Blended Implementation of Existing Precollege Engineering Programs: Teacher Perspectives of Program Impact

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***Abstract*—*Contribution:* This work examines the impact of a unique precollege STEM education initiative during its two pilot years. The study contributes to the growing body of research by unpacking the needs of and the impact on an important stakeholder group (i.e., the teachers) in the engineering education ecosystem to help inform the future design and development of teacher professional learning models.**

***Background:* Efforts to provide precollege students with engineering or robotics-specific experiences are on the rise. These efforts are typically undertaken independently of one another. A first-of-its-kind collaboration between two precollege STEM initiatives aimed to break down existing silos between programs and offer a blended engineering and robotics curriculum targeting underserved schools.**

***Research Questions:* 1) How does a program designed to blend two existing engineering and robotics programs at the secondary school level impact teachers? and 2) What program elements are deemed valuable by participating teachers who are implementing a blended engineering and robotics program at the secondary school level?**

***Methodology:* Four focus groups were conducted with teachers ($n = 16$) over a period of two years. Data was analyzed using open coding and constant comparison methods.**

***Findings:* Four themes of growing confidence, exercising agency, responsive professional development, and support structures emerged across the four datasets. Collectively these themes capture pragmatic understandings of offering a new, blended precollege STEM program and advance an argument for the involvement of all stakeholders to support the teachers.**

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

I. Introduction

EFFORTS to provide precollege students with engineering or robotics-specific experiences are on the rise around the world. Such initiatives are typically undertaken independent of one another and are often in competition to garner greater participation. Engineering For Us All (e4usa) and For Inspiration and Recognition of Science and Technology (FIRST) are two such programs originating in the United States (U.S.). e4usa is a nationwide effort consisting of a 30-week curriculum (200 min/week) designed for high-school students to learn and demonstrate engineering principles, skills, and practices through authentic, design-based experiences [1]. The course requires only high-school algebra as a prerequisite. The focus is on the "why" and the "who" of engineering rather than specific technology. The curriculum was piloted during the 2019–2020 school year and is now being implemented within schools across the U.S. and abroad. FIRST is a well-established, global not-for-profit initiative that provides mentor-based, informal learning robotics programs that motivate young people to pursue STEM pathways [2]. Participating schools typically offer the program as an extracurricular option where interested students meet after school approximately 3 times per week for 2 to 3 h each meeting. Both programs are designed with the underlying mission to prepare the next generation to better understand and potentially pursue careers in STEM, particularly engineering. The parallel missions of these two programs provided the impetus for a new partnership, e4usa+FIRST, that began in 2021. The National Science Foundation funded the initiative with the underlying notion of leveraging the collective strengths of each program.

The e4usa+FIRST program aims to expand engineering access to underserved schools and marginalized populations who often miss out on such opportunities due to cost and lack of resources, including qualified teachers. There has been a long persistent and significant educational gap for low-income students, females, and students of color in higher education due in part to these populations often receiving their precollege education from underserved schools [3], [4]. These disparities are further exacerbated in STEM fields, which according to a report from the National Academy of Engineering and National Research Council, has roots in the precollege system where "access and participation will have to be expanded considerably" [5, p. 10]. Numerous other reports have cited the critical need to expand STEM access, equity, and participation of students from diverse backgrounds [6]. Informal learning robotics programs may provide the needed milieu to excite students about STEM and a pathway to STEM careers in underserved schools [7]. Robotics provides opportunities for students to engage in STEM via nondidactic, social, and engaging ways [2], [7].

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Research also suggests that such informal learning programs struggle to sustain relevance and accessibility in underserved communities [3], [8].

The e4usa+FIRST program was initiated as a unique attempt to break down silos between two precollege STEM initiatives and provide students in underserved communities with opportunities to experience engineering and robotics. To achieve this overarching goal, the program has multiple objectives: 1) establish blended e4usa+FIRST models for high schools that have been unable to offer or maintain engineering course(s); 2) prepare teachers and schools to implement a blended model; and 3) connect teachers with multiple support systems (e.g., mentors, university partners, and industry partners) for long term sustainability.

This work presents a case-study of the e4usa+FIRST program. This study is framed to address the following research questions.

1) How does a program designed to blend two existing engineering and robotics programs at the secondary school level impact teachers?
2) What program elements are deemed valuable by participating teachers who are implementing a blended engineering and robotics program at the secondary school level?

Collectively these research questions help to unpack the needs of and the impact on an important stakeholder group (i.e., the teachers) in the engineering education ecosystem to inform the future design and development of professional learning (PL) models. This work also contributes to the growing body of research in precollege engineering education by capturing the pragmatic understandings of our experience blending two precollege STEM offerings.

II. Literature Review

Precollege engineering education has been gaining momentum and recognition all around the world. In the U.S., several trends are driving this advancement, including 1) an ever-increasing need for STEM professionals around the world [9]; 2) low gender, racial, and ethnic diversity in the engineering workforce [10]; 3) a shrinking engineering workforce [11]; 4) shortage of skilled technical workers [10], [11]; and 5) a below average performance by precollege students in science and mathematics [8]. The need for precollege engineering education is clear, but finding ways to integrate such content in an already jam-packed curricula is easier said than done. Any such solutions need to consider two key pieces that include status of existing programs and teacher PL.

