealth of authentic details covered under case study research provide the nuanced view of reality [51], [52]. A single case design with purposive sampling allows the researcher to examine the distinctive features while ensuring a deeper understanding of the research question [49]–[51].

B. Program Context

Contextual conditions are critical to understand the case [51]. This study is part of an ongoing nationwide effort in the U.S. that aims to make engineering education more inclusive for students and teachers alike. The National Science Foundation (NSF) in 2018 funded an initiative, engineering for us all (e4usa), to develop a high school level engineering program. Two key components of the program include: 1) curriculum design and development and 2) teacher professional learning (PL). The introductory e4usa course aims to demystify engineering for all high school students and teachers as a means of enhancing potential engineering pathways. The course was developed around four threads: 1) *Discovering Engineering*; 2) *Engineering in Society*; 3) *Engineering Professional Skills*; and 4) *Engineering Design*. The course specifically explores the interplay among society's need for engineering, engineer's intentions, and impacts of engineering using project-based learning. Students learn engineering design through progressively larger project experiences. The projects are embedded in the context of students' daily lives as well as global sustainability issues that are applicable to students' local context.

A complementary PL was designed to impart curricular knowledge and to be inclusive of all teachers regardless of their previous experiences with engineering. The PL includes multiple PD workshops (on-site and online) for teachers throughout the year and covers the curriculum, assessments, and inclusive pedagogy. The year-round PL also involves teacher participation in an online community wherein teachers share their implementation of various e4usa lessons and reflect on their experiences.

The e4usa course was pilot tested during the 2019–2020 academic year at nine high schools across six states. The first teacher cohort included teachers ($n = 9$) with diverse backgrounds and varying degrees of experiences with engineering teaching (0–20 years). The cohort included three teachers who had undergraduate degrees in engineering, four teachers with degrees in other STEM fields, and two teachers with degrees in non-STEM disciplines, including history and music. Seven teachers with STEM education backgrounds had previously taught engineering classes, while the two non-STEM teachers had no prior engineering teaching experience.

C. Participant Selection

The single case for this study is Mr. Richard Maxwell who participated in the first cohort. Mr. Maxwell was identified as a single case for this study for two specific reasons. First, Mr. Maxwell did not have any prior engineering experience. He has been teaching music for the past 22 years. The other non-STEM teacher in the first cohort had initially enrolled in an undergraduate mechanical engineering program prior to switching his major to history after the first year [37]. This experience afforded him some prior knowledge relative to Mr. Maxwell. Second, Mr. Maxwell is a highly accomplished musician with undergraduate and graduate degrees in Music Composition and Theory and Instrumental Conducting. He has established a long history of success within the field of music, including multiple awards and even Grammy nominations. The opportunity to analyze Mr. Maxwell's journey of teaching an engineering course was unique. Mr. Maxwell was also willing to share his experiences and reflections, including the discomfort he felt initially. The research team's proximity to his school and the ability to gather a rich dataset using classroom observations and participant interviews throughout the year added yet another reason to select Mr. Maxwell for this case study. The overall scenario enabled the research team to deeply explore Mr. Maxwell's distinct experiences involved in embracing and teaching the e4usa engineering course by a non-STEM teacher. The focus on Mr. Maxwell foregrounds a non-STEM teacher's voice pertaining to his undertaking of teaching engineering. His story illustrates how his experiences shaped and evolved his understanding of engineering and pedagogy while supporting the argument of making precollege engineering teaching more open to people from diverse backgrounds.

D. Participant and Classroom Context

Mr. Maxwell has an extensive educational background in a symphony orchestra. He runs a musical arts program at a public high school in the southwestern U.S. with a fully open creative platform and a record label run by students. Mr. Maxwell's high school is one of five in the school district; three other high schools in the district have had engineering course offerings. The school administration and district made the decision that Mr. Maxwell's school should also offer an engineering course but did so at a point in the year where it was difficult to hire another teacher. Mr. Maxwell was tasked with teaching this course due to his availability combined with his Career and Technical Education (CTE) certification. The CTE certification is required by the state to teach classes that fall under technology classification, which includes engineering. Mr. Maxwell subsequently applied to join a PD workshop associated with a nationally recognized K–12 engineering education program but was rejected due to his lack of STEM experience. The administrator for that program shared Mr. Maxwell's contact information with the newly created e4usa program and Mr. Maxwell became a part of the first cohort of e4usa teachers. He attended all offered workshops and participated enthusiastically in the online community.

