WIP: Exploring the Interest in Microelectronics of Computer Science and Engineering Students through a Multidisciplinary Approach

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***Abstract*—This research-to-practice WIP paper reports on a study that explores the comparison between two different exposures to microelectronics in engineering and computer science classrooms. Career choices for the semiconductor sectors are critical, as there is a current shortage of a trained workforce, with legislation such as the CHIPS Act supporting this need. Microelectronics have been introduced to the classrooms with the objective of more hands-on experience, using the best instructional practices. However, using microelectronics in the classroom may affect students' learning outcomes and their career choices. Therefore, in this paper we use Social Cognitive Career Theory (SCCT), to understand how exposure to microelectronics, and self-efficacy in computing tasks affects the interest of students in learning more about microelectronics. We found that longer exposure to microelectronics was correlated with a lower interest with microelectronics, potentially explained by the experiences of students with longer projects and troubleshooting. In addition, we found that most students felt comfortable solving computational problems, and that prior experience with microelectronics did not correlate with higher interest.**

Keywords—computer science education, microelectronics, semiconductor workforce, Arduino

I. INTRODUCTION

In the rapidly evolving semiconductor industry, the role of microelectronics has become increasingly important in shaping technological advancements but also requires technically relevant educational pedagogies [1]. Microelectronics represents a critical area of study within multi-disciplinary engineering applications. This paper explores the significance of integrating microelectronics into engineering education, arguing that such integration is essential to prepare adept engineers capable of driving future innovations and addressing complex global challenges.

The urgency of embedding microelectronics into engineering curricula stems from its ubiquitous influence across various sectors, including telecommunications, healthcare, automotive, and consumer electronics [2]. Most importantly, the need for educational initiatives and experiences that expose students to both hardware and software applications through hands-on learning. The need for graduates in the semiconductor industry has been spurred by the recent supply chain disruptions, emphasis on workforce development, and legislation such as the CHIPS Act. The integration of microelectronic components and the consequent exponential growth in their functionality demand a robust understanding of microelectronic circuits and systems from aspiring engineers. Foundational knowledge in microelectronics will equip students with the skills necessary to design, optimize, and innovate within an increasingly digital-centric and automated world [3,4].

Technological advancements in microelectronics, characterized by the ever-shortening product life cycles and the escalating complexity of integrated circuits, supports the need for engineering and computer science programs and degrees to continuously evolve. Educators are thus tasked with not only transferring knowledge but also instilling a mindset geared towards innovation and lifelong learning [5]. This paper posits that the effective integration of microelectronics into engineering and computer science education can significantly enhance students' learning experiences and career readiness by providing them with practical, real-world applications and problem-solving techniques.

This study explores the impact of incorporating microelectronics modules, specifically Arduino microcontrollers and code, into undergraduate education programming and design courses to meet the objectives of exposing and educating students on the widespread application of semiconductors. The paper reports on a specific implementation of Arduino-based mini-projects that cover topics which highlight the circuit design and coding in the context of applications that students may not traditionally think of as a semiconductor field, e.g. topics outside of electrical engineering. Students from engineering and computer science majors participated in either a short-term activity or multi-stage activity where they must build and code a working device that utilized microelectronic components that have a real-world or relatable application.

II. INTEGRATING MICROELECTRONICS IN EDUCATIONAL SETTINGS

A. Potential challenges to teaching microelectronics

A significant challenge is the necessity of hardware/software co-design in modern microelectronics education. As products increasingly integrate hardware and software, understanding the interactions between these components becomes crucial. This requires a shift in traditional microelectronics courses to include comprehensive studies on how changes in hardware can impact software functionality and vice versa. Such integration equips students with the essential skills to design and optimize integrated systems effectively [6].

The reliability and quality of microelectronic devices are critical, especially as these components are used in more crucial applications. It is imperative for educational programs to incorporate robust testing methodologies and quality assurance practices into their curriculum. This not only provides students with theoretical knowledge but also practical skills in ensuring the reliability of the products they will work on in their professional lives [7].