A. Relevance and Status of Precollege Engineering and Robotics Programs

There are a number of existing, high-quality, STEM early learning programs that provide precollege students with opportunities to engage in engineering. Many such programs in the U.S. fall under the banner of integrated-STEM following the formal inclusion of engineering design in Next Generation Science Standards (NGSS) [13]. The integrative nature of NGSS was intended to situate the teaching and learning of STEM concepts and practices in engineering design-based pedagogy as a mechanism to promote STEM literacy and to pique student interest in STEM careers [14], [15].

Research on integrated STEM education approaches has been mixed. A well-established body of literature indicates positive impacts of embedding engineering practices and instruction into science curricula [15], [16], [17], while other studies argue that scientific inquiry and engineering design differ in ways of implementation. Attempting to teach engineering practices as part of science curricula compromises students' understanding and appreciation of engineering as a separate field of study [18], [19]. This concern is magnified considering that very few science educators have educational training in engineering [20], [21], [22]. This has led to separate efforts to promote engineering as its own subject in precollege education [23], [24].

One context for engineering education that has seen repeated growth in precollege settings is educational robotics. Educational robotics has its roots in Papert's Constructionist Theory [25], [26], which supports student-centered learning and emphasizes discovery with more tangible objects (e.g., robots) to construct knowledge. Papert's pioneering work gave rise to educational robotics by showing that young kids can learn programming and coding to solve problems [27], [28], [29]. The evolution of robotics education through the availability of new tools for both formal and informal precollege settings has now advanced into applied and tangible educational resources for educators [27], [30], [31]. Educational robotics initiatives have advanced from short term robotics camps and competitions in informal settings to longer term, formal endeavors within state and national curricula (e.g., LEGO Education and Project Lead the Way) [31], [32]. Research on educational robotics has consequentially expanded.

Researchers have focused on better understanding the incremental nature of knowledge construction, goal directed learning, situated knowledge, and procedural knowledge that can occur through educational robotics experiences [33], [34], [35]. Numerous studies have shown that robotics can provide youth with an opportunity to interact with computer science concepts, improve their problem-solving abilities, and enhance their fine-motor skills and hand-eye coordination [33], [36]. Educational robots have been shown to help students reach an understanding that allows them to construct knowledge and enhance their critical thinking skills [37]. Several studies have shown educational robotics catalyzing a significant increase in students' creativity, interest, confidence, and motivation to learn STEM concepts and pursue studies in computer science and engineering [2], [38], [39], [40], [41]. This includes studies that have additionally found educational robotics to be an effective tool for broadening participation and sparking interest for females [41], [42], minorities [43], [44], and other groups that are historically under-represented in STEM fields [45], [46].

The future success of precollege engineering offerings should build upon the foundation that has been provided by integrated-STEM offerings, educational robotics, and other engineering programs. New offerings would benefit from leveraging the collective strengths of these programs, while pairing these programs with effective teacher PL.

B. Engineering Teacher Professional Learning

The longevity and success of precollege engineering education is and will continue to be largely dependent on the preparation of teachers. Precollege educators come to teach engineering from a variety of different backgrounds and starting points. There is no one-size fits all approach to engineering teacher preparation [47], but the need for such opportunities is essential for growth of precollege engineering education [48]. Currently, very few primary and secondary teachers have educational or practical experience with engineering [49]. Engineering-focused courses within teacher preparation programs are limited [50]. Programs that do exist (e.g., minors, concentrations, certificates, and majors) typically integrate engineering into science courses [15], [16], [17]. The limited availability of precollege engineering opportunities and the relative newness of such offerings suggests a heavy reliance on in-service teacher training and professional development (PD) is warranted. It is important to clarify the difference between PD and PL. The term PD is often associated with one-time workshops or seminars, that create knowledge and awareness. PL is a more interactive, sustained effort that encourages teachers to shift practice by applying the learning [51].

PD or PL are essential mechanisms that provide opportunities for teachers to acquire engineering content knowledge, pedagogical content knowledge, and confidence in teaching engineering [52], [53]. A variety of programs exist, including certificate programs and in-service PL experiences. Teachers and schools can also leverage freely available resources like TeachEngineering or opportunities offered by professional organizations. The sum of such offerings has been shown to positively influence teacher self-efficacy toward pedagogical content knowledge, engagement, and disciplinary knowledge [47], [54], [55]. Key to the effectiveness of engineering PL experiences is structure [56], hands-on, real-world experiences [57], and opportunities to collaborate [58]. A challenge associated with any such PL experience is the applicability of the training provided for teaching engineering at different levels and using different program resources. There is a need to better understand how such training can meet the needs of teachers to teach a variety of different topics within the engineering field, including engineering design and robotics.

III. Research Design

An exploratory qualitative research design was selected to understand teacher perspectives of implementing a unique blend of curricular and extracurricular engineering and robotics programs. The qualitative research design with a constructivist epistemology recognizes subjectivism and contextualism [59]. The aim was to uncover insights and construct knowledge from the viewpoint of the teacher participants. This study took place over a period of approximately two years (April 2021 to April 2023) in order to gather rich datasets and better understand the impact of the program on teachers.