The e4usa course was offered as an elective at Mr. Maxwell's school in Fall 2019; 38 students (21% females) enrolled. Students included 20 freshmen, seven sophomores, eight juniors, and three seniors. The cohort was also racially and ethnically diverse, with 16 Hispanic Americans, 14 Non-Hispanic White Americans, three African Americans, two Asian Americans, two Mixed Race students, and one student identified as Middle Eastern American. The class met five days a week for 55 min each day.

Mr. Maxwell's classroom is larger than average size due to the space required for musical instruments and equipment (e.g., stage, drum kits, guitars, amplifiers, and synthesizers). The walls are adorned with pictures of artists and a few quotes about creativity and failure, such as "Failure is a better teacher than success" or "You cannot be creative and competitive at the same time." Computer stations line the walls for student use.

The current study took place during the 2019–2020 school year. Here on, the terms "the participant," "the teacher," and "Mr. Maxwell" will be used interchangeably.

E. Data Collection

A good case study uses a variety of data sources [53]. A multifaceted approach was used for this study to collect data from a variety of sources, including: 1) interviews; 2) classroom observations; and 3) reflective entries written by Mr. Maxwell as he participated in the year-round online community.

Eight formal interviews were conducted during the school year as the primary data source. The semistructured interviews included: 1) two sessions, each about 60-min long, conducted at the beginning and the end of the school year and 2) six sessions, each approximately 30-min long, conducted at the end of each unit of the e4usa course. The interview questions prompted Mr. Maxwell to reflect on his experiences, while the semistructured approach allowed the interviewer to probe and deeply explore his lived experiences. The interview questions at the beginning of the school year focused on the PD experience, anticipation of any challenges, and preparations for teaching the new course. The end of the year interview questions centered on overall experience and changes that may have occurred in the teacher's beliefs and perceptions regarding engineering teaching. End of unit interviews probed the teacher for what did and did not go well and any "aha moments" found during the teaching of the unit.

Classroom observations and online reflection entries were used as secondary data sources for two purposes: 1) to further explore the themes identified from the interview data and 2) to verify interpretations and triangulate resulting themes. The lead author visited Mr. Maxwell's classroom eight times between August 2019 and February 2020 and collected detailed field notes regarding classroom setting, teacher actions, interactions with students, and student engagement. Informal interviews also took place after observations to understand Mr. Maxwell's teaching approaches and confirm researcher's interpretations. In-person classroom visits ceased following the disruptions caused by the COVID-19 pandemic. The reflection entries were posted by the teacher on the Canvas Learning Management System as part of participating teacher PL activity. These reflections were in response to questions posted by the project team on the discussion forum throughout the year.

F. Analysis

A variety of approaches can be used for analyzing case study data [51]. This study elected to apply an inductive coding approach that was further broken down into a multi-tiered coding process [54]. First, holistic coding was used on the interview transcripts to grasp basic themes in the data. This involved reading transcripts, inductively identifying underlying themes, and labeling them using the constant comparative method [55]. Identified themes were confirmed or refuted through the triangulation of secondary datasets using an iterative process. Themed chunks of data were further parsed using affective coding methods [54] to understand nuanced and subjective qualities of human experience, such as emotions, conflicts, changes in beliefs, and values. Field notes and reflective entries were continuously used to further interpret data and refine coding.

Members of the research team, including student research assistants, engaged in discussions about the data, interpretations, and resulting themes to ensure trustworthiness [56]. Member checking [53] took place throughout the study during different phases. The lead researcher frequently summarized statements made by the participant during interviews to verify interpretations and emailed the participant during the analysis phase when a clarification was needed. Identified themes were shared with the participant to provide feedback. This manuscript is coauthored with the participating teacher for further credibility.

G. Positionality Statement

The authors of this article include a subset of the overall research team and a teacher associated with e4usa who is also the focus of the case study. The e4usa project invites all schools, teachers, and students to fully participate in the program regardless of their technical background or preparation. This open approach aims to achieve the greater programmatic mission of an inclusive, nationwide precollege engineering curriculum. The authors have a shared and invested interest in the success of the e4usa for all involved.

