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NSF DRK-12: Cultivating Engineering Identities Through Altruistic Applications of Embedded Intelligence and Microelectronics

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Introduction

The rapid proliferation of Artificial Intelligence (AI) is transforming not only industry and research but also the everyday experiences of students. Yet most high school students encounter AI primarily through consumer-facing software such as chatbots, recommendation engines, and voice assistants [1]. These interactions provide only a limited view of a field that is increasingly shaped by embedded intelligence. In embedded AI, algorithms run on microcontrollers and sensor networks, enabling real-time sensing, actuation, and data driven decision making within the physical world [2]. This shift requires that future generations are prepared not only to use AI but also to understand, design, and deploy intelligent systems that are tangible, locally meaningful, and capable of producing social impact.

Despite the rising importance of embedded systems in contemporary engineering and technology, opportunities for secondary students to engage meaningfully with these technologies remain scarce, particularly in ways that reflect their lived realities and local environments [1], [3]. Current AI curricula often emphasize abstract coding exercises or generalized software applications, with limited connection to engineering practice, societal challenges, or students' developing sense of agency. Such gaps risk excluding learners from the emerging landscape of intelligent systems and limit their ability to envision themselves as future engineers.

To address these gaps, our AI Hardware Adventures (AHA!) project, supported by the National Science Foundation's Discovery Research PreK-12 (DRK-12) program, is co-designing and piloting an innovative high school curriculum that integrates foundational AI concepts with hands-on, project-based experiences in embedded systems. The project brings together a diverse team of high school teachers from Florida, Texas, and Kansas, alongside informal educators from museums and community organizations. These partners play an active role in shaping curricular materials, ensuring their adaptability and relevance across a range of formal and informal learning contexts. Our curriculum emphasizes experiential learning through locally meaningful engineering challenges, such as environmental monitoring and transportation safety, that invite students to connect technical learning with altruistic action and community betterment.

During the first two years of development and prior to widespread classroom adoption, the project prioritizes deep collaboration with teachers and informal educators through co-design workshops, iterative pilot testing, and multiple feedback channels, including shared documents, synchronous meetings, interviews, and classroom observations. The design of these activities builds on insights gained from previous NSF funded projects conducted by the team [4], [5], [6], which have highlighted the importance of sustained partnerships, contextual responsiveness, and educator driven refinement when introducing advanced technologies into secondary classrooms.

This collaborative and iterative process has allowed the project team to surface insights about how educators interpret embedded intelligence and engineering within their unique educational contexts and to refine the curriculum to better serve both students and practitioners. In this paper, we present outcomes from the initial year of co-design, including representative curricular modules, strategies for effective partnership, and lessons learned from adapting the curriculum for both classroom and out of school settings. Through this work, we aim to advance a scalable and inclusive model for secondary AI and engineering education that links technical skill development with socially meaningful practice and community engagement.

Conceptual Framework

The design and implementation of the AHA!'s framework is grounded in the principle that meaningful engagement and robust identity development in engineering and technology occur when students participate in **authentic, contextually situated** problem-solving [7]. Foundational research in situated cognition and communities of practice highlights the importance of real-world, community-anchored experiences for deepening student engagement, fostering personal investment, and cultivating a strong sense of belonging in STEM [8], [9], [10]. This conceptual foundation is illustrated in Figure 1, which synthesizes the project's commitment to collaborative co-design, authentic engagement, technical and social fluency, and student agency, all situated within **iterative research practice partnerships** focused on engineering identity development.

Central to our approach is the conviction that students are more likely to see themselves as capable and ethical contributors to society when they are empowered to address challenges that affect their own communities [8]. By framing engineering and AI as a form of altruistic action in which technology is used to improve local conditions and support others, the curriculum seeks to strengthen students' sense of agency, social responsibility, and evolving engineering identity [7]. This perspective aligns with emerging research in STEM education showing that agency, ethical awareness, and identity develop through opportunities for students to engage in community relevant work that foregrounds the social implications of technology [10].

