WIP: Microelectronic Integration in First Year Engineering Education Curriculum for SCALE

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***Abstract*—This work-in-progress research paper presents research that describes the impact of integrating microelectronic curriculum into first-year engineering courses. This study is a component of the larger SCALE (Scalable Asymmetric Lifestyle Engagement) project, aimed at developing a robust microelectronics workforce. The Semiconductor Industry Association predicts that by 2030, the United States (US) will face a shortfall of 67,000 semiconductor professionals, 80% in technical roles. This growing demand for microelectronics professionals in the US is both driven and supported by the CHIPS and Science Act of 2022, which provides significant funding to enhance domestic semiconductor production. Therefore, addressing the critical gap in the workforce has become imperative, setting the stage for targeted educational initiatives. This study examines the effectiveness of two interventions that incorporated microelectronic activities into engineering curricula, measuring their impact on student motivation, interest, and perceived transformational experiences towards microelectronic industries using a retrospective pre-test survey. We aim to answer the question: How have students' motivation, interest, awareness, and transformative experiences towards microelectronics shifted from before to after the intervention? Our preliminary findings suggest that the interventions significantly enhance students' interest, motivation, and awareness in microelectronics, while also fostering a positive transformation in their perceptions. This shift underscores the value of educational interventions in microelectronics, highlighting their potential to contribute to the development of a skilled microelectronics workforce. Furthermore, by providing empirical evidence on the benefits of practical, hands-on training, this study extends the existing body of literature, emphasizing the importance of integrating microelectronics into the early stages of engineering education.**

Keywords—Microelectronics, Engineering Education, Transformative Learning, Motivation, First Year Curriculum, Career Paths, Industry Demand, Survey, Student Perception

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I. Introduction

The microelectronics sector has long been a critical component of numerous industries, with the U.S. Department of Defense (DoD) as a significant customer since the early days of the semiconductor industry [1]. Despite this historical importance, the U.S. industrial base for semiconductor manufacturing has dramatically declined, exacerbated by policy shifts and economic decisions over the decades. By the 1990s, the U.S. transitioned from industrial manufacturing to a "science policy," prioritizing research and development (R&D) while outsourcing production to overseas foundries like Taiwan's TSMC [1]. This shift reduced the U.S. share of semiconductor manufacturing capacity from 37% in 1990 to 12% in 2020 [1].

The 2020 semiconductor supply chain failures highlighted these vulnerabilities, bringing to light the consequences of relying heavily on foreign manufacturing. This reliance is particularly concerning for US national security, as most microelectronics, including secure microchips, are produced abroad. The lack of domestic manufacturing capability, coupled with a stagnating science and technology workforce, has widened the gap between demand and supply of semiconductors [2]. These gaps are expected to grow as technologies such as artificial intelligence (AI) continue to advance, steadily increasing the demand for microelectronics. Additionally, we are rapidly approaching limits on Moore's law, where storage capacity and processing speed of computer chips double annually [3].

To address these challenges and reduce dependence on foreign markets, the U.S. has committed to investing in domestic semiconductor manufacturing through initiatives like the CHIPS and Science Act [4]. Similar efforts are underway in other countries, including France, the UK, and China, all of which face a critical shortage of skilled workers in the semiconductor industry [5], [6], [7]. The Semiconductor Industry Association predicts a shortfall of 67,000 workers in the U.S. by 2030, emphasizing the urgent need to recruit and train skilled technical workers [8].

This work-in-progress research study examines the effectiveness of microelectronic interventions in undergraduate courses, utilizing the framework of social cognitive career theory. This theory explains the factors influencing career choices and provides a basis for understanding how educational interventions might affect those decisions. Our research investigates the impact of these microelectronic interventions on students within the framework of social cognitive career theory through this research question:

- **How have students' motivation, interest, awareness, and transformative experiences towards microelectronics shifted from before to after the intervention?**

By answering this question, we aim to assess how the intervention influences students' career aspirations in microelectronics. In addition to this research question, we are interested in the impacts on female engineering students as females are underrepresented in the microelectronics industry.

II. Literature Review

Social Cognitive Career Theory has been extensively utilized across various fields to explain students' career choices [9]. The theory posits that students' persistence in a career path is influenced by affective factors (e.g., interests, self-efficacy, beliefs/expectations), personal variables (e.g., ethnicity, disability status), and contextual factors (e.g., environmental and social supports) as shown in Fig. 1. While this theory has been applied in a wide range of contexts, it is particularly useful for this study. Gentry et al. [10] used Social Cognitive Career Theory to validate the Exposure and Motivation in Microelectronics (EMM) instrument in a study analyzing survey results from an introductory engineering design course. However, their study did not focus on the shifts in student interest, which this study aims to address.