IV. RESULTS

The analysis resulted in six major themes that depict a non-STEM teacher's journey teaching an introductory engineering course. The themes illustrate that Mr. Maxwell experienced imposter syndrome, numerous challenges, and momentary frustrations. Mr. Maxwell also discovered parallels between music creation and engineering design along the impedimental path that led to joy, excitement, and ultimately a rise in confidence. Mr. Maxwell felt inspired to transfer pedagogical approaches from music classes to the engineering class and experienced a shift in many of his perspectives. The following sections reconstruct Mr. Maxwell's experiences in a somewhat chronological order with embedded participant quotes to collectively answer the research questions.

A. Imposter Syndrome as Engineering Teacher

Mr. Maxwell started the PD with skepticism and apprehension about his abilities to teach an engineering class. He admitted, "I thought that engineering was not fully applicable to me, let alone to any students I would be teaching. Or more appropriately I should say my ability to facilitate a viable educational experience." He was also concerned about the outward assumptions of the school community, particularly parents. He did not have "a reputation for teaching math or science and here [he was] teaching engineering!" He participated in e4usa Summer PD often admitting his discomfort but also showing a willingness to learn.

A day before the school year started, he said, "I am anxious in the sense of I've never facilitated a class like this before." He was concerned that even though his classroom is "pretty cool, it doesn't scream engineering [especially] if you have in your head the stereotype that we're trying to break." The discomfort lingered and the imposter syndrome set in. A month into teaching the course, he posted an update on the community forum which said, "Generally, all is going well (at least no one has figured out that I am making this all up as I go, yet! Kidding! Sort of. Haha!" Two months later his posts still described feelings of inadequacy, including a post that said, "I've been playing a lot with lesson pacing - particularly in Unit 2. If I am being honest, I am doing this mostly because I still feel like I am a bit out of my depth and so a lot of what I am creating for my students is also for me in many ways."

The imposter syndrome prevented him from recognizing and accepting success. He frequently shied away from taking credit stating, "I don't want to jinx anything, and obviously things can change." His school had opened more than a month before some of the other e4usa schools. He often shared lesson plans and activities on the community forum to help other teachers. He confided one day, "I am glad others find this useful, but I am also doing this for myself. It's always nice to know I am not completely off the mark with regard to this sort of thing." As the community discussions ended in Spring 2020, he wrote, "I am truly grateful for this community. The idea exchange is beyond wonderful, and everyone has been so supportive and kind. Far more so than I likely deserve [...] If nothing else it has made all the difference for me to feel confident in my execution of the curriculum." Mr. Maxwell slowly, but steadily overcame his imposter syndrome with every lesson delivered and gained confidence in his abilities to teach engineering content.

B. Discovery of Parallels Between Music and Engineering

Mr. Maxwell's increase in confidence is not simply a matter of practice and experience. He encountered the topic of the engineering design process for the very first time during the e4usa PD, but was pleasantly surprised that "this was exactly the same thing" he implemented in his music classes "if you change just a little bit of the jargon!" The eureka moment inspired him to explore further similarities by engaging in conversations with friends who worked at engineering firms and university faculty associated with e4usa. He went through a deluge of different emotions as he learned about the detailed steps of the engineering design process. This included being overjoyed that the engineering design process and music creation process "were virtually identical!" He was pleased and thrilled for the new journey, while feeling optimistic and excited to continue the quest. He mentioned, "I'm excited like I said, to see the connections [...] I'm excited for those engineering students to be in the facility they're going to be in and start exploring concepts outside of their sense of what engineering is supposed to be."

The parallels he discovered between engineering and music were flabbergasting on two specific fronts: 1) the individual steps involved in creating an engineering artifact or a piece of music and 2) the collaboration component that is required in an engineering design team or a musical symphony. He elaborated, "It is the exact same [process] with musical ideas and concepts. We create music, then we listen to it, we evaluate it and then we take that piece, and we go back to refine it until we are sure it will reach the audience. You could call it the creative and iterative design process for music, if you will." He went on listing collaboration parallels between engineering and symphony during one of the interviews. He explained, "...it's more about the collaborative skill element. The life skill elements stuff. In one case, it is manifesting in the world of music. In another case, it is manifesting in the world of engineering [...] You have a collective goal when you are part of an ensemble musically, you have a collective goal when you are part of a design team. In both cases you have other factors involved that may or may not be out of your control [such as] the quality of your musical instrument. Despite all of my musical ability, and I might be able to compensate, to some extent, but my performance is going to suffer. In the design, it is kind of the same concept if you have, a substandard element, if a member of the ensemble has not practiced their part, you know what I mean. It all kind of relates." He highlighted other similarities, "There's a bigger engineering project that has got multiple projects all around it. You might also have a project manager. So, to me, that is very much like sections of an orchestra. Here is my trumpet section and I'm going to have a lead trumpet player. But the trumpets by themselves, we're not getting an orchestra."

