



Overcoming Challenges in Robotics Education: Examining Teacher Facilitators and Barriers

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ABSTRACT

CONTEXT

The industry demand for highly trained engineers is escalating. Robotics has proven effective in motivating high school students to pursue engineering education. However, robotics programs are predominantly extracurricular, limiting exposure to a select few. Other significant barriers exist, such as the high cost of robotics kits and the scarcity of adequately trained teachers and mentors. These challenges underscore the urgency of our initiative, a blended engineering + robotics program for pre-college students to learn and experience engineering through robotics in a formal classroom environment.

PURPOSE OR GOAL

To address the barriers, we designed cost-effective robotics kits and established blended robotics education models for secondary schools in the United States. Teachers were supported through a year-round teacher professional learning and a community of practice (CoP). This study answers the following research question: What are the facilitators and barriers faced by teachers when implementing robotics lessons?

APPROACH OR METHODOLOGY/METHODS

We used design-based implementation research (DBIR) and collaborated with secondary school teachers (n=7) to develop and refine the robotics lessons, leveraging teacher insights. A feedback card was designed to facilitate the collection of teacher feedback and reflections as they implemented lessons. Data was also collected through focus groups during monthly teacher CoP sessions. All data were analysed qualitatively for emergent themes.

OUTCOMES

Teachers appreciated structured curriculum materials, professional development, peer collaboration, and hands-on robotics activities that kept students engaged. However, challenges such as adapting lessons for diverse students, providing timely troubleshooting support, and balancing engaging activities with deep learning emerged as barriers.

CONCLUSIONS

Our project bridges the research-to-practice gap by leveraging DBIR, ensuring the curriculum evolves with direct stakeholder input and actionable insights from classrooms and expands access to engineering and robotics education for all students.

KEYWORDS

Design-based implementation research, engineering education, curriculum development, teacher challenges.

Introduction

The demand for highly trained STEM professionals continues to rise sharply, driven by rapid technological advancements and increasing industry needs (National Academies, 2022; National Science Board, 2023). This demand is shaping educational strategies, particularly through the expansion of pre-college engineering programs, which play a pivotal role in nurturing student interest in STEM fields. Robotics, in particular, has demonstrated significant effectiveness in engaging students and motivating them toward careers in engineering and technology (Burack et al., 2019; Melchior et al., 2005). Such programs, however, are often offered as extracurricular activities, limiting participation to students who can access these resources outside regular school hours (Dalal et al., 2024). Other significant barriers exist, such as the high cost of robotics kits and the scarcity of adequately trained teachers and mentors. This situation underscores the need for integrated, accessible robotics and engineering education within the standard school curriculum to reach a broader demographic, including those from underserved communities.

To address these barriers, the e4usa+FIRST initiative was created in 2021 as a groundbreaking collaborative effort between two pre-college STEM education programs. Engineering For Us All (e4usa) is a comprehensive educational program designed to offer secondary school students authentic, design-based engineering experiences with a curriculum that only requires algebra as a prerequisite (Reid et al., 2020). For Inspiration and Recognition of Science and Technology (FIRST) is a well-established global initiative that provides mentor-based robotics programs, aiming to inspire young individuals to pursue education and careers in STEM (Dalal et al., 2024). The e4usa+FIRST program represents a unique fusion of these two approaches, aiming to leverage the strengths of both in order to provide a blended curriculum that addresses the need for scalable, impactful pre-college engineering education, particularly targeting underserved schools.

Under the e4usa+FIRST initiative, significant work has been directed in the first phase towards overcoming traditional educational barriers and enhancing the accessibility of quality engineering education. For example, 3-D printed cost-effective robotics kits were developed [Figure 1]. We also developed blended engineering+robotics education models working with various stakeholders (Dalal et al., 2022) which included: i) Curricular + Extracurricular – in this model, one teacher offers the e4usa curriculum in the classroom, and the same or another teacher offers FIRST robotics as an extracurricular activity, integrating cross-cutting concepts and activities from both programs through various co-teaching approaches; ii) Co-Curricular + Extracurricular – this approach teaches engineering and robotics as formal, integrated curricular activities within the classroom, while also establishing a school robotics team that participates in competitions as an extracurricular option, providing all students with foundational robotics knowledge; iii) Sequential Curricular – this model structures the educational experience as two separate courses—engineering followed by robotics—either sequentially across two years or within the same year, ensuring a progressive learning pathway from basic engineering to applied robotics; iv) Concurrent Curricular – this model embeds robotics projects directly into ongoing engineering lessons, allowing teachers the flexibility to blend robotics concepts with the e4usa curriculum in real-time, fostering an integrated learning environment. These models were established for implementation in varied settings, working with 16 secondary school teachers across the nation. Teachers were supported through a year-round teacher professional learning and a community of practice (CoP) wherein the research team hosted monthly online sessions for teachers to discuss lesson implementation and share experiences (Efe et al., 2022).