A. Blended Program Creation Process

The collaborative effort undertaken between e4usa and FIRST began with a kick-off workshop held virtually over one and a half days [3]. The workshop purposefully invited a variety of stakeholders to collaboratively brainstorm approaches for blending the two programs. The 22 total attendees included engineering teachers ($n = 4$), FIRST team members ($n = 5$), school administrators ($n = 4$), e4usa team members, including university representatives ($n = 5$) and industry representatives/robotics coaches ($n = 4$). Attendees were first divided into homogeneous groups to discuss their stakeholder perspective before being placed in heterogeneous groups tasked with collaboratively developing one to two ideas for how to blend the programs. The heterogeneous groups were asked to capture a general description of the blending, including needed support, required resources, and other logistical considerations. Groups were also asked to describe the strengths of their selected approach in comparison to potential drawbacks [3].

The emergent models from the kick-off workshop were then used to conduct a team design sprint. Design sprints are an intense, "time-boxed" process where user-centered teams map out challenges, explore solutions, pick the best solutions, create a prototype, and test it [60]. The e4usa + FIRST team engaged in 3-h long weekly sessions over a period of two months to inductively identify potential models for blending the programs. An effort was made to identify commonalities across the recommendations, and criteria and constraints listed by each of the heterogeneous groups. The affinity diagram method [61] was used on a Google Jamboard to identify potential blending approaches, logistical challenges, flexible options for teachers, and general recommendations for program implementation. Four blending approaches or models emerged: 1) curricular + extracurricular; 2) co-curricular + extracurricular; 3) sequential curricular; and 4) concurrent curricular.

1) *Curricular + Extracurricular:* The curricular + extracurricular model involves one teacher offering the e4usa curriculum in the classroom and the same teacher or a second teacher offering FIRST robotics as an extracurricular opportunity for students. This model leans on the initial intentions of the two programs. The blending component occurs when a single or multiple teachers ensure coverage of cross-cutting program concepts and synergistic activities across offerings. A co-teaching approach could take a variety of forms, including parallel teaching, alternating engineering, and robotics concepts, or separate facilitation.
2) *Co-Curricular + Extracurricular:* The co-curricular + extracurricular model involves teaching both engineering and robotics as a formal, curricular activity and establishing a school robotics team for participation in robotics competition as an extracurricular option for interested students. This model would provide basic

robotics knowledge to all students enrolled in the engineering course.
3) *Sequential Curricular:* The sequential curricular approach requires schools to offer two separate courses: a) engineering, and b) robotics. The courses would be designed to be taken in sequence. The two courses could be taught over two years or split across the first and second half of the school year.
4) *Concurrent Curricular:* The concurrent curricular approach entails embedding robotics content into engineering lessons and teaching them concurrently in the classroom. The model would provide freedom to the teachers to decide how to embed robotics into the e4usa units.

Workshop data revealed numerous other aspects of the program implementation that should be considered regardless of the blended model. These aspects include: 1) resources (fabrication tools, dedicated space for engineering and robotics activities, materials handling, storage for materials, trained volunteers/mentors, and travel funds for robotics competitions); 2) logistics (scheduling and timings of the classes, number of students relative to the available robotics kits, transportation for after school activities, mentor engagement platforms, and potential fundraising); 3) instructional practices (identifying overarching skills between both programs, differentiating between robotics and engineering, embedding game elements throughout the engineering curriculum, organizing guest lectures with industry mentors, and selecting engineering design projects that align with the robotics competition theme); 4) potential pitfalls (students and teachers should not equate robotics with engineering, use of different terminologies across the activities of the two programs, and emphasis on competitions); and 5) flexible options for teachers (student enrollment process, setting prerequisites for enrollment, assessments, budget management, and stakeholder partnerships).

Workshop attendees expressed concerns regarding the participation of student teams in robotics competitions at district and national levels because potential losses and failures, especially for entry-level e4usa+FIRST teams and teachers with no prior experience in robotics, could negatively impact students' STEM identities and even dissuade them from considering engineering pathways. A few related suggestions included, developing a growth mindset [62] among students and teachers, creating a better scaffolded "on-ramp" for incipient teams, such as inviting them to observe the district-/national-level FIRST competitions, competing within the class, or competing with other e4usa+FIRST teams.

The overarching work conducted across the kick-off workshop and design sprints was used as a foundation to form the structure for the program's yearlong teacher PL, which includes a summer PD workshop, year-round community of practice (CoP) with monthly online gatherings, and a winter PD workshop. These organized efforts are supplemented with support from the project team, experienced teachers identified as coaches, and local university and/or industry liaisons.

TABLE I
PARTICIPANTS' PROFILE

Category	Year 1 teachers	Year 2 teachers
Gender		
Male	7	6
Female	3	4
Race/ethnicity		
White	8	7
Black/African American	1	1
Hispanic	1	1
Mixed Race	0	1
Teaching experience		
0-2	2	0
3-5	1	1
6-10	2	4
>10	5	5
Engineering teaching experience		
0	2	1
1-2	5	6
3-5	0	0
>5	3	3
Robotics experience		
0	5	2
1-2	3	3
3-5	2	4
>5	0	1

B. Participants

The study involved 16 secondary school teachers who were recruited through a nationwide open call and participated in the e4usa + FIRST program from 2021 to 2022 and from 2022 to 2023 academic years. Each cohort included ten teachers with four returning teachers in the second year [Table I]. They were teaching in public, or charter high-schools spread across the U.S. in the states and territories of Arizona, California, Florida, Indiana, Kentucky, New Hampshire, New Mexico, Tennessee, Virginia, and U.S. Virgin Islands. Their teaching experience ranged from 1 to 26 years, with an average of 11 years. Participants reported a wide range of exposure and experience teaching engineering (0 to 10 years) and robotics (0 to 8 years). Their robotics experiences included exposure either as a college student, coaching as a parent, or conducting a robotics club but with another robotics program.