Another pleasant discovery was how the word 'failure' was understood without a negative connotation in the engineering design world. He reflected, "during the PD, we were told right off the bat that it's okay to fail. And I thought, this is it, because I do that all the time in my music classes. Because you cannot have people creating new things under the illusion that they cannot make mistakes." The emphasis on ideation and iteration after failure "blew [his] mind away in terms of similarities." Mr. Maxwell felt invigorated with the discoveries. He was ecstatic talking about the instructional ideas and activities that he had lined up for the engineering class.

C. Increased Confidence to Teach Engineering

Discovering and understanding the parallels between music and engineering enabled Mr. Maxwell to attain the confidence to teach engineering content while bridging the two seemingly disparate subject areas. He explained, "I started in the summer as they are kind of similar. They are pretty close. This is interesting. And now I am like, nope, it is mirror images! Change a couple of words but not changing concepts. It is just that the green button in this piece is the purple button over here. But when you press each button, you essentially are doing the same fundamental tasks. So, if we understand the fundamental task, conceptually, it really shouldn't matter if you're sitting in front of a device that uses the green button or a purple button."

He realized during the PD that "The whole point of this project in some respects is first and foremost to knock that wall down. Not just for me, but for everybody." He explained the transformation, "Once I bought into that, it was really transformative. The idea that the things that you think are limitations are actually benefits and are actually resources." He provided an example; since everyone knows him as "the music guy, they don't know what to expect in [his] engineering class. There are no preconceived notions, which helps."

His approach at the beginning of the semester was to teach the e4usa course "verbatim." He did not feel comfortable deviating from the suggested lesson plans (e.g., dropping or modifying a lesson). The discomfort and uncertainty slowly started fading as evidenced by this post on the community forum. He wrote about Unit 2 lessons: "I am also playing a bit with the notion of assigned teams. Like everything else, we shall see, but I continue to be excited to continue this journey. There are a number of other (small?) deviations I am making from the lessons and those I am posting in the Unit 2 area."

The tone of his reflections on the community forum changed as the year progressed from that of an imposter to someone with growing confidence. When he created lessons to introduce 3-D modeling and TinkerCAD, he wrote on the community forum, "I was rather pleased with the intro I created for this one. It took me quite a bit longer to make than I had anticipated but I found it quite effective overall." The following post at the end of the first quarter further confirmed that Mr. Maxwell had finally started believing in his own abilities to teach an introductory engineering course. He wrote, "Certainly there are a number of things that I will refine and reconsider for upcoming years, but overall things have gone well. I have outlined a lot of the details already, but I do want to just comment that, on balance, after a full quarter, I no longer feel like I am totally out of my depth on this. In fact, I have become quite fascinated by just how many parallels there seem to be between the parameters of this engineering design class and my work with musicians over the years. I am keen to see how I might be able to foster even more direct connections moving forward."

He was quick at the end of the year to attribute the confidence gain to other external factors, such as the support from the e4usa team, the e4usa online community, and the school and district administration. He described, "I'm almost amused at it myself now. But I really suffered from a lack of appropriate understanding of what engineering was myself. And that quickly got remedied, thanks to the e4usa team, most significantly, but the other folks as well. And realizing that my hang ups on credibility, my hang ups on what this class was going to be about or my ability to facilitate it, were because of me. I was looking at it as though I was defining the sky as a car. And then wondering why the sky wasn't driving... I now feel like I have a better understanding of the content."

D. Transfer of Pedagogy From Music to Engineering

The discovery of the parallels between music and engineering enabled Mr. Maxwell to contextualize engineering lessons with examples from the music world. He also leveraged project-based pedagogical elements from his music classes to teach engineering content. For example, to convey how engineering is embedded in everyday lives, his students explored the evolution and engineering behind music listening—from long play records to streaming services. Students participated enthusiastically and did not want the class to end when he explained the concepts of professional ethics and intellectual property with specific examples from the music industry, such as Napster and Spotify.

