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EWFD: Building Teacher Capacity to Advance Pre-college Engineering and Robotics Education

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Introduction

The industry demand for highly trained engineers is escalating [1], yet access to authentic engineering learning in U.S. high schools remains uneven [2]. Packed curricula, varying state standards, and a menu of commercially available books, curricula, and kits have led to inconsistent pre-college engineering education. This work sought to leverage the collective strengths of existing programs and resources to shift the landscape from one competing for adopters toward one that works together toward the shared purpose of improving engineering for all.

Inspired by Engineering For Us All (*e4usa*), a high school engineering offering, and For Inspiration and Recognition of Science and Technology (FIRST) robotics program, the combined e4usa+FIRST program set out to explore the possibility of blending the two programs. The groundwork to explore different implementation models of these programs has transformed into a larger scale effort to establish a sustainable model for engineering and robotics education nationwide. This includes creating an affordable robotics kit, designing robotics lessons that could be used independently or embedded within an engineering curriculum, establishing a model for teacher professional development (PD), and creating AI-enabled tools that specifically support teachers and students with engineering and robotics activities.

Research Design

We complement the programmatic developments of this endeavor with scholarship designed to better understand the impact of the interventions on stakeholders, including teachers, students, and administrators. This paper describes our design-based implementation research approach [3] and emerging findings to the following research question: How do implementation conditions and support structures shape high school teachers' capacity to deliver, adapt, and sustain robotics-integrated engineering instruction across diverse school contexts?

Design-based implementation research emphasizes working iteratively with key stakeholders in authentic contexts toward desired outcomes [4]. We have been working with 16 high school teachers in the last 1.5 years. Teachers were recruited through a nationwide open call in two cohorts. Cohort 1 included 7 teachers (5 males and 2 females) in year 1 teaching in public or charter schools in the states of California, Maryland, New Mexico, Tennessee, and Virginia. Cohort 2 included 9 teachers (5 males and 4 females) from Arizona, Hawaii, Massachusetts, Maryland, Rhode Island, Virginia, and Utah. Data were collected through focus groups, lesson-embedded feedback cards, and monthly Community of Practice discussions. An open coding and constant comparison approach for data analysis [5] led to the following findings.

Findings

Findings indicate that teachers' capacity to deliver, adapt, and sustain robotics-integrated engineering education grows when practical supports are tightly aligned with their day-to-day realities. Hands-on, in-person professional development was repeatedly described as essential, especially for teachers new to programming or robotics. One teacher who had "never touched Python coding before" shared that learning it "in different chunks" during the PD meant that by the end "I was able to start writing my own code and I didn't think I was going to be able to do that in two days." Another noted that being in the same room mattered: "It felt really comfortable to do that in person…people could see if we were struggling or hop over and solve a problem for us really quickly. I really value that it was in person these last two days." Teachers carried this expectation of responsiveness into the school year, describing their "ideal support system" as one that combines scheduled office hours with project team, peer support, and "in-depth enough" documentation so that when "I have an issue that all of them are having…having somebody accessible" would prevent small glitches from derailing a whole period.

Teachers also pointed to the stabilizing role of modular lessons. Several participants contrasted earlier "home brew" efforts where they felt "lost and overwhelmed" by the volume of online resources—with the relief of having a vetted structure: "Just having some sort of a curriculum structure to work off of whether I follow it exactly or not, at least it's a starting point…before that, I tried doing this kind of stuff for a couple years and…felt like I was flailing in the wind a little bit." Such comments underscore that ready-to-use, modular lessons with a clear progression do more than save planning time. They give teachers a stable backbone they can adapt to different schedules, student readiness levels, local constraints, and existing engineering lessons.

Finally, Community of Practice (CoP) emerged as a critical mechanism for reducing isolation and building confidence. Many teachers described being "a department of one" or "the only guy who does what I do" at their school, making "any opportunity to do cross collaboration and thinking with other people that are doing what I'm doing is huge as a resource." They emphasized the value of having "you guys to ask questions," colleagues "that know a little more than we do…to support us and help us and back us up," and a space to "bounce ideas around and see maybe some blind spots that I have." One teacher linked this directly to student outcomes, noting that their robotics team moved from third place one year to first the next "because of things that I've learned here, I did not know enough before that to teach them things like that." Taken together, these findings suggest that flexible implementation models only succeed when they are coupled with in-person PD, just-in-time support, structured curriculum, and a strong professional community that makes teachers feel they are no longer "on an island."

Discussion

The findings reinforce and extend prior work on the importance of context-aligned supports in implementing STEM innovations at scale [3], [6]. Teachers' descriptions of feeling "on an island" before joining the program, and their strong preference for hands-on, in-person PD, underscore that technical tools alone may not be adequate. Pedagogical and relational supports are equally essential. Our results show that teachers' capacity to deliver and adapt robotics-integrated engineering instruction grows when supports are designed with local realities in mind. These realities include varied times for class periods, diverse learner needs, varied school district IT policies, and mixed teacher backgrounds in coding or engineering. Modular lessons with pacing guides, robotics hardware and software troubleshooting tips, and a list of materials needed for projects or mazes functioned, not just as convenience items but as critical infrastructure that allowed teachers to move from "struggling" to purposeful experimentation and adaptation. These findings align with design-based implementation research principles that emphasize co-design, iterative refinement, and attention to the "ecology" of implementation rather than assuming a one-size-fits-all solution [4], [7].

At the same time, the strong impact of CoP observed here echoes prior work. Community support and professional learning networks foster teacher agency and greater confidence in navigating new curricula [8], [9]. Teachers described the CoP as vital to their success, enabling them to refine lesson delivery and troubleshoot challenges in real time. CoP sessions also helped mitigate teacher isolation by providing a trusted space to share challenges, co-develop workarounds, and connect robotics lessons to their students and specific contexts. Together, these emergent themes suggest that scaling robotics-integrated engineering education is less about "pushing out" a fixed curriculum and more about building an evolving ecosystem of supports that includes PD workshops, CoPs, AI tools, partnerships with universities and industry, and administrative support [2], [8]. Inviting teachers as co-designers within this ecosystem is especially powerful [10], both for producing context-responsive materials and for strengthening the confidence and professional agency needed to sustain robotics education in diverse high school settings.

Future work will focus on integrating AI-enabled tools to further support teachers and students in robotics programming. In collaboration with Google's Gemini team, we are developing a new coding environment that will provide targeted hints, suggestions, and explanations as students write programs. This "AI as coach" model is designed to mirror the role of a mentor, helping students debug, reason about, and refine their own code. We anticipate that this approach will lower the entry barrier for novice programmers while preserving productive struggle and deeper conceptual learning. Overall, by emphasizing continuous improvement and adaptation based on design-based implementation research, this work contributes to a deeper understanding of how formal robotics education can be effectively tailored and sustained to meet diverse educational needs at the pre-college level and ultimately strengthen the future engineering workforce.

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