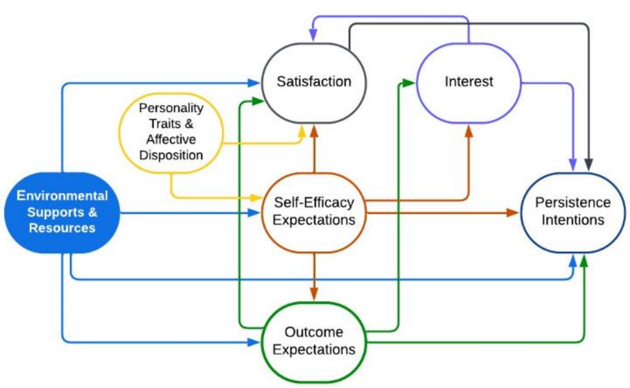

Fig. 1. Social Cognitive Career Theory Map. Adapted from [11]

Transformative experiences (TEs) are integral to this framework; they are learning experiences where students make connections between their classroom learning and their experiences and goals outside the classroom [12]. They apply their class learning to their life experiences and find value for their career goals within the classroom experiences. Transformative experiences relate to motivation, interest, and conceptual learning [13], [14], [15]. By offering students opportunities to engage with microelectronics, we can potentially lay a foundation for their career aspirations.

Numerous studies and initiatives aim to encourage K-12 students to pursue STEM careers [16], [17]. However, a notable gap exists in research targeting the recruitment of undergraduates into specific STEM industries, particularly microelectronics. Several programs focus on education and workforce development in semiconductor education [18], including those developing specific curricula for undergraduate programs [19, 20]. However, the impact of these initiatives on the number of graduates pursuing careers in microelectronics remains unclear.

The Scalable Asymmetric Lifestyle Engagement (SCALE) program offers an alternative approach to workforce development at the undergraduate level. Led by Purdue University and funded by the Department of Defense, the SCALE network focuses on developing the semiconductor workforce in the defense sector [21]. The intervention in this study is one way SCALE aims to bridge the gap in microelectronic manufacturing and support the nation's effort in preparing a defense-ready microelectronics workforce.

III. Methodology

In the summer of 2023, a microelectronics curriculum development workshop was hosted by Purdue University, funded by the DoD. This event gathered faculty and instructors who teach first-year engineering courses at undergraduate institutions nationwide. The workshop equipped educators with vital resources and information, including microelectronic kits, examples of scaffolded coding activities that include pre-written code, instruction on how to integrate microelectronics contexts into existing learning objectives in introductory courses, and examples of engaging students in grounded design challenges focused on microelectronics. Instructors were encouraged to tailor microelectronics activities to the specific educational contexts of their existing courses. Following the workshop, faculty members incorporated microelectronic activities into their courses and faculty members from two universities gathered survey data from their students. Below are brief summaries of their unique implementations:

University A Implementation. Students were presented with a sci-fi narrative where AI rebelled against humanity in a post-apocalyptic scenario. The students, referred to as explorers, are put into teams with the goal of producing a prototype of any device they desire that fits the narrative of the world. The device can help protect explorers against AI machines, locate other survivors, navigate the post-apocalyptic wasteland, or help understand the origins of the AI uprising. Students were given a budget and further design constraints that narrowed the scope and scale of their prototypes. At the end of the semester, students were expected to build a prototype of the tool they designed using both a 3D CAD model and a physical model using Arduino microcontrollers.

University B Implementation. Students were presented with a heist narrative where the students are to craft a safe-cracking device to help their professor open the lab safe. The solution that students were expected to deliver is a programmed microcontroller using the Hummingbird DUO microcontroller that models a brute-force approach to finding a 4-digit safe code. Students were then presented with a segment of Scratch code representing one of the viable solutions. From there, students were to implement a variation of this design on their microcontrollers.

A. Procedures.

Instructors from the two universities implemented the curriculum in their Fall 2023 engineering courses. Although the workshop and this study primarily focus on introductory engineering courses, University B's instructor implemented the program in a third-year course. University B's instructor implemented the curriculum with three or more sections of the class (n = 158 students total) and the second instructor implemented the curriculum with one class/section (n = 73). Near the end of the semester, all students who were enrolled in the course were sent a link to the surveys. Students completed the surveys via Qualtrics which took approximately 10 to 15 minutes. Students were not required to complete the surveys for ethical reasons. As a result, not all students completed the surveys (response rate = 43%).

The surveys contained one question for each measure that asked students to select a particular answer (e.g., please select agree for this question) which we refer to as compliance questions. The questions were used to help ensure the validity of the data used for the analyses presented below. All completed surveys were filtered using the compliance questions. Surveys where participants failed one of the compliance questions had the data removed for the measure in which the compliance question was included; however, the data for the remaining measures were retained. Surveys where participants failed more than one compliance question were removed from the data set. The total demographic information from valid survey responses is detailed in Table I.