Figure 1: 3D-printed robotics kit

The second phase of the program aims to design adaptable, standalone robotics lessons to allow any engineering program to selectively incorporate the robotics lessons with engineering lessons or projects. This approach ensures that robotics lessons enhance students' understanding of foundational engineering principles and concepts. As it stands today, there is no formal, widely accepted robotics curriculum for secondary education. One of the objectives is to build a nationally recognized set of robotics lessons while actively engaging teachers throughout the process to gather input, pilot test, and refine the lessons. The involvement of teachers as “design partners”, enhances the practicality and relevance of lessons and also bridges the gap between theories of curriculum development and classroom realities (Davis et al., 2014; Zuiker et al., 2017). With this context, this study aims to answer the following research questions:

RQ1: What features do teachers consider essential for robotics lessons to be effective in formal secondary classroom settings?

RQ2: What are the facilitators and barriers when teachers implement robotics lessons?

Methods

Research Design

This study employed a Design-Based Implementation Research (DBIR) approach to collaboratively develop and refine an introductory robotics curriculum for secondary school students. DBIR, a form of Design-Based Research (DBR), is grounded in the learning sciences and aims to bridge the gap between educational research and classroom practice (Fishman et al., 2013). Unlike traditional experimental methods that often simplify variables to enable measurement, DBIR embraces the complexity of real-world educational environments (Penuel et al., 2011). It emphasizes iterative design, continuous feedback, and collaborative engagement with practitioners—in this case, secondary school teachers—throughout the research process.

Participants

The research team partnered with secondary school teachers ($n=7$, 5 males and 2 females) who acted as co-designers in the curriculum development process. Teachers were originally recruited through a nationwide open call when we kicked off the program, and have been working with the program team for the last four years. They are teaching in public or charter schools in the states of California, Maryland, New Mexico, Tennessee, and Virginia. These teaching partners bring an average teaching experience of 15.7 years, ranging from 7 to 30 years, an engineering teaching experience of 7.8 years, with a range of 5 to 13 years, and

robotics experience of 5.1 years on average, ranging from 2 to 7 years. Their robotics experiences included exposure either as a college student, coaching as a parent, or conducting a robotics club.

Data Collection and Analysis

Qualitative data was collected using two primary methods: teacher feedback cards and focus groups. A custom feedback card [Figure 2] was designed to efficiently capture teachers' in-process reflections on lesson implementation and classroom challenges. Adapted from the Test Cards used in entrepreneurship (Osterwalder, 2015) and prior NSF-funded engineering transformation initiatives (McKenna et al., 2016), these feedback cards have been embedded with lessons as well as converted into open-ended survey questions. This approach enabled teachers to document observations, student questions, and any issues immediately after lesson implementation. This paper analyzes feedback collected across five lessons, providing insights into teachers' experiences over multiple instructional contexts.

