Collaboration Instead of Competition: Blending Existing Pre-College Engineering Programs for Greater Impact

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Abstract*— This Innovative Practice Work-in-Progress paper aims to capture a unique attempt to break down silos between two pre-college STEM initiatives. A myriad of programs has emerged to provide pre-college students with engineering or robotics experiences. Such initiatives are typically undertaken independent of one another. Engineering For Us All (e4usa) and For Inspiration and Recognition of Science and Technology (FIRST) are two such programs designed to excite youth about STEM careers, specifically engineering. One provides a classroom experience, while the other is primarily extracurricular, affording informal learning experiences. The parallel missions of these two programs provided the impetus for a new partnership, e4usa+FIRST, to leverage the collective strengths of each program and expand engineering access to underserved schools. A workshop was conducted that brought together a variety of stakeholders to explore numerous approaches of blending the two programs. This paper details the design of the workshop and the five emergent blending models. The results advance an argument for the involvement of all stakeholders to create an ecosystem at the pre-college level to broaden participation in engineering education. The study has the potential to impact future motivation and design of pre-college STEM education and outreach programs.

Keywords—pre-college preparation

I. Introduction

There are a variety of programs offered around the world to provide pre-college students with engineering or robotics experiences. 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 (US) designed to prepare the next generation to be more appreciative, knowledgeable, and equipped to understand and potentially pursue careers in STEM, particularly engineering. *e4usa* is a nationwide effort consisting of a 30-week curriculum (200 minutes/week) designed for high school students to learn and demonstrate engineering principles, skills, and practices through authentic, design-based experiences. It requires only high school algebra as a prerequisite. The focus is on the 'why' and the 'who' of engineering rather than technology. The curriculum was piloted during the 2019-20 school year and is now being implemented within 50+ schools across the US. FIRST is a well-established, not-for-profit initiative that provides mentor-based, informal learning robotics programs that motivate young people to pursue STEM pathways [1]. Participating schools offer the program as an extracurricular option where interested students typically meet afterschool, 3 times per week for 2-3 hours each meeting. 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 and expanding engineering access to underserved schools and marginalized populations.

The focus on underserved schools and marginalized populations stems from the fact that there has been a long persistent and significant educational gap for low-income students, females, and students of color in higher education. These disparities are further exacerbated in STEM fields. According to Katehi, Pearson, and Feder [2], the lack of diversity present in higher education has its roots in the K-12 system, where "access and participation will have to be expanded considerably" [p. 10]. Numerous other reports have cited the critical need to expand STEM access, equity, and participation of students from diverse backgrounds [3]. But *how do educators inspire these students to discover STEM education and careers as their calling*? Informal learning robotics programs may provide the needed milieu to excite students about STEM and a pathway to STEM careers in underserved schools [4]. Robotics provides opportunities for students to engage in STEM via non-didactic, social, and engaging ways [1, 4]. Research also suggests that such informal learning programs struggle to sustain relevance and accessibility in underserved communities [5].

This Innovative Practice Work-in-Progress paper aims to capture a unique attempt to break down silos between two pre-college STEM initiatives and provide students in underserved communities with opportunities to experience engineering and robotics. The biggest challenge facing the blending of these two programs into one offering is the integration of content, while keeping intact the core values of each program. This paper details the design and results of a workshop that brought together a variety of salient stakeholders to explore potential approaches of blending the two programs.

II. METHODS –WORKSHOP AND DESIGN SPRINTS

A. *Kickoff Workshop*

A collaborative design workshop, involving a variety of stakeholders, was conducted to explore potential blending approaches. Participants (n=22, 50% females) recruited via email included engineering teachers (*n*=4), FIRST team members (*n*=5), school administrators (*n*=4), e4usa team members and university representatives (*n*=5), and industry representatives/robotics coaches (*n*=4). The workshop was held virtually over two days with synchronous and asynchronous activities spread over seven steps [Fig. 1].

Activity	Time (minutes)
DAY 1 [SYNCHRONOUS SESSION 1]	
1. Welcome, Introductions, and Workshop Purpose	15
2. Individual Reflection	15
3. Homogenous Group Discussion	60
Break	15
4. Heterogeneous Group Brainstorming	60
DAY 1 [ASYNCHRONOUS SESSION 1]	
DAY 2 [SYNCHRONOUS SESSION 2]	
Welcome & Recap	15
5. Heterogeneous Group Share-Out	60
Break	
6. Heterogeneous Group Idea Refinement	90
7. Top 2 Ideas Presentations	30
Workshop Closing	15

Fig. 1. Workshop schedule

Step 1: The workshop started with the PI team providing an overview of the two individual programs and a description of the project's overarching goal to bring engineering education experiences to underserved high schools with scalability and sustainability. The workshop purpose was explained and the notion of creating blended models for underserved high schools through collaborative design was clarified.

