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Analyzing First-Year Students' Motivation and Exposure Towards an Advanced Topic During an Introductory Coding Course

Emily Haluschak

Emily M. Haluschak is a Research Assistant in the School of Engineering Education at Purdue University. Emily primarily works on integrated curriculum for K-2 computational thinking and post-secondary microelectronics workforce development efforts. Her research background is comprised of K-2 student problem scoping and teacher actions in response to implementation of STEM integration in the classroom. Additionally her work in program equity evaluation as part of a graduate degree in education policy led her to refocus on designing curriculum with the goal of expanding access and increasing retention for underserved populations in engineering.

Breejha Sene Quezada

Breejha Sene Quezada is an Engineering Education PhD student at Purdue University.

Gavin David Bidna

Gavin Bidna is a material science and engineering student at Purdue University interested in the ways scientific phenomena and engineering principles can have a positive effect on the world.

Amanda C Johnston (Postdoctoral Researcher)

Amanda Johnston is a lecturer at California Polytechnic State University, San Luis Obispo.

Kerrie A Douglas (Assistant Professor of Engineering Education)

Dr. Kerrie Douglas, Assistant Professor of Engineering Education at Purdue, studies how to improve the quality of classroom assessments and evaluation of online learning in a variety of engineering education contexts. She holds a PhD in Educational Psychology and a M.A. in Educational Studies, with focus on school counseling. She is a co-PI on the SCALE project, leading the evaluation and assessment efforts. She recently received an NSF award to study engineering instructor decisions and student support during COVID-19 and impact the pandemic is having on engineering students. She also recently won the prestigious CAREER award from the U.S. National Science Foundation to study increasing the fairness of engineering assessments. In total, she has been on the leadership of more than $24 million dollars in research awards. Her research on evaluation of online learning (supported by two NSF awards #1544259,1935683,) has resulted in more than 20 peer-reviewed conference and journal publications related to engineering learners in online courses. She was a FutureLearn Research Fellow from 2017-2019; a 2018 recipient of the FIE New Faculty Fellow Award and was the 2021 Program Chair for the Educational Research Methods Division of ASEE.

Tamara Moore

Tamara J. Moore, Ph.D., is a Professor of Engineering Education, University Faculty Scholar, and the Executive Director of the INSPIRE Research Institute for Pre-College Engineering at Purdue University. Dr. Moore's research is centered on the integration of STEM concepts in K-12 and postsecondary classrooms in order to help students make connections

among the STEM disciplines and achieve deep understanding. Her work focuses on defining STEM integration and investigating its power for student learning. She has examined different mechanisms of bringing engineering content and standards into the classrooms that led to a framework for quality K-12 engineering education. Dr. Moore's team has developed several sets of instructional modules for elementary and middle school learners that employ engineering and literacy contexts to integrate STEM and computational thinking content in meaningful and significant ways. In 2012, she received a U.S. Presidential Early Career Award for Scientists and Engineers (PECASE) for her work with urban youth. In 2016, she received Purdue University's Faculty Engagement Scholarship Award for working with teachers and students across the United States on teaching and learning engineering.

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Technological innovation has heightened the need for specialized workers trained in niche STEM-related fields. The pandemic has only exacerbated this growing trend of workforce shortages. Specifically in the field of microelectronics, 77% of manufacturers polled in 2018 by Deloitte cited talent shortages as a major concern. There is a critical need to develop strategies to train and retain workers to satisfy industry demands. One challenge to meeting the educational demand is that niche topics within microelectronics, such as radiation hardening and heterogeneous integration & advanced packaging, are relegated to upper-level courses if taught at all [1]. Before they reach these upper-level courses, students often have had internships or co-ops and considered areas of specialization. Thus, students have likely decided on a career path long before they have awareness of the existence of the high need areas in microelectronics.

The goal of this study was to give students exposure to a critical but lesser known industry and provide resources to interest students while supporting their growth in potential career fields. To do this, a multi-university effort, the Scalable Asymmetric Lifecycle Engagement (SCALE) was launched supported by the US government. One of the many project goals is to introduce microelectronics contexts in a variety of undergraduate courses. It is vital that when looking at career choices, interventions start happening as soon as the institutions receive their students, which for an increasing number of universities is during a First Year Engineering (FYE) program [2]. One of the introductory courses was targeted using multiple microelectronics interventions through modules and assessment questions. Students were then surveyed on their exposure to, awareness of, and motivation for the field of microelectronics. Although microelectronics content may not fit within FYE coursework, the real-world context of microelectronics can be used to expose students to the field early in their academic careers.

The purpose of this study is to examine the connections that first year engineering students are able to make between their class content, their careers, and upper-level topics. Our research questions for this study are: How do first-year engineering students conceptualize microelectronics after introduction to microelectronics contexts within computer programming learning experiences? To what extent do first-year engineering students connect their interest in and understanding of microelectronics to their future life?

