Engineering Educators Bringing the World Together
2025 ASEE Annual Conference & Exposition
Palais des congrès de Montréal, Montréal, QC • June 22–25, 2025
Paper ID #48512

BOARD # 278: NSF IUSE: Empowering Future Engineers. An Inclusive Curriculum for AIoT and Intelligent Embedded Systems

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NSF IUSE: Empowering Future Engineers. An Inclusive Curriculum for AIoT and Intelligent Embedded Systems

Introduction

The exponential rise of Artificial Intelligence (AI) hardware technologies, fueled by rapid advancements, has reshaped the computing landscape, transforming machine learning from a theoretical pursuit into a driving force behind real-world innovation. From the early days of basic processors to today's Graphics Processing Units (GPUs), Tensor Processing Units (TPUs), and specialized AI accelerators, hardware breakthroughs have continuously redefined the boundaries of scalability, efficiency, and application[1]. Our project, funded by the NSF Improving Undergraduate STEM Education (IUSE) program, began in 2022 with an ambitious vision: to create a gamified curriculum for teaching hardware fundamentals through Field-Programmable Gate Array (FPGA) platforms. As the project evolved, we expanded to include Artificial Intelligence of Things (AIoT) applications, and most recently, we've sharpened our focus on intelligent embedded systems. Central to this initiative is our commitment to exposing first-year engineering students to these cutting-edge technologies early in their education, helping them make empowered career choices while ensuring the workforce is prepared to keep pace with accelerating technological advancements. By adapting swiftly, our curriculum not only equips students to stay ahead but positions them to lead in the next wave of innovation.

Over the past three years, the curriculum has been iteratively refined and implemented at a large R1 university in the Southwestern US, following Design-Based Implementation Research (DBIR) principles. Grounded in equity-centered practices informed by Culturally Relevant Pedagogy (CRP)[2] and Universal Design for Learning (UDL)[3], the program combines inquiry-based[4] and experiential learning[5] in a Project-Based Learning (PBL) format[6]. This approach effectively builds students' understanding of key hardware concepts like binary numbers, Boolean logic, sequential circuits, and memory, while also integrating AI and machine learning algorithms to gather data from IoT devices and solve real-world embedded systems challenges. The use of FPGAs and IoT boards provides multiple entry points into the material, offering a hands-on, exploratory experience that fosters self-efficacy, particularly for neurodiverse learners. This strategy ensures students gain both foundational knowledge and the confidence to navigate the rapidly evolving field of intelligent embedded systems.

This paper and poster presentation will explore the evolution of this curriculum, enriched by data collected from Fall 2023 to Fall 2024 on students' career choices, identity, interest, outcome expectations, and self-efficacy in hardware engineering, AIoT, and intelligent embedded systems. To gauge participants' interest and perceptions, we administered both pre- and post-surveys, conducted focus groups, and held purposefully interviews with 17 students in Fall 2023 and 16 students in Fall 2024. These mixed methods provided a deeper understanding of their experiences and perspectives regarding the curriculum. Offered as an elective in the Electrical and Computer Engineering (ECE) department and open to all engineering majors, the program has attracted a diverse student body, both in terms of academic backgrounds and demographics, with each iteration showing an increase in race and gender identity diversity. These results demonstrate that the curriculum's inclusive, hands-on approach resonates with a broad range of students, positioning them to thrive in the growing field of intelligent embedded systems. The findings carry significant implications for educational practice, highlighting the value of inclusive, experiential learning environments in attracting and retaining diverse talent within rapidly advancing technological fields.

Keywords: STEM education, hardware engineering, interest, situated learning.

Conceptual framework

Our curriculum conceptual framework[7], [8] is designed to strengthen engineering identity by fostering student interest, self-efficacy, and positive outcome expectations. Interest[9] develops from situational factors, driven by external influences, into enduring personal motivation, which is essential for students to identify with the engineering field. A strong sense of self-efficacy[10]—confidence in one's ability to succeed—encourages persistence in engineering studies by enhancing motivation, engagement, and academic control. Additionally, positive outcome expectations[10] motivate students by shaping their goals, guiding decision-making, and reinforcing their belief in their ability to succeed.

To support these outcomes, the curriculum integrates equitable practices, experiential and inquiry-based learning, collaboration, reflection, and gamified activities. Lessons are structured into activation, mini-lessons, gameplay, student-led work time, and debriefing, with a focus on inclusive teaching through Universal Design for Learning (UDL) and Culturally Sustaining Pedagogies (CSP). Educators' confidence in teaching hardware concepts is bolstered through implementation strategies and educative materials informed by the Technological Pedagogical Content Knowledge (TPACK) framework[11], aligning instructional strategies with curriculum design to effectively engage both students and teachers.

Method- Measures and Data Sources

The instructional approach of the curriculum evolved through iterative implementation, progressively integrating hands-on and interactive learning experiences to engage students in hardware engineering. During the January 2023 pilot test, seven high school students (six girls and one boy) participated in FPGA-based games focused on binary numbers and Boolean logic. These activities involved configuring FPGA boards with components such as seven-segment displays and LED lights, accompanied by brief, interactive lectures to introduce foundational concepts. Designed to foster both competition and collaboration, these games aimed to support students with no prior knowledge of the subject while encouraging active participation. The average System Usability Score (SUS) was 61, below the industry standard of 68[12], indicating the need for curriculum adjustments. Feedback from usability surveys, observations, and focus groups highlighted the need to minimize external components, balance collaboration and competition, increase conceptual complexity, and involve students more deeply in circuit design.