C. Teacher Professional Learning

All teachers engaged in a variety of PD and CoP sessions as part of PL to prepare and support their efforts in the program. Teachers first attended a two and a half weeklong, virtual summer PD workshop. The PD focused on 1) FIRST training; 2) e4usa PD; and 3) sessions focused on the blending of the two programs and implementation. These three sets of activities built upon each other to enable and empower teachers to identify and ultimately offer a blended model at their schools. Teachers had complete autonomy to select, adapt, or change the proposed models.

Monthly CoP sessions were used to provide updates, discuss implementation, and share experiences. Programming knowledge was identified as a key area of emphasis and became a primary topic of discussion during these sessions. Additional support in the form of an on-demand helpline and project team office hours were set up to scaffold teacher learning of programming.

Teachers requested and were invited to engage in a 1.5 day, in-person winter PD workshop. The workshop focused primarily on programming and integrating such content within the engineering curriculum. Time was taken to reflect on successes and challenges as teachers entered the second half of the academic year.

Additional support was provided and has varied across the two years based on available resources. All teachers received support from project team members as needed. Teachers in the first cohort were provided with a helpline led by one of the FIRST state leaders, which was converted to team-led office hours for the second cohort. Teachers in the second cohort were provided with a coach who was an experienced teacher from the first cohort. Coaches received additional PD specific to being a coach alongside an abridged returning teacher summer PD workshop. Each teacher was also assigned a liaison who is a local university faculty member or industry employee. The sum of these experiences provided the overall context for teacher PL in the blended program.

D. Data Collection

Data sources included semi-structured focus groups (FGs) conducted each year during the summer and winter PD sessions. The 60-min long FGs resulted in four datasets.

1) *Summer 2021:* Nine teachers were divided into two groups of five and four for an online FG discussion.
2) *Winter 2021:* Six teachers participated in a single FG where all but one joined in-person.
3) *Summer 2022:* Seven teachers were divided into two groups of four and three for an online FG.
4) *Winter 2022:* Ten teachers were divided into two groups of five for a hybrid FG (eight teachers joined in-person).

FG questions attempted to unpack teachers' confidence in teaching the blended curricula, their needs, and any challenges encountered implementing the blended models. Four primary questions guided all FGs with additional questions prompted by participant responses.

1) What is the current level of confidence you are feeling toward your ability to teach the e4usa + FIRST curriculum?
2) What is positively/negatively influencing your confidence?
3) What aspects of the program have been most exciting/challenging for you as the teacher?
4) What recommendations do you have to improve the overall teacher experience in the program?

E. Data Analysis

Transcribed data sets were entered into Dedoose, an online tool for qualitative analysis. Two members of the research team used open coding and the constant comparative method [63] to analyze data. First, the Summer 2021 transcripts were coded individually by the two researchers. The two coders then met with an additional member to review emergent codes and resolve any discrepancies. One of the researchers then analyzed new transcripts as they were added to the dataset. Analysis followed the same process of open coding and constant comparison. The data was repeatedly compared with the previous data to use existing codes or create new codes as necessary [63]. The iterative process of reading and coding continued with each dataset. Two researchers met again to organize the open codes into similar categories and create axial codes in alignment with the research questions [64]. Finally, categories were compared to identify four themes pertaining to the research questions.

Several measures were taken to ensure robust qualitative research [65], [66]. A code book was developed to maintain consistent coding [64]. Member checking was used to verify interpretations [67]. For example, participants were contacted by email seeking clarifications during the analysis phase. The research team engaged in several discussions about the data and meaning of the resulting themes. These discussions helped the lead author make meaning of relevant outcomes in relation to the research questions.

IV. Results and Discussion

Four themes—*teacher confidence, teacher agency, responsive PD*, and *support structures*—emerged across the four datasets [Table II]. These themes are described in the next two subsections organized by the research questions. Participant quotations are embedded in the narrative with the FG information for contextual understanding.

A. Impact on Teachers

Teachers are the direct participants and key stakeholders in any new precollege offering. One of the goals of this research was to understand the program-level impact on the teachers to identify areas for improvement. This section answers the first research question: *How does a program designed to blend two existing engineering and robotics programs at the secondary school level impact teachers?* Two emergent themes of *growing confidence* and *exercising agency* capture the impact of the program on teachers.

1) Growing Confidence: The theme of growing confidence depicts collectively all teachers' journey in the e4usa+FIRST program—how the teachers embraced the blended offering, what challenges they encountered, the variability in their confidence, and the overall resulting impact. Teachers voluntarily joined the program but were all initially apprehensive about their abilities to teach the e4usa+FIRST curriculum. This feeling was aptly caught by one teacher stating, *"Oh, my confidence has definitely been on a roller coaster since the beginning of training. Some of the stuff we learned about FIRST makes me a little anxious"* [Winter_2022 FG]. Some