The curriculum itself is developed through a collaborative co-design process that values the contextual expertise of teachers, informal educators, and students as essential for effective and sustainable educational innovation [11], [12]. Rather than imposing a fixed sequence of technical content, this co-design process enables adaptation and customization, allowing for the integration of local issues, student interests, and disciplinary connections, an adaptability recognized as a critical factor in broadening participation and fostering equitable outcomes in STEM [8], [10].

Methodologically, the project draws on the Four Component Instructional Design (4C/ID) model [13] and an iterative Design-Based Implementation Research (DBIR) framework [14]. Ongoing cycles of pilot implementation, classroom observation, educator feedback, and collaborative review ensure continuous curricular refinement and empirical validation in authentic educational settings. Through this integrated approach, the AHA! project advances a scalable and contextually relevant model for engineering and AI education, one that is technically rigorous, socially meaningful, and anchored in students' developing identities as engineers.

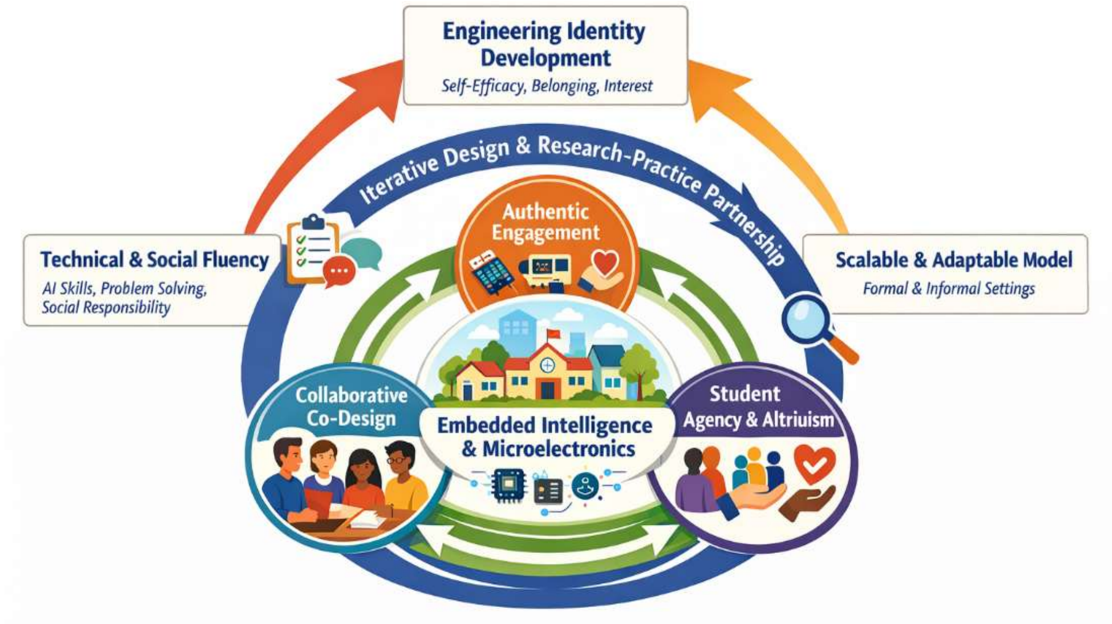

Figure 1. Conceptual framework for the AHA! Project. AI-enhanced image

Curriculum Design

The AHA! curriculum operationalizes this conceptual and methodological foundation by guiding students through a carefully sequenced progression from concrete, hands-on exploration to open-ended, community-grounded engineering design. Learning begins with direct engagement with the custom AHA! board, where students identify sensors, microcontrollers, and outputs while examining the distinction between embedded systems and broader Internet of Things (IoT) technologies. Through interactive worksheets and structured activities, students explore how physical phenomena such as motion, light, and moisture are sensed, measured, and transformed into data that intelligent systems can use.

Building on this foundation, AI is introduced not as an abstract software concept but as an integral component of embedded systems. Using the AHA! board, students construct and test AI models that perform meaningful real-world tasks such as classifying fruit ripeness or detecting water leaks. In doing so, they work with both traditional rule-based approaches and AI enhanced models, manage datasets, deploy edge intelligent models, and reflect critically on the strengths and limitations of embedded intelligence.