In the June 2023 summer program, the curriculum was expanded and implemented with ten high school students attending an honors seminar at a large R1 university. Of these, six students (two girls and four boys) provided informed consent to participate in data collection. The program blended FPGA games, simulations, and real-world circuit design projects to address practical challenges, such as smart home energy management. Pre- and post-surveys using the Student Interest in Technology and Science (SITS) instrument[13] showed an increase in students' individual interest in computer hardware and engineering careers. Notably, the greatest improvement was observed in students' perceptions of careers in engineering and computer hardware. Focus group discussions confirmed this positive shift, indicating a transition from situational interest to sustained individual interest. These results led to recommendations for balancing FPGA-based games with deeper explorations of advanced topics, such as AIoT and edge AI, and increasing student involvement in the hardware design process.

During the Fall 2023 semester, the curriculum was implemented in an undergraduate elective course within the Electrical and Computer Engineering (ECE) department at a large R1 institution. Seventeen out of twenty-two first-year engineering students (four women and thirteen men) provided informed consent to participate in data collection. This iteration introduced sensor-based IoT boards and machine learning applications, encouraging students to use sensors (motion, weather, heart rate) to collect environmental data and develop real-world solutions with AIoT and edge AI. Collaborative group projects supported practical problem-solving and applied both hardware and software skills. Pre- and post-surveys revealed statistically significant increases in students' interest ($t(16) = 2.56$, $p < .02$), self-efficacy ($t(16) = 3.97$, $p < .001$), engineering identity ($t(16) = 4.78$, $p < .001$), and outcome expectations ($t(16) = -2.27$, $p < .05$), demonstrating the curriculum's effectiveness in fostering career intentions in hardware engineering[14].

In the Fall 2024 iteration, the curriculum was refined to incorporate insights from previous implementations and research. Enhancements included a balanced integration of FPGA games, simulations, and advanced applications of AIoT and edge AI, with a stronger focus on the hardware design process. Additionally, the curriculum introduced socially impactful projects aimed at increasing women's interest in engineering. This approach leveraged embedded systems to create solutions that benefit humanity, aligning with research showing that women are more likely to engage in engineering when projects focus on solving real-world problems with positive societal impacts[15], [16]. As a result, women participation and engagement in the course increased, demonstrating the effectiveness of integrating purpose-driven engineering projects to foster inclusivity and sustained interest in hardware engineering.

The latest version of the curriculum is divided into two main parts. The first part focuses on FPGA activities, utilizing the FPGA educational platform shown in Figure 2- left side, and covers foundational topics such as binary numbers, combinational circuits, finite state machines, and memory systems. The second part centers on AIoT activities, supported by the AIoT educational platform depicted in Figure 2- right side, where students engage with practical applications using sensors like light, ultrasonic, temperature, motion, and proximity sensors. This section concludes with project idea generation, development, and final presentations, encouraging students to apply their knowledge to real-world problems.

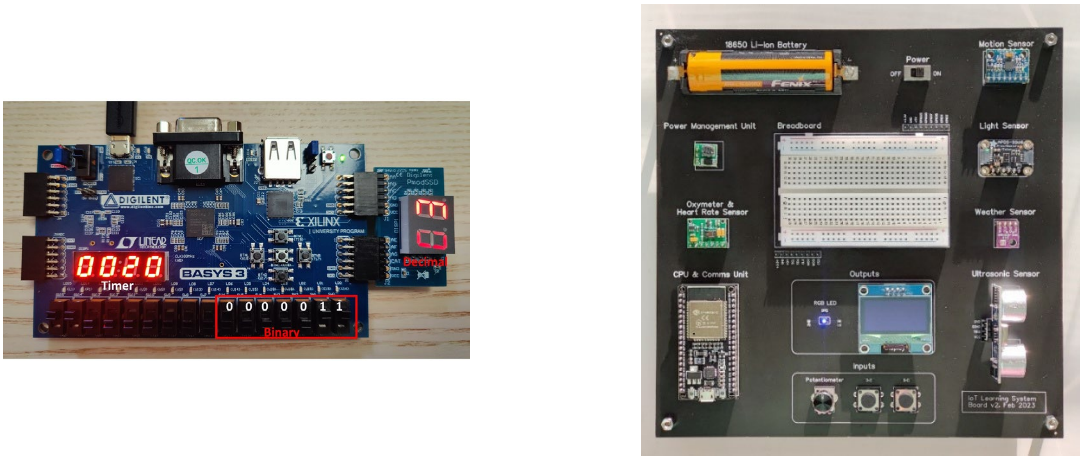

Figure 2. Left side - FPGA-based activity. Right side - AIoT learning board

Future implications

As this project approaches completion, the final phase will involve high school and higher education teachers in refining and testing the curriculum during the Summer of 2025. Engaging educators in this process will help ensure the curriculum effectively addresses diverse student needs and aligns with educational standards. Additionally, the team is developing comprehensive curriculum implementation guides to support widespread adoption and maximize the curriculum's impact. All resources will be available on the project website: https://education.ufl.edu/aihardware/

Acknowledgments

This material is based upon work supported by the National Science Foundation under Grant No. 2142473. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

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