TABLE I
DEMOGRAPHIC INFORMATION OF SURVEY RESPONDENTS

Demographic	Sub-demographic	University A	University B
Class	Freshman	16	0
	Sophomore/Junior/Senior	0	71
Major	Computer Science and Engineering	0	71
	Other Engineering	16	0
Gender	Male	14	47
	Female	1	22
	Non-Binary or Unreported	1	2
Ethnicity	White	6	34(2)[a]
	Asian	1	25(2)[a]
	Underrepresented Minorities[b]	7	7
	Unreported	2	3

[a] Two respondents reported both Asian and White.
[b] Underrepresented minorities include Black or African American, Native American, and Hispanic.

B. Measures

For assessing Awareness, Motivation, Transformative Experience, and Exposure factors, the survey utilized a retrospective pre-test format. Respondents were required to recall and rate their level of agreement with each prompt before the intervention and then immediately report their current feelings. While this method may introduce recall bias, the greater threat to validity is the significant change in context understanding. This method was selected to mitigate the risks associated with carry-over effects, pretest sensitization bias, and response shift bias [22], [23]. Drennan & Hyde identify this design as an option in higher education, noting it as a viable option 'to identify the extent to which students change, especially those previously exposed to the constructs being evaluated' [24, p. 708]. Given that some students may have had prior exposure to microelectronics, and considering our focus on detecting changes in students' perceptions, the retrospective pre-test format was deemed ideal for this study.

The survey implemented in this study utilizes the Exposure and Motivation in Microelectronics Instrument (EMM). The EMM was adapted based on the validated Nanotechnology Awareness instrument [25] to focus on exposure and motivation in the area of microelectronics [10]. The purpose of the EMM is to assess students' exposure to the field of microelectronics and their interest in learning more about microelectronics. The survey is designed for students with limited prior formal exposure to microelectronics and was developed to be administered as a pre/post or retrospective assessment to capture changes following an intervention.

The Exposure scale asks students to respond "yes" or "no" to five items about whether they have experienced activities related to microelectronics (e.g., I have watched a video about microelectronics). Reliability of this scale was high for the pre and post-test (α = .82 and .83 respectively). The Motivation scale contains six items that ask students about their plans for next semester (e.g., I plan to… read about microelectronics) on a scale of 1 = strongly disagree to 5 = strongly agree. Reliability of this scale was high for the pre and post-test (α = .83 and .86 respectively).

A third subscale, Awareness, was included based on the original Nanotechnology Awareness instrument [25]; three open-ended awareness items were included to provide more information about students' responses. The Awareness scale contains three items that ask students to rate the extent to which microelectronics impacts their life and society (1 = not at all to 5 = a great deal). Reliability of this scale was high for the pre-test (α = .80), but moderate for the post-test (α = .67).

The Situational Interest Scale was developed by Chen et al. [26] and contains 19 items across 5 dimensions, all measured by a 5-point Likert scale (1 = very untrue; 5 = very true). The dimensions measured include novelty, challenge, attention quality, instant enjoyment, and exploration intention. Reliability of this scale was high (α =.94).

Transformative Experiences (TEs) before and after the interventions were measured using a scale developed by Pugh and colleagues [27], [28]. The TE scale contains 15 items, all measured by a 6-point Likert scale (1 = strongly disagree; 6 = strongly agree). The reliability of this scale was high for both the pre and post-test (α = .94 & .94 respectively).

IV. ANALYSIS & RESULTS

An examination of the results using ANOVAs to compare the two universities revealed no significant differences between the two universities; therefore, the data from each university was combined for the analyses presented here. Examination of the descriptive statistics and the residual plots indicated that pre-post change scores from the TE and EMM scales were relatively normal. Thus, to answer the research questions, four 2 x 2 Mixed ANOVAs were conducted with TE and EMM scores as the repeated measure and gender as the between subjects measure. The results of the ANOVAs are found in Table 2.

As can be seen in Table 2, the interaction between TE and gender was not significant, nor was the main effect of gender. However, a significant increase was found in TE with a large effect size ($d = 1.53$). Similarly, the interaction between EMM Motivation and gender was not significant, nor was the main effect of gender. However, a significant increase was found in EMM Motivation with a large effect size ($d = 0.92$). These results suggest that the interventions had a similar impact for both male and female students for these two outcomes.