Step 2: Participants were asked to reflect individually on the workshop purpose and note their responses to two specific prompts: i) What initial ideas do you have for blending the two programs within a high school setting? ii) What might be some criteria impacting the potential blended models?

Step 3: Five stakeholder groups were formed based on participants' profession and current role. Participants were asked to share within the homogeneous, stakeholder groups their individual ideas from Step 2 and discuss constraints and criteria. This activity was specifically designed to gain a comprehensive understanding of the potential blending constraints from each of the stakeholders' points of view.

Step 4: Heterogeneous groups were formed to share stakeholder perspectives and collaboratively generate as many blended models as possible within a 60-minute window. A few example ideas were presented to clarify that the blending could be blending of content, classroom and extracurricular activities, or between teachers and offerings.

Each participant was then asked to further develop one idea of a blended model individually and asynchronously, considering what their heterogeneous group had discussed as potential solutions. The PI team provided a template (Fig. 2) for individual model idea generation.

Model Idea Name:	Brief name to identify the idea
General Description of blending	Use this space to provide some basic details that describe general features of the proposed blending of the engineering and robotics programs, i.e., how will these programs be blended (curricular, co-curricular, extracurricular, etc.)?
Considerations	Use the following sub-sections to provide additional details regarding the proposed model
Number of Teachers	*How many teachers will be needed to accomplish the model?*
School Support	*What local, school support will likely be needed for teachers?*
Student Enrollment	*How will students enroll? What students will enroll?*
Class Size	*What is the ideal number of students in the e4usa+FIRST offering(s)?*
Required Resources	*What non-material resources will be needed?*
Scheduling	*What scheduling options ((semester, block, etc.) would be able to facilitate the model?*
Learning Environment	*What learning environments (in-person, hybrid, online) would be able to facilitate the model?*
School Location	*In what locations (urban, suburban, or rural) could this model be implemented?*
Strengths	Describe the overall strengths of the proposed model.
Potential Drawbacks	Describe potential drawbacks of the proposed model.
Other Comments	Describe additional thoughts and comments.

Fig. 2. Template for model idea generation

The second day of the workshop engaged participants in additional heterogeneous group activities to arrive at a final set of recommended models.

Step 5: A group share-out of activities provided a platform for each participant to share their idea of the blend from the asynchronous work. Groups further discussed the model ideas considering time, resources, state and district standards, and scaffolding that may be required for students.

Step 6 and 7: Participants were asked to pick one to two promising models from their group to further refine or integrate all ideas into one or two recommended blended models. Each group (n=5) then presented their final suggested models (n=7) and addressed questions and concerns.

B. *Design Sprint*

The PI team engaged in a design sprint following the workshop. Design sprints are an intense, "time-boxed" process where user-centered teams map out challenges, explore solutions, pick best solutions, create a prototype, and test it [6]. The team engaged in 3-hour long weekly sessions over a period of two months to analyze all data generated from the workshop in order to inductively identify a few potential models for blending the two programs. The team started by looking for commonalities across the recommendations, criteria, and constraints listed by each group and within individual reflection documents. An affinity diagram method [7] was used on a Google Jamboard to identify a common set of considerations for all models. The team specifically looked for overlaps in the seven models with these considerations and overarching programmatic goals, which led to further refinement and final selection of five models that would be presented to participating teachers during the summer professional development.

III. RESULTS

Workshop data pointed to numerous aspects of the program implementation regardless of the blended model. These common aspects included: i) resources such as fabrication tools, dedicated space for engineering and robotics activities, materials handling, storage for materials, trained volunteers/mentors, and travel funds for robotics competitions; ii) logistics such as scheduling and timings of the classes, number of students relative to the available kits, transportation for afterschool activities, mentor engagement platforms, and potential fundraising; and iii) instructional practices such as identifying overarching skills between both programs, embedding game elements/mechanisms throughout the engineering curriculum, organizing guest lectures with industry mentors, and selecting engineering design projects that align with the robotics competition theme. It was recommended that the e4usa+FIRST classes be scheduled toward the end of the school day for students to easily transition into afterschool robotics activities.