Incorporating concurrent engineering into the microelectronics curriculum is essential. This approach, which involves considering all elements of a product's lifecycle during the design process, including technical, economic, and organizational aspects, prepares students for the multifaceted challenges of the real world. It teaches them to think holistically about product development, which is vital for effective project execution in a professional setting.

This dynamic nature necessitates ongoing education beyond formal schooling. Integrating multimedia-based continuing education courses can help professionals in microelectronics keep pace with technological advancements and refine their skills continuously. This approach fosters a culture of lifelong learning, crucial for maintaining expertise and innovativeness in such a fast-paced field [1]. Educators need to prepare students for successful careers in a constantly evolving technological landscape, ensuring they are adaptable, proficient, and ready to meet the industry's demands.

B. Benefits of introducing microelectronics in classroom settings

Advancements in digital technologies such as gamification, visualization, and simulations have further enriched STEM education by offering more authentic learning experiences. Use of digital tools has been linked to improved student interaction, increased STEM interest, and enhanced problem-solving and confidence, particularly through open-source technologies like Arduino microcontrollers [8,9]. These technologies aid in learning specific disciplinary content and support the development of higher-order thinking skills like reflection and abstraction, which are crucial for understanding complex science concepts.

Teaching circuit analysis and programming using microelectronics, particularly through platforms like Arduino, Raspberry Pi, and Texas Instruments, offer significant benefits in STEM education by facilitating hands-on experiences with specialized equipment in a lab, classroom, or remote settings [9]. Studies have found that including more hands-on activities, design projects, and peer-led study groups has shown to increase student engagement and understanding of engineering principles [10,11]. Arduino kits provide affordable, practical learning experiences, bridging the gap between theoretical knowledge and real-world application [10], fostering programming skills, and promoting creative projects, ultimately enhancing the quality of distance education [8] and connecting the physical and digital worlds.

Our study was framed as an exploratory study to investigate how perceived competence and experience in computational thinking and hands-on experiences influences computer science and engineering students' interest in microelectronics. Students were recruited from a computer science course and an engineering design course that implemented the Arduino microcontroller (an open-source hardware and software prototyping platform) as the platform for prototyping and programming. The following research questions guided this study:

RQ1: What is the relationship between students' prior experience with microelectronics and their interest in learning more about microelectronics? **RQ2:** What is the relationship between students' perceived computational ability and their interest in learning more about microelectronics?; **RQ3:** What is the impact on students' interest of microelectronics based on short-term or longer-term exposure to microelectronics experiences with the Arduino microcontroller platform?

III. Theoretical framework

This research utilizes Social Cognitive Career Theory (SCCT) as a lens to examine the impact of microelectronics exposure in engineering and computer science classrooms on students' career choices. SCCT, developed by Lent, Brown, and Hackett in the mid-1990s, builds upon Albert Bandura's broader Social Cognitive Theory [13]. This theory focuses on how individuals form educational and vocational interests, make career choices, and achieve varying levels of success in their careers. SCCT suggests that career development is influenced by three interconnected factors: self-efficacy beliefs, outcome expectations, and personal goals. Self-efficacy refers to an individual's belief in their ability to succeed in specific tasks, while outcome expectations concern beliefs about the consequences of performing such behaviors. Personal goals act as drivers that direct individuals towards certain career paths. These elements are shaped by learning experiences and environmental interactions, which in turn influence interest formation and career decisions [13].

The relationship between previous experiences, self-efficacy, and interests plays a crucial role in career choices under the SCCT framework. Prior experiences, especially achievements and personal successes, significantly influence self-efficacy development. As individuals engage in various activities, their successes and failures either enhance or diminish their self-efficacy, which then impacts their career-related interests. For example, a student who excels in science projects and receives positive reinforcement may develop strong self-efficacy in scientific abilities and a heightened interest in science careers. This example illustrates the dynamic and reciprocal relationship among prior experiences, self-belief, and interest development as proposed by Lent and colleagues. Such connections are vital, shaping not only immediate educational decisions but also long-term career trajectories [13-15].