His engineering class enrolled his music class students as clients and started multiple local context projects related to sound engineering. One team designed a sound-proof glass window that would allow people from outside to see what was happening in the music room without opening the door. Other teams investigated anechoic properties of various materials and conducted experiments using decibel meters. A couple of teams explored solutions to eliminate the small gap underneath the door to prevent external noise that was affecting the recording quality. Field notes confirmed that students liked autonomy, collaboration, and open-ended problems. Mr. Maxwell agreed that "The more advanced engineering by nature is going to differ. But the level one course, the things we're doing, the amount of parallels is just overwhelming."

Mr. Maxwell was asked to describe how, if at all, he leveraged his music teaching experience in his engineering class. He explained, "what I decided to do was I looked at the whole lesson or the whole unit. And I am thinking to myself, okay, what's important here seems to be the idea that they work as a collaborative team more effectively." So he brought in various elements and activities from the music classes to the engineering class. He allowed students to select their own teams in the first quarter. Prior experience had taught him that it takes time for students to build the trust required to really share ideas and feedback among team members. He explained, "I am taking a longer view approach that has worked well in my music work with students. They can self-select, but they have to hold themselves and each other more accountable. There is an important lesson with regard to collaboration in learning that your best friend might be the worst person to collaborate with. And, at least in my experience, it is the kind of lesson that cannot be taught. It has to be experienced."

In the second quarter, he assigned teams based on a survey he often uses with his music students, "which is just a survey of where are you, what are your interests. What have you done?" He implemented a couple of ice-breaking activities he had used in the music class "to just get them talking to each other about different things." It became evident that creating the right environment for the classroom mattered the most. The notion was confirmed during an interview conducted after Unit 4 when Mr. Maxwell said, "I don't personally believe that it has anything to do with the content. I think that has to do with the atmosphere created and the level of buy-in that the individual student is ready to continue to contribute."

E. Challenges

Improved confidence and 22 years of teaching experience did not mean all challenges were alleviated. Navigating the state standards for engineering and preparing students for CAD certification down the road were at times, "… very confusing. And [he] felt like [he] was going to have to reinvent the wheel a little bit." The engineering class was taught as an elective at his school, which meant a mixed group of students from freshman to senior year. This setup was no different from what he regularly experienced in his music classes, but a mixed group of students in the engineering class turned out to be a very different experience. This aspect combined with new content and a larger enrollment made it challenging, "to create a safe space where students feel secure to outwardly personalize their thoughts and ideas." He elaborated, "… it is different. And what has become very clear to me is that the range is way bigger. The maturity level and the prior experience matters a lot more than it did in my music classes."

Lesson pacing was another big challenge. Mr. Maxwell had to manage eight to ten group projects for 38 students in 55 min of class time. Lack of prior engineering teaching experience also made him "feel obligated to try them all, the e4usa lessons, because [he didn't] know what works." In the music class, he could spend an entire class "having an incredibly important viable conversation that [he] did not plan for. Losing that day was a lot easier to make up." It was not as easy to deviate from the planned lessons of the engineering course.

There were other moments of doubts and frustrations throughout the year. He elaborated, "Not so much that I would not be able to continue the class, just in terms of my sense of where the students were and what they could handle as a group overall." There were also irritations related to not knowing "what materials to buy, when to buy them... implementation stuff." These frustrations were not enough to cause him to quit. In his words, "They were not horrible moments, you know, that was a deal breaking moment kind of thing. But, in the moment, it was frustrating. I was frustrated with myself, but I have been around long enough to realize that we did okay, for a first year."

COVID-19-related disruptions added to the frustrations and challenges in the last quarter. The school closed for three weeks and reopened online. Getting students to collaborate and work on team-based design projects became an almost unattainable goal, especially when "things became pass/fail." Among challenges, he experienced an aha moment. He noted, "I obviously still graded things, I still had expectations of the students […] I didn't realize until we hit the COVID closure how much the students were relying on me to motivate them." Inspired and invigorated again, this time for his students, Mr. Maxwell "… started looking at different things to motivate and engage students." He explained, "… we could not do finals as such, [so] I gave them a sort of reflective final project. I asked the kids to take sort of a bit of a self-analysis reflection of the entire year. I asked them things like, tell me of the entire process. What was the process? What was the step in the design process that you struggled the most with? And what was the step in the process you felt the most comfortable with? And why? How do you see engineering relating to your future career goals, or life goals in general?" COVID-19 closures that led to numerous adaptations made Mr. Maxwell realize, "The irony of so much of what happened with the closures, that's just one of several examples where I look at that, and I go, we are going to do that every year."