TABLE II
SUMMARY OF FINDINGS

Theme	Definition	Sample codes	Illustrative quote
RQ 1: Impact on teachers			
Growing confidence	Gradual rise in feeling assured to teach the blended program	Discussing ways to blend curriculum, prior engineering experience, lack of confidence, growth in confidence	"I think we're in pretty good shape, as far as my confidence and being able to do that and still a little shaky on some programming and those types of things."
Exercising agency	Constructing own plans of curriculum implementation through the choices and actions within the opportunities and constraints offered by the program	Plans to blend robotics, teacher agency, competition participation, integrated implementation	"I want to branch out and get some manufacturing piece involved. And that's what I want to bring into robotics. That's the piece that I want to introduce students."
RQ 2: Valuable program elements			
Responsive PD	PD organized around teacher needs and requests	New technology, in-person sessions, help with coding, PD found helpful	"This is the best PD I've ever been to […] I feel like [this PD] will make us more apt to reach out to one another, when we do need help."
Support mechanisms	Elements within the program structure and beyond that were deemed conducive	Support from the project team, school administration, university liaisons, coaches, peer group, community of practice	"I've got so much help and so much support and so much community that it's gonna be good. It's gonna be good."

also noted being, *"⋯ nervous that two programs all in one year may be a little much since I'm so new at this on my second year in STEM"* [Summer_2021 FG]. This general apprehension was primarily because seven teachers had no prior experience with robotics and three teachers had never taught engineering. Teachers who did not have robotics experience seemed to rely on their engineering teaching experience to carry out the new responsibility. A teacher stated, *"⋯ but I'm trying to rely on my previous experience in engineering, which has helped me tremendously"* [Summer_2021 FG]. Those with no prior experience in either engineering or robotics ($n = 2$) depended heavily on the PD provided by the program.

It became apparent that not knowing coding and programming was creating another barrier for teachers to feel fully confident, *"I mean the first time I ever saw block coding was when [THE ROBOTICS TRAINER] showed us how to open that, and I was like. And then they were like alright so write a code and I was like 'Oh, excuse me. I do not know what you're talking about.*" [Winter_2021 FG]. Additional contributors that seemed to negatively influence confidence included not knowing the pacing of the blended course, what materials to order, and not having a peer group of engineering/robotics teachers in their school or district.

Despite conveying less confidence, participants were *"excited about doing the blending"* because they saw value in teaching robotics and programming to the students, "*So what I have seen, most of the kids, they love engineering because they make things, they modify things like that. So that's kind of an easier part for them. Programming is slightly difficult. So connecting those two is important for one reason — engineering does not work without coding. Now every engineer has to know some programming[⋯]So it will take a little bit of effort to incorporate coding into engineering. But as a teacher, if I try, it'll work*" [Summer_2022 FG]. Some were excited that the engineering and robotics projects would develop professional skills of teamwork and problem solving for their students. Others were thrilled that participation would increase resources for students who did not have access previously, including access to materials and hands-on experiences.

A gradual increase in confidence was observed following the winter PD sessions. For example, a teacher commented, and others agreed: *"I feel like right in the middle, not high not low, I agree that this PD has been my positive influence on confidence. My negative is that I didn't start the year knowing what I know now. So I feel that next year will be even better because I will be starting out with this and having even more of a place to grow from so that will be good"* [Winter _2021 FG]. Other elements that contributed positively to teacher confidence included the year-round CoP and various opportunities to discuss and learn ways to blend curriculum through collaborative activities during the PD. The PD lessons and activities were "*helpful especially in understanding new concepts like FIRST*" [Winter 2021 FG].

The growth in confidence was linked not only to teachers' engagement in PL activities but also to their duration of PL experience and involvement in blended implementation of the curriculum. Those who continued their second year with the e4usa+FIRST expressed increased confidence and a desire to continue teaching the blended curriculum year after year, "*So you kind of learn in that curriculum of the first year, and then you kind of know where you are and where you're going. The second year, I say, trying to figure out what's happening first, and then so this year is okay. I kind of know what I need to do. Of course, this year will speak to next year right?*" [Summer_2022 FG]. This association between confidence growth and years of experience working with blended implementation emphasizes the importance of accumulated expertise in fostering this confidence.

Precollege engineering teaching is a relatively new endeavor for educators. STEM teachers are often unprepared to teach engineering as teacher preparation programs are not currently designed to include engineering teaching methods [50], [68]. Numerous studies suggest that internal (i.e., beliefs, confidence, self-efficacy, and knowledge) and external (i.e., technology resources and support) factors influence engineering technology adoption and confidence to integrate it in instructional practices [69], [70]. These factors take greater meaning when very few teachers have training in building and using robots [70], [71], [72]. A growing body of precollege education literature suggests that many science or math teachers display lesser confidence in teaching engineering/robotics despite long years of teaching experience because of the distinct nature of science and engineering [18], [21], [57], [73], [74]. These researchers contend that providing engineering-focused PD experiences is a necessary first step to build teacher confidence [74], [75].

The overall confidence growth in teaching engineering among our participants suggests that more teachers from a variety of disciplines could be trained to teach engineering with the appropriate PL and support structures. Preliminary work emerging from the current project has shown that appropriate PL combined with social support can lead to an increase in confidence across all teachers, including experienced STEM teachers and non-STEM teachers [50], [76].

2) Exercising Agency: Another impact was teachers learning to exercise their agency. The concept of agency has been defined with respect to structures, discourses, and power in social sciences literature both at the organizational and individual level [77], [78], [79]. In accordance with the definition of Shanahan and Elder [80], we operationalize agency at the level of the individual as the ability to formulate and pursue plans. Exercising such individual agency requires applied and active effort drawing on personal strengths to achieve a planned goal [81].