III. Methods

A. SETTINGS AND PARTICIPANTS

The data for this study was collected at a large public research-intensive institution in the southeastern United States. In Spring 2024, students were exposed to a microelectronics activity. The implemented activities utilized the Arduino Uno

Super Starter microelectronics kits, which included an open-source microcontroller board, various electronic components, and sensors and actuators. The kits are typically used in educational and hobbyist settings and are designed to teach the basics of electronics, programming, and prototyping.

Arduino is open-source electronics prototyping platform centered around an Atmel AVR microcontroller. It is a single-board system programmed via USB and utilizes digital inputs and outputs, and analog inputs. The Arduino platform's standardized programming environment allows the integration of a wide range of microcontrollers. Using the Arduino IDE (Integrated Development Environment), students can program multiple microcontrollers with mainly the same code.

Two courses participated: a first-year design course for engineering students and a computer science course primarily for computer science or computer engineering majors (N = 669). The first-year design course has predominantly freshman student enrollment from various majors and the computer science class has predominantly sophomore student enrollment (N = 49). IRB approval was obtained for both courses data collection separately.

A. *Long-Engineering Exposure (LEE):*

The engineering course was a multidisciplinary, university-level introductory engineering design course emphasizing hands-on learning through design principles that focus on the end-users' needs. The course teaches basic prototyping tools and methods, including solid modeling, 3D printing, Arduino electronics, and basic programming. For this exploratory portion of the LEE, we studied one section of the course and utilized 49 students' survey responses.

The course begins with two weeks on HCD, then six weeks of learning various prototyping technical skills (solid modeling, 3D printing, hand/power tools, Arduino electronics, sensors & actuators, basic programming), followed by a final six weeks of using those skills working in teams to research, design, and build a functional physical prototype to meet a human-centered societal need.

Circuit build examples were integrated into the course lectures/meeting times over approximately six weeks in the semester. The beginning examples focused on creating a complete circuit using the microelectronics components, i.e. did not use code. Students created series and parallel circuits and controlled LEDs using push buttons. Subsequent examples incorporated the Arduino IDE and code to control various sensors and actuators.

Instructor-led 'build' examples included circuit setups that modeled basic devices that utilize microelectronic components. A hands-free controlled "lock" (*Figure 1*). incorporated an ultrasonic distance sensor and LEDs and a servomotor as actuators to mimic how motion detection could be used to "unlock" a device, i.e. move the servomotor blade position, and signify the "lock" or "unlock" state using the red or green LED.

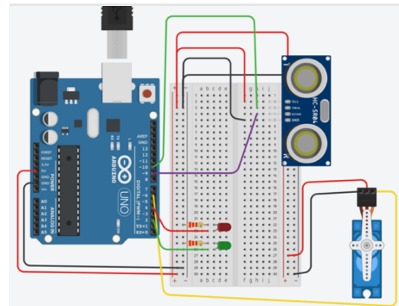

FIGURE 1. CIRCUIT DIAGRAM FOR AN EXAMPLE MICROELECTRONICS BUILD IN THE LEE SETTING.

The Arduino platform includes an Integrated Development Environment (IDE) where the user can create programs and utilize a variety of existing code and example sketches and libraries to control their hardware setups. In the LEE context, the initial build activities did not use code, e.g. series and parallel circuits, but the more advanced activities integrated short programs to mimic real-life applications such as the "hands-free" lock. Students needed to create a sketch (program) in the Arduino IDE uploaded to the Arduino Uno microcontroller board for the circuit to function. The Arduino platform, e.g. physical components and the IDE, is useful in educational settings to allow students to develop more 'real-world' applications by integrating programming and hardware to create something functional.

B. *Short Computer Science Exposure (SCSE):*

This exposure took place in a sophomore computer science class with 669 enrolled students. In week 12 of the semester, students were invited to participate in a workshop, with extra credit offered for participation. The workshop's purpose was not disclosed to the students. Sixty-one students registered for the workshop and 43 attended and participated. The 1.5-hour workshop involved four progressively complex tasks, starting with turning an LED on and off, e.g. a "blinking" light and culminating in a build that used a switch to sequence red LEDs. Four classrooms were used, each led by experienced students who volunteered to conduct the workshop.