F. Shift in Perspectives and Approaches

Mr. Maxwell reflected at the end of the school year on his journey through "uncharted waters." He said, "It all comes down to this issue of perception, how far can you open up your ideas? June of last year, the beginning of it, I was pretty freaked out. I was like, I don't think I can do this. I don't know how; I have no clue what I'm going to do. Less than a week [of the PD], and I am like, oh, I could do this. It will be bad, but I will do it. And once I started teaching like I said, breaking down those definitions, all of that kind of went away. I was like, okay, this is going to work. I don't know how but then it just kind of took off."

This is what he tried to teach his students in the engineering class, "How far are you willing to look at a topic that may not directly appeal to you but see if you can find a connection to something else." When asked about specific changes he explained that one of the things he had to change in his teaching approach was the emphasis on professional skills. He clarified, "…the design course, by its very nature are skills that are going to apply very concretely. Your ability to collaborate, your ability to iterate, your ability to analyze; [these] are going to be critical in any field you go into, even if you are a stay-at-home parent. But music education in the traditional sense, does not always push that as a priority. It is always a secondary thing." He explained that he "looked at a lot of the activities, and tried to find where can [he] put in the collaborative moment?" Observations of the second and third quarter classes confirmed that he was de-emphasizing homework, emphasizing collaborative groups, and underlining active participation. He explained that he wanted his students "to get to a situation where they start to really understand what it means to have a team and what a team really is, which takes time and takes some frank conversations and frankly, some failure."

Mr. Maxwell also adapted a more structured teaching style for engineering classes. His music classes were more free flowing (students come and start practicing and playing instruments), but for the engineering lessons, he adopted "a formula, where there's an intro, and then there's instructions, they do something, they reflect on it, either in groups or individually, and then we move on to the next one." Another "good change that came out" from engineering teaching, especially during COVID-19, was the flipped approach. He spelled out, "I was so caught up in the academic, the need to prove myself as being legitimate, that I was doing a lot of like, a lot of the lessons [...] But one of the things with the COVID closure that I realized is I don't need to do all of these in real time. With the students, I could free up, you know, going back to this idea of more hands-on projects and dive in more diverse projects, I got available time to have students exploring more of that if I flip the classroom more."

He said retrospectively that, "I had my hang ups regarding credibility and viability to be the facilitator of this class but now my biggest mantra is embrace not knowing what you don't know. So much of this has opened my eyes to so many things that I never thought were even possible. That has changed my perspectives completely." He further explained how stepping outside of his disciplinary comfort zone has taught him "how you could reach a kid in so many other ways and tie those connections as a facilitator." He said he has also learned that "Attributing music skills as music skills, and we all do that, is a limited view. They are actually applications of the engineering design process. How fascinating!" He was grateful for the transformation and excited for his fraternity of music teachers because, "There has been this struggle for arts teachers to be able to demonstrate the validity of what we do beyond just saying we are teaching cultural awareness, because ultimately, that seems to be what it all gets broken down to, in some variety of form. Now, with this process concept, I am able to show the engineering connection in a very direct way." He had a message for the administrators: "In retrospect, my district basically trusted me, which I'm grateful for. But I think now there is an ability to show that this could be helpful in terms of expanding opportunities for other teachers to do this. At least certainly in my state or even just in my district."

V. Discussion, Implications, and Limitations

The emergent findings of this single case study demonstrate a music teacher's effort to overcome his own and others' assumptions, find connections across music and engineering, and gain confidence to teach engineering content. Results suggested a change in the teacher's STEM/non-STEM understanding and a desire to extend similar opportunities for others. The study expands prior exploratory work [15], [37] and illuminates the potential of non-STEM teachers as a solution that could address the dearth of willing and qualified precollege engineering teachers relative to the demands for the increased number of engineering graduates [5], [11]. Teacher preparation programs are not currently meeting this growing need as few programs are geared toward teaching engineering [58]. The default is to have engineering courses taught by STEM teachers who are often unprepared to advise students about engineering pathways and careers [11]. If we want diverse groups of students to pursue engineering, we also need a diverse group of teachers to teach precollege engineering classes; diversity in this instance includes content areas and experiences. More teachers from all disciplines could be prepared to teach engineering with the appropriate PD and support needed to "knock the walls down" on who can and cannot teach introductory engineering. This study will hopefully encourage more precollege administrators to see the potential of non-STEM teachers in teaching engineering.