The e4usa+FIRST offered numerous flexible adaptation options for teachers. Some examples included choosing their own ways to blend engineering and robotics, offering extracurricular or curricular robotics activities, enrollment of students, choosing what materials and equipment to buy, and deciding to participate (or not) in FIRST competitions. These flexible adaptation options became enablers for the teachers to exercise and demonstrate agency. Agency in this context translated as the teachers' ability to construct their own plans of implementing the curriculum within the opportunities offered by the program while also keeping within the constraints of the district standards, school policies, and program limitations (e.g., budget). The following quotation captures how one teacher selected and acted on his plan, *"In my classroom, I mean, I have to dedicate two class periods a day. So the first class is the introduction in engineering. So I'll do the e4usa curriculum first. And in the second-class period, I'll be interweaving the concepts of the FIRST into it"* [Summer_2021 FG]. Many welcomed the flexibility regarding robotics competition participation and exercised their agency during the school year, *"Not going to really expect to do any competitions. I hope to be able to go to a couple competitions and kind of be a spectator and see what I can introduce the students to give them that experience"* [Winter_2021 FG].

Providing an opportunity to select and implement their choice of a blended model and the flexibility to adapt and use a completely different model next year created favorable conditions for exercising agency, *"so the way he's doing that it's really interesting. I love the way he's trying. And I'm really hoping to see next to see how that works is doing the FIRST first. So right now I'm doing it second after the e4usa making e4usa kind of as a prerequisite sort of. But the robotics is going to give you more freedom to do the things you want, and bring down just what you want to do, and then setting yourself up for what's coming in engineering"* [Winterr_2022 FG].

Literature [82], [83], [84] on teacher agency points to two critical understandings: 1) flexible conditions and structures give teachers more agency and consequently better engagement in their own PD, and 2) agency empowers teachers to support the growth and learning of their students. The quotation above suggests that the teacher was thinking about exercising agency and changing the sequence of engineering and robotics lessons considering the engagement, learning, and growth of their students. Overall, the flexibility offered under the program helped teachers overcome self-limiting plans, take risks, gain agency, and learn through the experience as captured by the following statement: "*And I know, this is a pilot stage, and we all kind of working together on this. And I think that's what's going to help us grow is seeing what's working, see what's not, see what we can change"* [Winter_2022 FG].

B. Valuable Program Elements

This section answers the second research question: *What program elements are deemed valuable by the teachers who are implementing a blended engineering and robotics program at the secondary school level?* Specifically, two emergent themes of *responsive PD* and *support mechanisms* collectively depict structures that could be put in place to support teachers as they develop knowledge and implement the curriculum.

1) Responsive PD: During the Summer2021_FG, teachers expressed concerns regarding the FIRST training. While some felt overwhelmed with the information presented, others expressed concerns regarding the assumption during the PD that they already had foundational knowledge for robotics. Teachers were not prepared for the technology introduced during the PD, specifically with coding and robotics, "*I think also, some of the, I guess, all the technology that they wanted us to use was a little challenging, because some of the stuff, you know, it, I tried, I couldn't figure out anything on it. And, and I asked the question, do we have to use it? They, said, well, we'll want you to, but to figure it out on your own. That's the impression I got. But, you know, I think all the technology that was introduced were good. But, you know, we all get so overwhelmed with technology*" [Summer_2021 FG]. Learning to put together a robot over an online session added to the difficulty and a suggestion was made to host an in-person PD during the winter break, focused specifically on programming and coding. The project team quickly arranged for in-person PD sessions (Winter_2021 and Winter_2022) that aligned with teacher requests.

The responsive PD sessions and activities were perceived as highly valuable and impactful by the majority of the teachers. One such activity was the co-planning of an engineering lesson that included robotics information/activity. Collaboratively discussing ways to blend the two curricula was a valuable experience, *"I thought the aspects of PD that were probably the most helpful were the days that we ran through some of the lesson planning activities. For example, [it] gave me a pretty good idea of how it would work in an actual classroom"* [Summer_2022 FG]. Likewise, coding sessions conducted during the winter PD were well received as teachers felt that they learned what they asked for and the teaching and learning took place at a pace they were comfortable with. In-person participation added to the overall experience. Teachers welcomed the opportunities to gather different perspectives, discuss, and learn from one another. A teacher stated, "*This was actually a very good opportunity for me to kind of meet people that I normally only see over the screen and I feel like I gleaned a lot just from their experiences are things that they had like we do this in our class we do this, and you can do that on a you can do that on a screen but it's not it's not the same*" [Winter_2022 FG].

The concept of responsive teaching is not new but rarely gets used in the PL context [85]. A responsive teaching approach focuses on foregrounding the learner's reasoning and tailoring instruction in response to student thinking [86], [87]. Just as teachers need to use responsive pedagogy, PD developers and teacher educators need to use responsive approaches to support teachers. The dynamic nature of a responsive PD requires flexibility on the part of the PD developers but leads to enhanced engagement and equitable participation while maintaining content-specific rigor [86], [88]. Watkins et al.'s [85] study has shown that a responsive approach not only supports individual needs and inquiry but also the collective needs of the group. The e4usa+FIRST responsive PD sessions were a unique experience for the teachers and were highly appreciated.

2) Support Structures: Teachers identified multiple other program elements besides the responsive PD as valuable and effective in providing support. These included the year-round CoP and the support from the school administration, university liaisons, coaches, the project team, and the community partners.