The Arduino platform was useful in the SCSE setting because it allowed computer science students to work with applications of hardware by integrating their programming experience to create something functional.

C. *Instrument development*

To develop an instrument that measures experience with microelectronics, self-efficacy with programming, and motivation to work with microelectronics in the future, we utilized Social Cognitive Career Theory (SCCT) as a guiding framework. The survey includes questions assessing students' prior hands-on experience and programming experience with microelectronics (Q1, Q3), providing a baseline understanding of their practical exposure to the field. Additionally, it measures students' self-assessed confidence in their current microelectronics knowledge skills (Q2, Q4), a core component of SCCT's self-efficacy construct. This set of questions is crucial for evaluating how students' confidence levels may influence their interest in pursuing careers in microelectronics, linking directly to their self-efficacy.

Further, the survey explores students' motivation to learn more about microelectronics and their perception of its relevance to future career prospects (Q5, Q6, Q7, Q8, Q9). This section examines students' interest in current and emerging technologies, reflecting their personal goals and outcome expectations, which are key aspects of SCCT. Questions focused on students' confidence in solving computational problems and debugging (Q11, Q12) provide insights into specific areas of self-efficacy that are critical for students interested in technical careers. Collectively, this survey framework, grounded in SCCT, helps explore how various factors such as self-efficacy, outcome expectations, and personal goals influence students' motivations and decision-making regarding careers in the semiconductor sector, offering valuable insights to enhance educational practices to align with industry needs and student career development in microelectronics.

B. *DATA ANALYSIS*

At the end of both exposures, students received a 12-item. From this instrument, this study focuses on the following three questions: *Q1: Prior to this course, I had hands-on experience with microelectronics components (e.g., microprocessors, sensors), Q2: I am interested in learning more about microelectronics, Q3: I feel confident in my ability to solve computational problems.* The answers to these questions were based on a Likert scale with the levels: Strongly Agree (SA), Somewhat Agree (SWA), Neither Agree nor Disagree (NAD), Somewhat Disagree (SWD), and Strongly Disagree (SD).

Given the exploratory nature of this study, we used descriptive statistics to describe our findings and guide future research. We employed contingency tables and bar plots to analyze the data. For RQ1, we examined the relationship between Q1 and Q2 using a contingency table. For RQ2, we analyzed Q2 and Q3 using another contingency table. To answer RQ3, we used a bar plot to show the distribution of responses by type of exposure. Due to the sample's size, we presented the counts instead of percentages so that the number of students is accounted when interpreting the data.

IV. RESULTS

RQ1: What is the relationship between students' prior experience with microelectronics and their interest in learning more about microelectronics? From *Fig. 2 it is possible to* observe that regardless of their experience, most students agreed they were interested in microelectronics. Conversely, most students who disagreed with being interested in microelectronics were those without prior experience in the field. A smaller portion of students expressed no interest in microelectronics. While student experience with microelectronics varied, most had some level of exposure before the study.

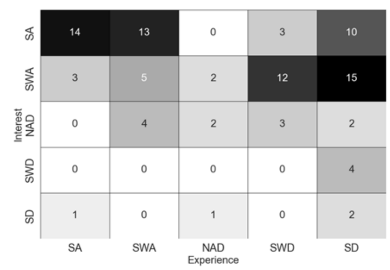

FIGURE 2. CONTINGENCY TABLE, SHOWING THE RELATIONSHIP BETWEEN STUDENTS' INTEREST IN PARTICIPATING IN MICROELECTRONICS, AND THEIR EXPERIENCE BEFORE THE CURRENT EXPOSURE.

RQ2: What is the relationship between students perceived computational ability and their interest in learning more about microelectronics? *Fig 3.* indicates that most students are confident in their ability to solve computational problems, with none expressing strong disagreement. Additionally, the majority exhibit self-efficacy in their computational skills while also showing a high degree of interest in microelectronics.