Mr. Maxwell's experience with *imposter syndrome* and *increased confidence* following PD can happen to many teachers, including STEM teachers who may be new to teaching or may not be familiar with engineering design concepts [14], [37], [57]. The unique aspects of this case lie in the themes of *discovery of parallels*, *transfer of pedagogy, challenges,* and *shift in perspectives and approaches*. These themes provide insights for other educators and researchers to explore similar connections between engineering design and other content areas. The circumstances at the school created an entry point for Mr. Maxwell, a non-STEM teacher willing to step outside his disciplinary comfort zone. He was able to find connections between music and engineering at multiple levels to seamlessly transfer pedagogy from one to another. Art provides a similar platform as engineering for conjuring creative transformational ideas that play a role in shaping the world [47]. Prior work has shown that there may be different types of creativity (e.g., general, artistic, or scientific) and there are opportunities to exercise and strengthen each type of creativity learned from other domains [41]–[46]. This connection between the arts and engineering likely influenced the emergent findings and may manifest differently for non-STEM teachers outside of the arts.

The results also offer insights regarding the necessary preconditions for bridging non-STEM content areas to engineering. Suggestions for future PD providers include an open, welcoming PD that embraces different content backgrounds, an environment that establishes a safe space for teachers to discuss their imposter syndrome and concerns, and most importantly, an approach that provides teachers with the time and agency to make the curriculum their own and discover the parallels between different content areas. Mr. Maxwell's shared experience highlighted many of the essential supportive ingredients for all teachers to be successful in teaching engineering (e.g., appropriate and sustained PL, a learning community of peers, interactions with practicing engineers and university faculty, one's willingness to step outside their comfort zone of teaching, and supportive administration) [12]. These supportive elements should be paired with local and district administrator support and much needed time to discover the inevitable parallels that exist between a non-STEM teacher's discipline and engineering. These parallels exist for all disciplines, but are not always evident until a teacher is given the opportunity to try (and potentially fail). Overlooking non-STEM teachers would mean missing out on a history teacher's ability to leverage historical events [37] to highlight engineering's impact or an English or drama teacher's insights into effective communication within and outside of an engineering team. Non-STEM teachers could also bring the pedagogical approaches from their subject areas, such as the jigsaw technique, think-pair-share activities, and project-based learning to teach engineering in an engaging manner [37].

This single case research study provides a concrete example for a music teacher and is limited in the extent to which the findings can be generalized both within the discipline of music and beyond to other non-STEM disciplines. The goal of any case study research is not to prove something through aggregation and generalization, rather it is to develop a nuanced view of the reality [50], [51]. The findings are inherently influenced by having taken place in the U.S. and partially during the COVID-19 pandemic. Some results (e.g., encountered challenges) may not transfer to other contexts because of policy and organizational differences. Other results may have been impacted by limited data collection cut off prematurely when the research team could not get permission from the school district in the time needed to observe Mr. Maxwell's online classroom. Other aspects and sociocultural factors also play a role in influencing a non-STEM teacher's experience, including existing social supports, personal identities, and curriculum [8], [20], [27], [36].

It should also be noted that such an undertaking may not be as effective for teachers with less teaching experience and that different themes may emerge with another participant. Mr. Maxwell was able to leverage his 22 years of teaching experience and project-based pedagogical knowledge. Knowledge for teaching is a combination of knowledge domains that includes subject matter content knowledge, curriculum knowledge, pedagogical knowledge, pedagogical content knowledge, and knowledge of educational contexts, learners, purposes, ends, and values [59]. As Shulman [59] suggested, the recognition that teaching is more than just subject matter content knowledge is of the utmost importance.