Most teachers reported their school administration to be highly supportive and willing to help teachers in their endeavors to implement the blended program. As an example, a teacher stated, "*It's been pretty great. They're very supportive about that, like the robotics, competitions, and stuff, is something that the students want and the school is promoting to the students like, hey, this is available for you like we're completely supportive of this"* [Winter_2022 FG]. Significant aspects of school support included willingness to assist and foster program partnership, active involvement in the project activities, and recognition of students' needs and opportunities. In a few cases administration arranged for the school technology support personnel to help with engineering or robotics technology and assist teachers during class time.

A couple of teachers also acknowledged challenges with support from their schools and district administration and expressed frustration regarding the district administration's limited vision and understanding of the potential benefits of the program. For example, a teacher reported, that *"my administration, you know really didn't get on board like you think [they] would."*. She continued, *"[it] was very frustrating as a teacher when I you know I saw potential of the program, it didn't seem like my administration do so"* [Winter_2021 FG].

Another supportive element recognized by the teachers was university liaisons. Many teachers expressed appreciation for the support provided by their local university liaisons in terms of communication, sourcing of engineering projects, provision of field trips, and liaison's visits to the classrooms. Partnerships with universities brought exciting opportunities for students, such as visiting college campuses and interacting with graduate students. Teachers received additional mentorship from the liaisons. One teacher explained the significance of his students' interaction with university graduate students and its impact on their motivation and learning in the following words: *"We're going to have freshmen and maybe some sophomores and a few juniors and seniors. So for them to be on a college campus, getting to see the lab and the work that people are doing in their own backyard is going to be really fun. That has me the most excited, I think. And then just being able to have the graduate students come in and visit and talk to our students and be in the classroom and maybe even help out in some of the projects and the assignments is going to be also great because then our kids are getting that direct mentorship from someone within their age group. That's pretty close proximity and understands what it's like to be in high school"* [Winter_2021 FG].

Likewise, teachers expressed appreciation for personalized attention from the project team and acknowledged that their involvement and support in the classroom has a positive impact on their students' learning. One teacher specifically mentioned that the team's weekly visit and presence in the classroom is greatly appreciated by the students. She further explained that this involvement and interest in students' learning beyond regular teacher-student dynamics is seen as making a significant difference. She stated, *"I have [project team member name 1] and [project team member name 2], and they are amazing as they come once a week. The kids absolutely love it, and I think that makes a difference when somebody actually takes interest in their [students] learning other than me [teacher], because I'm their teacher like you gotta do this. He [team member] comes in. They love it"* [Winter_2022 FG]. Discussions revealed that teachers valued compassion, responsiveness, clarity in communication, and guidance provided by the project team. Teachers also highlighted the understanding and flexibility displayed by the team for meeting schedules.

The presence of the coaches in the program provided a sense of reassurance to teachers knowing they had a dedicated person to turn to for guidance and support.

Teachers specifically mentioned coaches' supportive nature and availability emphasizing the positive impact on their involvement. Teachers also had a very positive view of the CoP and peer group support. They viewed networking with other teachers and professionals from various backgrounds, schools, and regions as an opportunity to enhance collaborations on the professional front. Teachers expressed gratitude for the strong support received from the broader community partners, such as engineers and technology experts. The involvement of community partners played a crucial role in facilitating students' learning process, boosted student engagement, and fostered a sense of accomplishment tackling local community projects. In a few cases such collaborations even extended to students' involvement with knowledgeable students assisting the teacher and the peers in programming and technology related tasks as expressed by one teacher, *"I have a student who completely knows it, [Python programming] so he's helping me with teaching the other students in the club. and then the tech guy is getting associated with it, too. He's super excited so like program wise he's helping me figure out because all the students have iPads"* [Winter_2022 FG].

The findings underscore the significance of support structures in ensuring teachers feel backed and capable of overcoming any obstacles that may arise during their participation in the project activities. A strong support system reinforces a collaborative and conducive environment for teachers, ultimately enhancing the educational experience for students and opportunities for all involved [74], [74]. The CoP brought together teachers, university educators, practicing engineers, and community partners who possess different backgrounds and experiences. The monthly CoP sessions provided diverse engineering perspectives and insights for teachers with limited engineering experience [89], [90]. The research team learned that the presence of coaches created a comfort level for novice teachers. Adopting the train-the-trainer model [91] and preparing experienced teachers to work as mentors/coaches is equally important as providing engineering PL to novice teachers.

Most importantly, the success of educational initiatives greatly relies on the support provided by the school and district administration. Multiple reports have emphasized the need to include engineering in precollege education [5], [92], [93]. These calls have not translated into a lot of action by districts and schools to incorporate engineering as a core subject in existing curricula [94], [95]. The pace of change has been slow, and the blame cannot be fully placed on districts and schools. Many programs and models have been developed to facilitate precollege STEM education. This has muddied the waters and made it difficult for schools to navigate available offerings [95], [96]. It is about time the engineering education community adopted a cohesive precollege engineering curriculum in alignment with state requirements rather than the piecemeal utilization of different engineering activities. The *Framework for P-12 Engineering Learning* [24] may be the needed foundational step toward future standardization efforts of engineering-specific education [23].

V. Limitations, Future Work, and Implications

The study used a purposeful sample of secondary school teachers recruited as part of the e4usa+FIRST program. We aimed for this study to be exploratory in nature, given the singularity of the attempt to break down silos between two precollege STEM initiatives. Generalizability is a limitation of such exploratory, qualitative inquiry [59]. Another participant group having different backgrounds or different school settings could yield different results. Though some of the teachers did not have any engineering or robotics experience, many of them had five or more years of teaching experience. Such an undertaking may not be as effective for teachers with less teaching experience. State or national standards could also affect the school level engineering and robotics offerings and implementation. Robotics programs besides FIRST (e.g., VEX Robotics or Botball) are available, and each has differing levels of impact.