As students' progress, they engage with a diverse suite of sensors through rotating learning stations focused on motion detection, heart rate and oximeter data, weather measurement, and time of flight analysis. These experiences emphasize procedural fluency, calibration, and data quality while giving students opportunities to collect, visualize, and interpret authentic data. To further deepen their understanding of machine learning, the curriculum includes an interactive exploration of supervised learning and deep learning concepts through a custom-built Python application. This environment allows students to experiment with model training, feature selection, and performance evaluation while receiving immediate visual feedback. Abstract concepts such as overfitting, accuracy, and generalization become concrete through guided inquiry and hands-on manipulation of models.

Equipped with an expanding repertoire of technical and analytical tools, students then transition to open-ended engineering challenges that are rooted in issues they recognize within their own communities. This phase culminates in the *Gator Tank* capstone experience, in which student teams select a community-centered pathway and engage in a structured process of problem identification, empathy building, ideation, prototyping, testing, refinement, and public presentation. Through this experience, students apply the Engineering Design Process (EDP) [15] and Design Thinking Process [16] to develop solutions that are both technically grounded and socially meaningful. The capstone concludes with a showcase event in which teams present their projects to peer investors and reflect on the broader impact of their work.

Throughout the curriculum, the AHA! Board shown in Figure 2 serves as the central platform that integrates microelectronics, sensing, and AI. The board includes an ESP32 microcontroller, multiple sensors, an expandable breadboard, and a high-resolution OLED display, supporting both reliability and flexibility for experimentation and prototyping.

Figure 2. AHA! board

Classroom Implementation, Outcomes, and Research Findings

Building on the project’s commitment to iterative, participatory design, the AHA! curriculum has been refined and validated through cycles of collaborative work with both teachers and students in authentic educational settings. In one iteration, twenty-four (n=24) high-school computer science and engineering teachers from Florida, Texas, and Kansas partnered as co-designers, reviewing materials, suggesting adaptations, and providing contextual insights through conversations, document comments, and reflective narratives. Their contributions shaped practical elements such as the integration of ethics and privacy, the creation of multimodal and tactile supports, and the development of classroom strategies that increase relevance, accessibility, and student agency. Teacher feedback was systematically mapped to science and engineering practices, interdisciplinary STEM frameworks, and empirical reasoning, strengthening the curriculum's alignment with both standards and the everyday realities of teaching.

A subsequent cycle of implementation took place in an informal learning setting, where twelve (n=12) middle school youth (ages 11–13, including seven girls) participated in a two-week summer camp focused on edge AI and community-engaged engineering. Over forty hours, students identified local issues, designed sensor-driven intelligent systems, and presented their work in a culminating public showcase. The instructional approach centered on collaborative problem framing, the use of scaffolds such as brainstorming reports and poster creation, and iterative prototyping with facilitator input. Analysis of design artifacts and presentations showed that all three project teams made meaningful progress in connecting technical reasoning to community concerns, practicing empathy, and articulating the broader societal impact of their innovations.

Across both teacher and student iterations, the curriculum's ongoing refinement resulted in greater opportunities for authentic engagement, agency, and the development of engineering identities, outcomes consistent with the project's foundational commitment to research practice partnership and socially meaningful, standards aligned innovation.

Broader Impacts and Future Directions

By bridging microelectronics, embedded AI, and human-centered design, the AHA! Project provides a scalable and inclusive model for secondary engineering education. The curriculum is already strengthening institutional infrastructure, catalyzing new partnerships, and equipping schools to sustain ongoing innovation. In the coming year, the program will reach more than five hundred (n=500) students, enabling systematic examination of how participation shapes both understanding of AI and the development of engineering identity.

To support long term impact and broad adoption, all curriculum guides, implementation materials, instructional videos, and educator resources developed through the project will be shared through a publicly accessible website, alongside a GitHub repository that houses edge optimized AI models, curated datasets, code libraries, and example projects. This open infrastructure ensures that educators, researchers, and community partners can adapt, extend, and sustain the work beyond the initial project sites.

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