The identified limitations influence this study, but do not devalue the insights garnered from Mr. Maxwell's experience. This case study shows another "truth," a different perspective from the one commonly accepted [52], [53]. The limited data and results presented are a mere opening to understand some of the experiences of a non-STEM teacher in the engineering education system. Results can be leveraged to inform engineering education programs and PD efforts, so that they consider and include non-STEM teachers. Such a step would create a more welcoming environment, which is more open to recruiting and considering all teachers as possible engineering educators. Research on the topic of non-STEM teachers' experiences teaching STEM content is limited in the extant literature, particularly in precollege engineering education. This study provides a useful contribution to further the understanding of non-STEM teachers' abilities to teach engineering at the secondary level.

VI. Future Work

A. Future Plans of Mr. Maxwell

Mr. Maxwell continued to teach the introductory engineering course during the 2020–2021 academic school year. He was also asked to teach a follow-on course within his school's engineering track. Mr. Maxwell's near-future plans include: 1) making the engineering courses "much more hands on, much more interactive with students experimenting with their own ideas, and going through the design process"; 2) "hitting more variety of engineering disciplines" throughout the year beyond the more common electrical and mechanical engineering; 3) modifying some of the assignments "to have [students] document things more specifically"; and 4) applying for district CTE funds for student projects that could be undertaken to solve local-context problems in and around the school. He also wants his students to improve their general understanding of the engineering design process and what is expected in an engineering report. He has started working with the e4usa team and other teachers to introduce the engineering design process portfolio scoring rubric (EDPPSR) in his engineering class. EDPPSR houses 14 elements of engineering design for reliably evaluating student performance in the underlying knowledge and skill areas [60]. By the time of this writing, Mr. Maxwell has also adapted the EDPPSR for his music classes.

This journey has been about exploring how he might "...merge the engineering content with the creativity concepts he has been working to perfect for years." The challenges of teaching during the COVID-19 pandemic have made him realize that the issues facing students and teachers "...were not rooted in the pandemic at all. The issues were ultimately about engaging students." Engineering content is a crucial subject to teach in high school but is often perceived as dry. He wants to make the engineering education experience not only viable but also engaging to pique students' interests that could "...lead to additional opportunities and careers and college and all these other things."

This undertaking clearly changed Mr. Maxwell's perceptions of engineering and now his plans include a mission to change the perceptions of others. In his words, "If engineering is ultimately about people, which I believe it is, then by definition it is about how people interact, identifying and solving problems, creating not just solutions but advancing life experiences. But it does not happen in a vacuum. The COVID vaccine, for example, required such a massive number of interlocking parts to work together. It was very much like a symphonic ensemble. All those different instruments, played by all those individuals, coming together for a common goal. A piece of music!"

B. Ongoing and Future Research

The e4usa team is in the process of getting Engineering Teacher PD Endorsement [61] from the American Society of Engineering Education and aims to publish the PD materials on the TeachEngineering hub [62]. Future research plans include similar detailed studies [63] with other non-STEM teachers participating in the program to explore the necessary preconditions for transfer across seemingly disparate and unconnected content areas. The intent will be to understand what does and does not transfer and identify key experiences and factors that influence non-STEM teachers' foray into teaching engineering content [35]. Such information could help address the growing challenge in precollege education regarding the scarcity of teachers to teach engineering classes.

The broader e4usa team is working on a case study to explore and compare STEM versus non-STEM teachers' pedagogical content knowledge and implementation of the e4usa course. There are also opportunities to explore bidirectional transfer of knowledge and experiences between arts and engineering domains in higher education focusing on faculty who teach or collaborate in such interdisciplinary spaces.

VII. Conclusion

The challenges of precollege engineering education are multifaceted and need "out-of-the-box" thinking to address often intertwined problems of teacher scarcity, appropriate and sustained teacher PL, and curricular standards [16], [64]. This work represents a unique attempt to explore a music teacher's experiences teaching a high school level introductory engineering course. The results demonstrate a non-STEM teacher's effort to challenge outward assumptions (including his own), find connections across seemingly disparate content areas, and gain confidence to teach engineering content. This case study contributes to the knowledge of evidence-based practices in precollege engineering teaching while informing future PD and educator hiring efforts to broaden the pool of teachers capable of teaching precollege engineering classes. The paucity of trained and willing teachers to teach engineering content will remain a problem in precollege education until focus is placed and efforts are made to empower a diverse group of teachers to teach precollege engineering classes.

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