Three overarching themes emerged that included potential pitfalls, recommended practices for effective blending, and flexible adaptation options for teachers. Potential pitfalls covered numerous aspects ranging from higher level programmatic missions to the details of daily classroom practices. One of the concerns expressed by the workshop attendees was that students and teachers should not equate robotics with engineering. It was recommended that robotics be presented during the summer professional development as a subdiscipline and application of engineering. Use of common, harmonized language across the activities of the two programs was highly recommended. Attendees expressed concerns regarding the participation of student teams in robotics competitions at district and national level. 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 or pursuing engineering pathways. Developing a growth mindset [8] among students and teachers was recommended. Attendees suggested creating a better scaffolded "on-ramp" for incipient teams such as inviting them to observe the district and national-level FIRST competitions, forming multiple teams in the class and competing within, or competing with other e4usa+FIRST teams. These suggestions revolved around the desire to create a culture that prioritizes all students.

Workshop results also converged around a common set of flexible adaptation options for teachers regardless of the suggested model. It was recommended that teachers should have the agency to decide if they want to include a robotics competition aspect in their course. The process for enrolling students in the combined offering, setting prerequisites for enrollment, onboarding processes between programs, pedagogical approaches, assessment tools, budget management, and stakeholder partnership and communication were some of the items suggested to keep as flexible options in the program for teachers.

The seven workshop-generated models were revisited with these considerations which resulted in five recommended models for implementing the blended e4usa+FIRST program prior to the pilot efforts. The five models include: 1) curricular + extracurricular (single teacher), 2) curricular + extracurricular (multi-teacher), 3) co-curricular + extracurricular, 4) sequential curricular, and 5) concurrent curricular. The following subsections describe the models.

A. *Curricular + Extracurricular (Single Teacher)*

The curricular + extracurricular (single teacher) model involves one teacher offering the e4usa curriculum in the classroom and FIRST as extracurricular. This is a basic and traditional model which entails robotics as an extracurricular component. The only difference being, the same teacher teaches engineering in the classroom and facilitates afterschool robotics to ensure coverage of cross-cutting program concepts and synergistic activities across offerings. Both curricular and extracurricular offerings would be open to all students and would allow students to participate in either offering or participate simultaneously within the same semester or academic year. The whole engineering class or a subset could participate in the extracurricular robotics and/or robotics competitions. The afterschool robotics program could welcome students who are not enrolled in the e4usa+FIRST course.

B. *Curricular + Extracurricular (Multi-teacher)*

The curricular + extracurricular (multi-teacher) model involves a co-teaching approach where more than one teacher teaches and facilitates learning of engineering and robotics content. Afterschool robotics activities and competition are an added opportunity to bolster students' passion in STEM. The model is an extension of the previous single teacher model recognizing that a single teacher may not have the capacity or confidence to teach or facilitate afterschool robotics. This approach would provide freedom for teachers to collaborate with one another to offer both options at their school. Teachers could choose parallel teaching, one teaching and the other assisting, alternative teaching of engineering and robotics concepts, or one teaching in the classroom and the other facilitating the afterschool robotics. The teachers would prepare a single set of assessments and ensure that cross-cutting program concepts are covered. The course would be open to all students. The whole class or a subset of the class could participate in extracurricular robotics. The afterschool robotics program could welcome students who are not enrolled in the course.

C. *Co-curricular + Extracurricular*

The idea behind the co-curricular + extracurricular model is to provide basic robotics knowledge to all students enrolled in the engineering course and offer greater competition experiences to interested students via an extracurricular club. It involves teaching of both engineering and robotics as a formal, curricular activity and establishing a school team for participation in robotics competition as an extracurricular option for interested students. The FIRST program offers a classpack of basic robotics lessons for teachers to implement the blended program. This model would provide freedom to the teachers to collaborate with another teacher to teach engineering and robotics content in the classroom and/or facilitate afterschool robotics. The course would be open to all students. The whole class, a subset of the class, or students not enrolled in the e4usa+FIRST course could participate in extracurricular robotics.

D. *Sequential Curricular*

The sequential curricular approach requires schools to offer two separate courses designed to be taken in sequence. The two courses could be taught over two years (60 total weeks at 200 hours per week) or split across the first and second half (30 total weeks at 400 hours per week) of the school year. Students would complete the engineering or robotics class as a prerequisite for the other course. Students engaged in the robotics course would compete either in a local competition or within the course. An optional extracurricular component can also be established for students who want to continue with robotics following the course sequence.

E. *Concurrent Curricular*

The concurrent curricular approach entails embedding robotics content in 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. For example, teachers could offer robotics activities as a lab experience associated with the course, teach engineering and robotics on alternating days of the week, or modify the e4usa lessons to bring in robotics activitiess. A single teacher would teach the course, prepare a single set of assessments, and ensure that cross-cutting program concepts are covered. The course would be open to any and all students and the whole class or a subset of the class could participate in robotics competitions.