All teachers have in some way offered robotics content to their students in addition to the e4usa course over the course of the two years of this study. Each teacher has had their successes and challenges as they have engaged in this program. Most of the challenges faced were related to two unforeseen issues post COVID-19: 1) supply chain issues made it difficult to procure additional robotics kits and materials, and 2) COVID-19 related student absences resulting in recruitment challenges and inconsistent participation. A virtual robotics offering was provided and leveraged by some teachers. Affective factors, such as the school administration's support, are also crucial to the curricular and extracurricular activities of the program.

This collaborative effort has also provided opportunities for the two programs to learn from one another. One of the impacts in the pilot year of this project is to recalibrate expectations around the challenges facing engineering education and robotics clubs in underserved communities. For example, participation in robotics competitions assumes a baseline that does not exist in all communities. Many readily available resources, training, and support assume a level of familiarity with engineering or robotics basics. Our experiences working closely with teachers in under-resourced communities illuminated the common misconception that all students grow up exposed to tools at home. Many students have had little prior experience with simple tools like screwdrivers, hex wrenches, or nut drivers. Only two teachers were able to get their students to participate in a FIRST competition. Nine teachers have indicated their desire to register for a competition next year.

A major barrier is the cost of robotics kits, which are priced out of reach for underserved schools, regardless of the program. Additionally, the support available is often lacking. Such insights have prompted a rethinking of the support elements, and lower-cost robotics kits with better scaffolding for entry level programs at the high-school level. One result was the creation of the eXperiential Robotics Platform (XRP) in collaboration with Worcester Polytechnic Institute and FIRST. The XRP team has developed cost-efficient robotics kits that have drastically reduced the cost to engage in robotics education. e4usa+FIRST teachers were able to buy a kit for each student in their classrooms. The kits are designed to operate with simple, tool-free assembly and perform basic tasks. The replacement parts are easily 3-D printed. The platform also provides online programming lessons for teachers and students using open-source software.

This collaboration made it clear that there are opportunities to combine classroom-based (i.e., engineering) and extracurricular (e.g., robotics) learning experiences more effectively. The project team has started exploring business model innovations as part of this effort to address the future scalability, sustainability, and overall reach of collaborations with universities and industry. This includes identifying sustainable funding opportunities for schools and partnering with the local community. One potential model under consideration is local corporate sponsorship of individual teams. This model was pioneered by secondary school athletics teams and is well aligned with the scale of local charitable giving. There is an added benefit of developing relationships between community employers and the education system.

The PI team continues to gather implementation data and evolve the blended program models. Student FGs were conducted at the end of each academic year and data is being analyzed [97]. Future plans include another manuscript detailing how the students are impacted. Overall, this study provides pragmatic understanding regarding working with secondary school teachers on new STEM initiatives. Findings could inform the future design and development of teacher PL models. The study also has the potential to help future investigators who are interested in examining cross-cutting programs. The e4usa+FIRST initiative impacts precollege STEM education's perspective on what is possible when programs collaborate toward a shared mission. Implications also encase the future motivation and design of precollege STEM education and outreach programs that provide reinforced engineering learning and pathways leading to engineering careers for a diverse population.

VI. Closing Thoughts

A major goal of e4usa+FIRST is to implement blended e4usa and FIRST programs targeting underserved high schools that have been unable to offer or maintain engineering offerings. Blended implementation models were developed, and a complementary PL was provided to the teachers to bring curricular and/or extracurricular opportunities for students in underserved communities to experience engineering. This study explored the impact of the initiative on teachers and their needs in terms of effective program elements and support structures.

Important lessons learned from this work include: 1) avoiding the assumption that all teachers who express interest and engage in the program bring some form of prerequisite engineering or programming knowledge; 2) starting with an informed sense of specific barriers (e.g., prohibitive costs, teacher understanding of programming file systems, and school IT infrastructure and policies); 3) providing teachers with the scaffolding (e.g., basic engineering knowledge as well as programming concepts) to comfortably deliver content at a pace that makes sense for them; 4) creating and providing spaces (e.g., CoP) where teachers can freely share their challenges and learn from peers; 5) providing support structures (e.g., helpline, office hours, and connections with local experts from universities, industry, or professional societies) and resources (e.g., troubleshooting guide to resolve easy to fix hardware/software issues); and 6) engaging teachers through occasional in-person PD that provides collaborative practice time for a subset of relevant content.

The findings advance an argument for the involvement of all stakeholders (e.g., school administration, university liaisons, and community partners) to create an ecosystem at the precollege level to excite youth and broaden participation in engineering education. Engineering is not a core component of precollege education in the U.S.. The challenges of precollege engineering education are multifaceted and need "out-of-the-box" thinking. Investigating models to embed engineering-related opportunities more readily for all must be prioritized in precollege education. Schools do not necessarily need to choose one program or model. This project demonstrates that such programs can be blended if there is a shared vision and mission to ensure that all students learn. The importance of precollege engineering education will only continue to expand as technologies continue to advance. Now more than ever, e4usa+FIRST and similar precollege efforts represent an important contribution in developing a more diverse future STEM workforce.

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