FEEDBACK CARD	
Lesson#/Title: _____	Date: _____ Duration (Mins) _____
Teacher Name: _____	School Name: _____
1. What percentage of students were Engaged with the lesson?	
2. What percentage of students were able to Demonstrate Understanding ?	
3. What percentage of students were Able to get the robot perform as expected ?	
4. How easy were the XRP assembly instructions for you to follow?	
5. How easy were the XRP assembly instructions for most of your students to follow?	
6. How useful did you find the following components of the lesson (<i>Provide any details about these components or any other components</i>):	
a. Procedures/Descriptions	b. Code Samples
c. Images & Videos	d. Examples
7. Were the learning objectives for the lesson CLEAR? Yes/No (<i>Please specify and elaborate</i>)	
8. Were the contents of the lesson appropriate to achieve the learning objectives? (<i>Please specify and elaborate</i>)	
9. Did this lesson provide new and useful information about robotics to majority of your students?	
10. How well did the provided lesson fit within your scheduled class period?	
11. Were there any specific concepts in this lesson that you found hard to teach? (<i>Please specify and elaborate</i>)	
12. Did students have any issues in this lesson that you couldn't help them solve? (<i>Please specify and elaborate</i>)	
13. What challenges/barriers, if any, did you face while preparing for this lesson?	
14. What challenges/barriers, if any, did you face while delivering this lesson?	
15. Did you deliver the lesson as prescribed? Yes/No, if not, what did you change and why? How did it go?	
16. What suggestions do you have to improve the lesson?	
17. Did you use just-in-time AI support while preparing for or teaching this lesson? Please share details about the situation, the quality of support received, and suggestions for improvement.	
18. Tell us if your students utilized the just-in-time AI support for coding assistance or troubleshooting any issues and how?	
19. Use this space to share any additional thoughts, suggestions, problems, or recommendations.	

Figure 2: Lesson feedback card

To answer RQ1 with triangulation across data sets, a qualitative approach was employed to analyze teacher feedback on the implemented curriculum. Teacher responses to feedback cards were systematically reviewed, and key statements were highlighted to capture insights related to instructional effectiveness, student engagement, and implementation challenges. These statements were then grouped and synthesized to identify recurring patterns and emergent themes. The resulting thematic analysis allowed for the construction of a cohesive narrative that reflects the shared experiences and perspectives of participating teachers (Braun & Clarke, 2006; Nowell et al., 2017). An inductive coding approach was used to allow for natural theme development (Thomas, 2006). To supplement the feedback cards, the research team also conducted periodic focus groups during monthly CoP sessions. These focus groups enabled collaborative reflections and collective dialogue on motivations, challenges, and opportunities for improvement (Krueger & Casey, 2014). Two Semi-structured focus groups were conducted with six and seven participants. The second focus group was divided into two groups of four and three. Focus group discussions were driven by the following main questions, with additional questions for further exploration depending on the teacher's

responses: i) Could you describe your experience teaching robotics lessons since you joined the program? ii) What motivates you to continue engaging with the program? iii) What barriers or challenges, if any, have you encountered while implementing the lessons? iv) What supports are crucial in delivering the robotics lessons?

Focus group data were transcribed, anonymized, and analyzed using thematic analysis (Xu & Zammit, 2020) to uncover emergent themes related to teacher experiences, focusing on facilitators and barriers. We employed an inductive coding approach, allowing themes to emerge directly from the data rather than applying pre-existing categories (Thomas, 2006). Initially, two doctoral student researchers independently coded the transcripts to identify preliminary themes. They then met to discuss their codes, resolve discrepancies, and collaboratively refine the codebook. Following this, a third member (the first author) reviewed the codebook and a subset of coded excerpts to ensure consistency and credibility. Any disagreements were resolved through group discussion to reach a consensus. A combination of data sources — feedback cards and focus groups allowed for triangulation to enhance the trustworthiness of the findings (Patton, 1999; Carter et al., 2014).

Results

Results are presented for each of the research questions in the following subsections.

Essential Features for Robotics Lessons to Be Effective in Formal Secondary Classroom Settings

Analysis of teacher feedback revealed several key features considered essential for effective robotics instruction in secondary classrooms. First, hands-on, interactive learning grounded in real-world context emerged as a critical factor in student engagement. Teachers consistently reported that activities involving building, testing, or programming robots were particularly effective in maintaining student interest. One teacher noted that students “were excited to get it built” and highly engaged because “they like doing things with their hands.” Open-ended challenges that encourage problem-solving were similarly successful at keeping learners focused, as a teacher observed, students became “very engaged in trying to figure out how to make the robot complete the maze”. Activities that connected technical content to familiar real-world contexts, such as classifying examples of robots, helped internalize abstract concepts. Teachers found that seeing concepts in action (such as coding a physical robot and observing immediate results) improved students’ enthusiasm and comprehension. One teacher shared that having an actual robotic kit on hand for demonstrations allowed students to “see and touch the actual components” of a robot, making technical terms more concrete. Overall, teachers expressed a desire for even more tangible, authentic learning experiences, and warned that if activities are too basic or too disconnected, students would lose interest or “phone it in”. Hence, maintaining an appropriate level of challenge and novelty is critical to student engagement.