IV. IMPLEMENTATION

Nine high school teachers were recruited during the e4usa+FIRST pilot year to offer a blended model at their schools. The teachers attended a two and a half weeklong summer professional development in July 2021. The professional development focused on 1) FIRST training, 2) e4usa professional learning, and 3) sessions focused on the blending of the two programs and implementation. These three sets of activities built on each other to enable and empower teachers to offer a blended model at their schools [9]. Details pertaining to the summer professional development [9] are outside the scope of this paper.

The five models were presented to the teachers to determine what approach may be best suited for their local context. Teachers reviewed the models and discussed various implementation approaches with project team members. Three teachers selected the curricular + extracurricular (single teacher) model, one teacher selected the curricular + extracurricular (multi-teacher), one teacher selected the co-curricular + extracurricular, one teacher selected the sequential curricular models, and three teachers selected the concurrent curricular model.

Each teacher has had their successes and failures as they have engaged in this program. Only one teacher was able to get their students to participate in a FIRST competition, primarily due to the competition calendar. All teachers have in some way offered robotics content to their students in addition to the e4usa course. The majority of the challenges faced were related to supply chain issues and procuring additional robotics kits and materials. A virtual robotics offering was provided and leveraged by some teachers. Teachers also struggled to maintain student participation especially, in afterschool robotics activities due to frequent COVID-19 related student absences throughout the first term (Fall 2021). It is also important to note that the implementation of the e4usa+FIRST blended program is also highly dependent on affective factors such as the school administration’s support for either or both the curricular and extracurricular activities of the program. The PI team continues to gather implementation data from the pilot teachers.

The program also facilitates monthly community of practice sessions for teachers to meet with each other and project team members to discuss implementation of their chosen blended model and to share their experiences.

V. DISCUSSION

The emergent models advance an argument for the involvement of all stakeholders to create an ecosystem at the pre-college level to broaden participation in engineering education. Engineering is not a core component of pre-college education in the United States. The challenges of pre-college engineering education are multifaceted and need “out-of-the-box” thinking [10, 11]. Investigating models to embed engineering-related opportunities more readily for all must be prioritized in pre-college education. Many programs and models have been developed to facilitate pre-college STEM education. This has muddied the waters and made it difficult for schools to navigate available offerings. 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. Our initial work demonstrates how two established programs could blend and the benefits such offerings can have for students. The project’s impact is still to be determined, but one can hypothesize from the success of the individual programs [1, 12] that the experiences provided to students will lead to a greater number and diversity of today’s youth considering engineering (and broadly STEM) careers.

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 assumes 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 experiences with simple tools like screwdrivers, hex wrenches, or nut drivers. Most of the robotics kits, regardless of the program, are priced out of reach for underserved schools, and the support available is lacking. Such insights have prompted a rethinking of the support elements, and lower cost robotics kits with better scaffolding for entry level programs, something lacking at the high school level. The FIRST team is designing a lower cost kit based on open-source software and hardware to help unify and standardize resources.

We acknowledge that robotics programs besides FIRST (e.g., VEX Robotics or Botball) are available, and that each have differing levels of impact. It's also important to note that state or national standards could very well affect the school level engineering and robotics offerings and model selection [11].

Overall, this Innovative Practice Work-in-Progress paper provides a foundational understanding of how two successful programs, such as the e4usa and FIRST, can be blended and play a role in educating high school students about engineering and engineering careers. The study helps future investigators who are interested in examining cross-cutting programs. The e4usa+FIRST initiative also impacts pre-college STEM education's perspective on what is possible when programs collaborate toward a shared mission. This paper may also contribute to the future motivation and design of pre-college STEM education and outreach programs that provide reinforced engineering learning and pathways leading to engineering careers for a diverse population.

VI. FUTURE WORK

We are continuing to evolve the blended program models using gathered implementation data that includes challenges, workarounds, and potential pitfalls. Multiple teacher and student focus group sessions were conducted at the end of the academic year and data is being analyzed [13]. Strengths and weaknesses to the various approaches will be identified and shared in the future. The program will expand to additional underserved schools in 2022-2023. The pilot year teachers will also take a more active role next year sharing their experiences of implementing their selected model during the summer professional development. A subset of these teachers will also serve as coaches for the new teachers.

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 high school athletics teams and is well aligned with the scale of local charitable giving. There is also the added benefit of developing relationships between community employers and the education system. Work is underway to evaluate the potential for developing cost-efficient kits that could leverage open-source software and components to make robotics resources more accessible. The importance of pre-college engineering education will only continue to expand as technologies continue to advance. Now more than ever, e4usa+FIRST and similar pre-college efforts represent an important contribution in developing a more diverse future STEM workforce.

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