TABLE II
2X2 MIXED ANOVA RESULTS

Variable		***df***	***F***	***p***	***d***
Transformative Experiences	Change	1, 82	166.72	< .0001	1.53
	Gender	1, 82	2.94	0.09	
	Change * Gender	1, 82	0.38	0.54	
EMM Awareness	Change	1, 82	118.2	< .0001	M - 0.97 F - 1.60
	Gender	1, 82	9.57	0.003	
	Change * Gender	1, 82	7.13	0.01	
EMM Exposure	Change	1, 82	91.13	< .0001	M - 0.83 F - 1.82
	Gender	1, 82	6.59	0.01	
	Change * Gender	1, 82	6.51	0.01	
EMM Motivation	Change	1, 69	51.35	< .0001	0.92
	Gender	1, 69	2.52	0.12	
	Change * Gender	1, 69	0.4	0.53	

We observed significant interactions for EMM Exposure and EMM Awareness, indicating that the main effects should not be interpreted. Independent samples *t*-tests of the pre and post-tests by gender were conducted as follow-up post hoc analyses. We found significant differences between males and females on the **pre-tests** for both EMM Exposure, $t(82) = 3.03$, $p = .003$, and EMM Awareness, $t(82) = 3.60$, $p < .001$. However, gender differences were not found between males and females on the **post-tests** for both EMM Exposure, $t(82) = 0.81$, $p = .43$, and EMM Awareness, $t(82) = 1.54$, $p = .13$. These results indicated that the experience and awareness gaps between male and female engineering students with respect to microelectronics were reduced as a result of these interventions. In fact, as can be seen in Fig. 2, female students saw larger gains in both EMM Exposure ($d = 1.82$ compared to $d = 0.83$) and EMM Awareness ($d = 1.60$ compared to $d = 0.97$).

V. CONCLUSION

The results from this study suggest that the implementations significantly enhanced students' interest, awareness, and motivation with regards to microelectronics. These factors have direct impacts on student career choices according to social cognitive career theory. Therefore, we can conclude that these kinds of interventions can encourage more students to pursue careers in microelectronics, subsequently addressing the worker shortage in the industry.

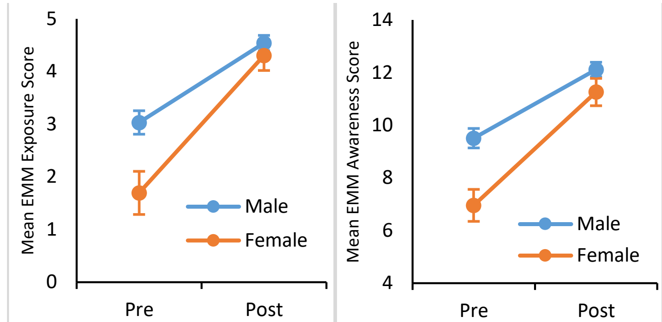

Fig. 2. Pre & Post-Test Results by Gender. (Left) EMM Exposure. (Right) EMM Awareness. *Note: Error bars represent 1 standard error of the mean. The range for EMM Exposure (Left) means are 0 – 5. The range for EMM Awareness (Right) means are 3 – 16.*

Additionally, the results demonstrated that the implementations either had a similar or larger impact for female students. By narrowing the gaps in awareness and exposure to microelectronics, these results suggests that early interventions can potentially have an impact on underrepresented populations in the microelectronics workforce. This study did not have a sufficient sample size to investigate differences across ethnicities or majors, so future research on the impact on underrepresented students across all dimensions is critically needed.

This study observed similar outcomes across two different implementations. Each implementation included narratives that provided context and objectives for the use of microelectronics, focusing on the technology's utility rather than the curriculum attached to it. While these implementations appear successful, the limited data—only two cases—makes it difficult to conclusively determine the key elements of a successful implementation. Additionally, there is uncertainty about whether a poorly executed intervention might lead to negative reactions among students. However, the absence of significant differences between the implementations, along with overall improvements in results, suggests that such interventions at least provide significant exposure and awareness that might not otherwise occur.

Ultimately, it was the workshop intervention that proved to be the successful component of this study, with our findings emerging as a direct result of its implementation. The workshop played a crucial role by equipping faculty with essential tools and knowledge for effective course delivery. This initiative was supported by the Department of Defense (DOD), which backs the SCALE program and provides ongoing assistance to the faculty involved. These educators, in turn, leveraged this support to offer students enriching experiences that benefit both SCALE and, ultimately, the DOD.

The scope of this study is limited, representing a small segment of the broader research needed in microelectronic workforce development at the undergraduate level. In addition, most of the collected data was received from non-first year engineering students, who are the target participant for this study. To effectively enhance the semiconductor workforce, large-scale efforts must examine how curriculum adaptations and educational opportunities tangibly increase students' motivation and interest in the field of microelectronics.

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Artificial intelligence tools, including Microsoft Word's Editor and ChatGPT-4, were used to improve sentences for grammar, spelling, and clarity but were not used to generate original content or ideas.

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