Teachers emphasized the importance of instructional scaffolding, appropriate pacing, and clarity in lesson design. Lessons that introduced too many new concepts simultaneously were seen as overwhelming, especially for students new to coding. As one teacher expressed, lessons “way too long” with “way too many new concepts introduced at once” led to disengagement. Several teachers modified pacing by breaking lessons into smaller segments. One teacher explained, “I slowed way down and did deeper dives into each section rather than try to cover it all at once.” When learning content and directions were straightforward, teachers found them “clear and easily understood” by both themselves and their students. However, unclear materials and directions hindered learning. For example, an ambiguous maze diagram left one teacher with “no idea how large it was or what it was supposed to look like.” Teachers recommended simplifying objectives, clarifying instructions, and providing stronger transitions between lessons. Finally, practical barriers such as limited time, diverse student backgrounds, and hardware inconsistencies were frequently cited. While experienced teachers can navigate

these challenges successfully, they stressed the importance of providing clear, modular lesson materials and robust troubleshooting guidance to support broader implementation. Overall, teachers found that effective robotics lessons require a balance of experiential learning, instructional clarity, and flexible design responsive to real classroom conditions.

Facilitators and Barriers to Implementing Robotics Lessons

Participating teachers identified three key facilitators (Table 1) for robotics lesson implementation: (1) structured curriculum materials and design, (2) support through professional development, and (3) community and collaboration.

Teachers valued having access to a pre-designed curriculum and a structured pacing guide, which provided a solid starting point for lesson planning and delivery:

"It would be really beneficial for us to see the curriculum. It may or may not be adaptable. We might start working through it and inform what we want to add to the curriculum. [Some] might be at a higher level than what we can currently do, but we might be able to adapt them."

Teachers, especially those with limited prior experience, highlighted the need for professional development, expressing interest in both virtual and in-person formats. Hands-on sessions were valued for familiarity with the program's robotics tools. The following excerpt illustrates these perspectives.

"I think the training [will be] good... either do a Zoom or in person. We really like the in-person [one], because it's good to get to see each other and do hands-on stuff...when we have the XRP [Experiential Robotics Platform] in front of us and do some of that stuff."

Teachers emphasized the importance of collaboration and community in improving robotics instruction. They described feeling isolated prior to joining the program and participation in the e4usa+FIRST network provided opportunities to exchange ideas, troubleshoot challenges, and learn from peers with diverse expertise. The CoP enabled them to bounce ideas off peers, uncover blind spots, and collaboratively refine their teaching practices. This collaborative environment was especially beneficial for those with limited robotics backgrounds, helping them gain confidence and improve student outcomes. For example, teachers mentioned:

"I feel like I am able to bounce ideas off of folks, understand different ways of doing what I'm doing, and have available resources. Before getting involved with [the team], these weren't there and we were doing a lot of homebrew and kind of on an island, but in this environment, I find that the collaboration definitely enhances what I do in the classroom and with my robotics too, so that's the biggest takeaway for me."

"My background was in chemistry and no one at my school teaches robotics. Since no one at my school really knows how to do it, it's been really helpful to work with you guys so that I know what I'm doing, and I think that it's my kids are getting so much more from the class now."

Table 1: Codebook for facilitators

Category	Definition	Sample Quotes
Readymade Curriculum	Teachers value a pre-made curriculum as a helpful starting point, making it easier to implement robotics without feeling overwhelmed.	"... 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."
Need for Professional Development	Teachers explain the need for various professional learning, both virtual and in-person, for robotics education.	"I mean, for me, I really don't have much of a background at all in robotics. It would be cool to actually dive into it for a week or two uninterrupted and actually learn it to a deeper level myself than what my kids probably get to."

Community and Collaboration	Teachers emphasize the value of cross-collaboration, idea-sharing, and resource access in enhancing classroom and robotics instruction.	“... any opportunity that I have to do cross collaboration and thinking with other people that are doing what I'm doing is huge as a resource.”
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The focus group findings also revealed several challenges in implementing robotics instruction (Table 2): (1) troubleshooting technical issues in real time; (2) making robotics concepts relatable; (3) developing programming skills; (4) serving as the sole lead; and (5) providing differentiated instruction.