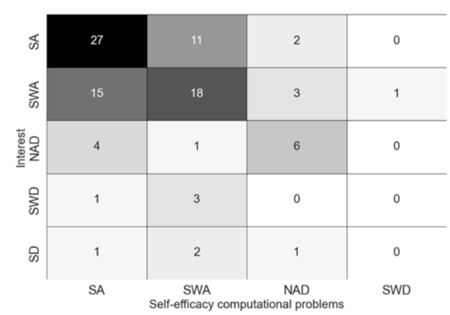

FIGURE 3. CONTINGENCY TABLE, SHOWING THE RELATIONSHIP BETWEEN STUDENTS' INTEREST IN PARTICIPATING IN MICROELECTRONICS, AND THEIR SELF-EFFICACY IN SOLVING COMPUTATIONAL PROBLEMS.

RQ3: What is the impact on students' interest of microelectronics based on short-term or longer-term exposure to microelectronics experiences with the Arduino microcontroller platform? Fig 4. reveals that in both LEE and SCSE exposures, most students expressed a positive interest in participating in microelectronics, with over 70% somewhat agreeing or strongly agreeing. However, the LEE exposure showed a significantly larger percentage of students disagreeing with their interest in microelectronics compared to the SCSE exposure.

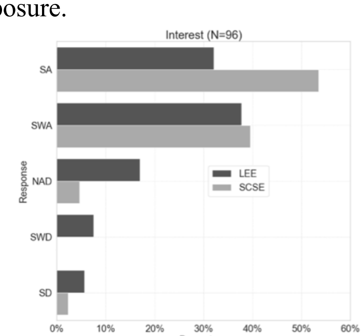

FIGURE 4. BAR PLOT SUMMARIZING THE ANSWERS TO THE QUESTION RELATED

TO THE INTEREST OF STUDENTS TO PARTICIPATE IN MICROELECTRONICS, DIVIDED BY THE TYPE OF EXPOSURE.

V. Disscussion

Recent studies in engineering education have shown that incorporating microelectronics significantly enhances students' practical skills, engagement, and understanding of complex concepts such as circuit design and embedded systems, effectively preparing them for industry demands. These hands-on learning modules bridge the gap between theoretical knowledge and real-world application.

After both exposures, most students remained interested in microelectronics, indicating that they did not negatively affect their interest. In addition, while most students expressed interest regardless of their experience, those who were not interested typically had no prior experience with microelectronics (*see Fig 2.*). This suggests a two-fold interpretation: either increased experience leads to greater interest, or students who are already motivated are more likely to seek out microelectronics opportunities. Understanding the reasons behind past exposure is crucial for evaluating the relationship between experience and interest.

Interestingly, most students who were not interested in microelectronics belonged to the LEE exposure group (*See Fig 4*). This suggests that longer exposure may lead to frustration, resulting in decreased interest, a phenomenon less likely to occur in shorter interventions like SCSE. Evaluating the balance between exposure duration and student engagement is essential to understand some constraints and trade-offs that might exist when intending to respond to the need of the microelectronics workforce.

As we continue to integrate technology into our classrooms, maintaining a balance between exposure time and interest is crucial, especially as students assess their career options. This study sheds light on the distinctions between two microelectronics interventions and their impact on students' interests and future career pursuits. The methods and practices we employ in our classrooms play a significant role in influencing their career choices. Therefore, it is essential to be conscientious about our current classroom practices.

VI. Limitations and Future directions

This study has several limitations and future directions for improvement. One limitation is the reliance on self-reported self-efficacy in computational tasks, which may not accurately reflect actual skills. Future research should incorporate assessments or proxies to better evaluate the relationship between programming skills and interest in microelectronics.

Additionally, expanding on previous experiences is crucial for a deeper understanding of the relationship between experience and interest. To enhance the evaluation of interventions, a pre-post design will be implemented in future studies, allowing for a more comprehensive assessment of their impact. Finally, future research could also be strengthened by adding qualitative data to provide additional insights into the quantitative data.

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