Teachers reported challenges with troubleshooting technical issues in real time, acknowledging that they are not trained engineers:

“And I mean, I'm not a super robotics person. I kind of just am winging it sometimes. But once we just pulled the ones off the old ones, it worked. So I don't know what was wrong.”

They also described instructional challenges in teaching multiple robotics concepts—such as coding, sensors, and actuators—simultaneously during the initial stage :

“I've been running a robotics team at my school for 8 years now... The very first part of it is when kids are learning this, they are learning everything all at once. How do you grab and prioritize things with kids in a way that makes sense? That's challenging...because you need a coding piece, a piece about sensors and actuators all at the same time, and it's managing that initial uptick and uplift with kids that have no knowledge.”

Teachers expressed a desire to improve their programming skills, aiming to write more efficient code and better support students who may find programming intimidating:

“Maybe more into programming. It seems now my skill is that I can make it work, but it's not pretty or efficient. I [have watched] one of my students doing something that I did in 30 lines in six. I'd like to maybe get better in that regard.”

Table 2: Codebook for barriers and challenges

Category	Definition	Sample Quotes
Troubleshooting Technical Issues in Real Time	Participants explain the challenges they face troubleshooting the robot and components along with raising the reliability concerns	“I do know that when we used the XRP in the fall semester, the motors that operate the arm didn't work.”
Making Robotics Concepts Relatable	Teachers find it challenging to help students understand complex concepts in robotics.	“...it's learning everything all at once... you need a coding piece, you need a piece about sensors and actuators all at the same time, and it's managing that initial uptick and uplift with kids that have no knowledge. I think that is one of the big things.”
Developing Programming skill	Desire to write more efficient code and improve programming skills.	“The programming part always seems to be a scary thing for the kids, right? ”
Serving as the Sole Lead or Lone Representative	The teacher is the sole instructor for engineering and robotics at their school.	“It's like I am an individual teacher of engineering and robotics at my school. The other part of my job is that I work in a math department. I don't have an engineering and tech department that I work in. I am the guy.”

Providing Differentiated Instruction

Struggles to keep both beginners and experienced students engaged in robotics.

"I think another thing is when you have a diverse group of students and how to differentiate within the group. You might have some kids that have some serious background with it, and you have other ones that do not."

Several teachers described being the sole instructor for engineering or robotics at their schools, highlighting the challenges of working in isolation without departmental support:

"It's nice to have a cohort of people that are doing something similar to what I'm doing. And most of the time, or prior to this when I was planning something, it was just me alone in my school."

Teachers emphasized the importance of differentiated instruction to meet the needs of students with varied skill levels, language backgrounds, and interests. Strategies included using familiar, real-world examples to explain abstract concepts, providing sentence stems and modified prompts for multilingual learners, and offering scaffolded materials such as slides to support self-paced learning. The quotes below exemplify this theme.

"I think a differentiation is always a tricky bit in things. If you go to the kid who's at zero, you're going to lose the kid who's got knowledge. If you've got the kid who has knowledge, then the kid who's at zero is just following along and will lose interest."

"Some of my kids are almost out of the EI program, but some of them are new to the country. I provide them with differentiated materials to be able to help them with their writing. And then I can start sharing some of that tomorrow when I'm at school...I start by asking them to explain, like a robot or robotic element in their daily life that has a motor or something that has wires. It's just making sure they understand what I'm asking."

"The other thing I was thinking about was the reason for the slides and things like that. Does it help me to differentiate the classroom? If I can distribute something to the kids, I can get those kids who are more advanced go faster. I find that the more stuff I can give out to kids and let them figure out, the better it goes. The less teacher led stuff, the better."

Discussion

Throughout the project, we worked closely with seven high school teachers as co-designers to refine and enhance the robotics lessons, centering their lived classroom experiences and insights into teacher support needs and student learning outcomes. Their feedback, drawn from real classroom implementation, informed successive refinements of the robotics lessons. This iterative process not only enhanced the practicality and contextual relevance of the curriculum but also served as an embedded form of professional development for participating teachers. By positioning educators as partners, the DBIR framework ensured that the resulting curriculum was both theoretically grounded and tailored to meet the diverse needs of students.

The findings of this study reinforce the critical role that teacher-centered curriculum design and ongoing support structures play in the successful implementation of robotics education in formal secondary school settings. Teachers emphasized that clear, simple lesson objectives and the use of hands-on, exploratory learning activities are not just helpful but necessary to maintain student engagement and accessibility. These results echo prior research suggesting that inquiry-based, action-first instructional strategies are essential for motivating diverse student populations to engage with STEM concepts (Burack et al., 2019; Hira & Hynes, 2019).

The importance of robust scaffolding throughout the robotics build and coding processes also emerged as a major theme. Teachers' calls for embedding more explicit instructional support, such as diagnostic tools and step-by-step guided activities, align with broader learning sciences literature advocating for structured, yet flexible learning pathways in technical subjects (Edelson, 2001; Penuel et al., 2011). Teachers' reflections revealed that even minor gaps in instruction—such as unclear terminology or assumptions about coding familiarity—can

create barriers, particularly for students from underserved or less technologically advanced backgrounds (Dalal et al., 2024). These insights affirm the necessity of carefully designing robotics curricula that are not only theoretically sound but are practically viable for a wide range of classroom environments.

Moreover, the strong impact of community support and professional learning networks found in this study resonates with earlier findings that ongoing teacher collaboration fosters greater confidence, agency, and resilience in navigating new curricula (Dalal et al., 2024; Kouo et al., 2023). Teachers described the CoP as vital to their success, allowing them to refine lesson delivery and troubleshoot challenges in real time. Truly transformative robotics education indeed requires dynamic, responsive systems of teacher support that evolve alongside classroom implementation.

Overall, these findings suggest that future efforts to design pre-college robotics education must prioritize flexible, scaffolded lesson design; embed continuous opportunities for teacher input; and offer comprehensive, accessible professional development that builds community, confidence, and capacity.

Future Work

Future work will aim to address both the facilitators and challenges identified in implementing robotics instruction. Further research will examine how structured curriculum materials, accessible robotic kits, and professional learning communities could be systematically integrated to support the broader adoption of robotics in diverse educational settings. Given the reported technical and instructional challenges, future studies will explore the development of adaptive instructional supports and troubleshooting guides tailored for classroom use. Particular attention will be given to effective differentiation strategies, including scaffolded materials for learners with diverse backgrounds, and open-ended project designs that accommodate varying skill levels. In addition, research will investigate how targeted professional development could better prepare educators with limited programming backgrounds to implement robotics with confidence and flexibility. Building on the program's core strengths—modular lessons, flexible instructional models, and cost-effective robotics kits—subsequent efforts will explore their potential to be scaled and adapted across diverse school contexts. The project team has started working with a handful of state department of education authorities to expand the reach and advance access to robotics education for all.

Recommendations

To guide future development and implementation of pre-college robotics curricular initiatives, we recommend robotics curricula to be structured in modular units that allow for flexible implementation across diverse classroom contexts. The lessons must include clear objectives, visual guides, and step-by-step scaffolding to support student learning and reduce cognitive overload, particularly for beginning students as well as teachers. Continued engagement of teachers in curriculum co-design ensures the materials remain relevant, usable, and adaptable to real-world classroom dynamics. Teachers, especially those new to robotics, benefit from immersive, hands-on training that builds their confidence with both hardware and programming components of the curriculum. Support systems in the form of CoP helps reduce teacher isolation, facilitate collaboration, and provide just-in-time support. We strongly recommend ongoing professional development, combining in-person facilitated workshops with virtual communities of practice that encourage peer mentoring, shared lesson development and continuous improvement. These networks are essential for teacher professional growth, ultimately equipping educators to better prepare students for pursuing engineering careers and meeting the demands of the future workforce.

Conclusion

This study highlights the value of integrating teacher perspectives into the development of robotics curricula to ensure context-responsive learning experiences. The findings reaffirm that effective robotics education is not solely a matter of curricular content but also of supportive infrastructure, including professional development, community networks, and adaptive materials. As schools increasingly seek to incorporate hands-on STEM instruction, the e4usa+FIRST initiative serves as a promising model for bridging theory and practice, empowering teachers, and expanding access to engineering education in pre-college settings.

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