Literature Review

In this section we investigate previous research on Social Cognitive Career Theory (SCCT), early exposure to career fields, and ways of measuring student exposure, awareness, and motivation [3]. The SCCT model has been used continuously throughout the workforce development project, in which our study is embedded, to inform decisions made about the overall structure, design of interventions, and evaluation process. The importance of exposing students to career related options early is the rationale behind the interventions used in this study, specifically why we implemented them in an introductory engineering course. To understand how students conceptualize microelectronics and connect microelectronics to their future lives we need to have a way of assessing student awareness of and interest in microelectronics as a career field.

Social Cognitive Career Theory (SCCT) takes inspiration from the constructivist idea about individuals, in this case students, having influence over their own development [3]. SCCT applies this specifically to careers to explain the motivators which drive career choice and therefore can be used to target the key components in the model. Career development takes place on an individual or localized basis, and this study strives to extend SCCT to workforce development applications. Our workforce development project has utilized the interest model shown in Fig. 1, to create interventions for undergraduate level coursework with the goal of increasing student exposure in microelectronics.

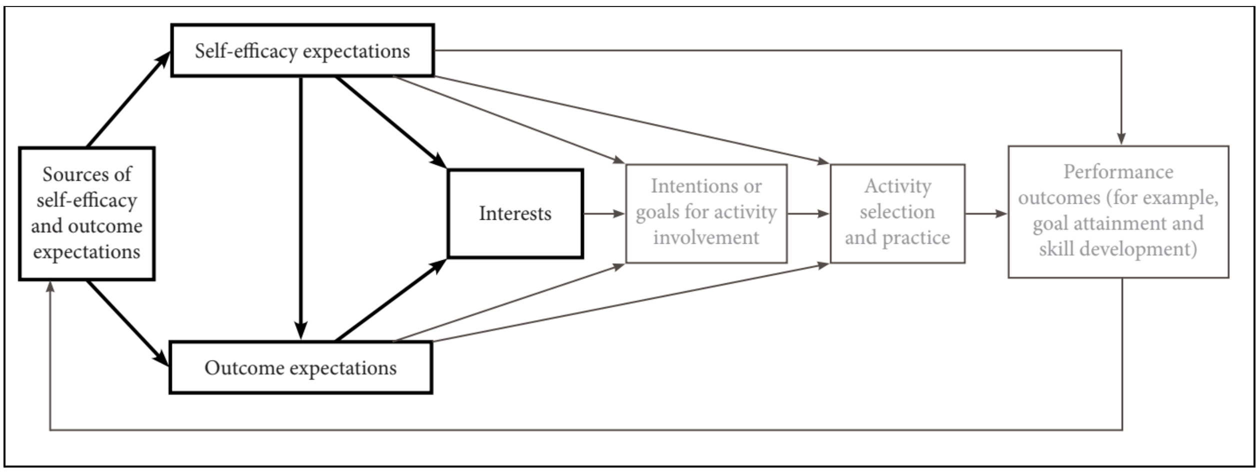

Fig. 1. Social Cognitive Career Theory Interest Model Flow Chart. Adapted from [3]

Students having an idea about what they as individuals can contribute to a field (self-efficacy), and developing outcome expectations for their schooling and career can trigger the following stages in the flowchart. The program that is being developed aims to be a source of activity selection and practice, eventually certifying performance outcomes for the students. SCCT was used in the planning and development of this program, and Figure 1 outlines many of the aims of the program. Although the project as a whole aims to target all aspects of the SCCT model, the focus of the early stages is outcome expectations, self-efficiency, and interests. These are three out of five of the factors which are primarily responsible for career choice as explained in [3]. Students' ability to connect interest and understanding of microelectronics to their future personal and professional lives directly relates to outcome expectations. These connections help assure students of the viability of the microelectronics industry, and its potential to improve society as a whole. Student self-efficacy is also a contributor to student interest, but exploring this particular aspect is outside of the scope of this study. All of these components are examined with the data-backed expectation that exposure followed by stimulated motivations increase the chances that a student will choose a specified career path [4]. To bolster self-efficacy, outcome expectations, and interests, students first need to be exposed to the field of microelectronics.

The root of motivation and career choice is exposure, because exposure sets off all of the other factors that educators, recruiters, and students participate in to bolster niche industries [4]. When students start engineering programs where they have to select a major, "the knowledge of the major is either superficial or limited" [5]. Considering an FYE program may be students' first source of engineering knowledge, it is a useful space to incorporate exposure to potential career paths as well as technical knowledge. Additionally, many students who pursue a science-related career indicate this intention from a young age [2]. Early career-related decision making coupled with limited student knowledge of their options provides the support for integration of advanced topics in FYE curriculum. Exposure and interest should be targeted just as much as technical skills to increase student awareness of niche fields as early as possible in students' academic careers [2].

In an effort to answer our research questions we utilized a survey instrument to investigate student exposure, awareness, and motivation related to microelectronics. This survey was modified from an instrument used to understand undergraduates' nanotechnology awareness, exposure, motivation, and knowledge [7]. Once modified to fit the microelectronics context instead of a nanotechnology context, Gentry [7] examined the factor structure and item sensitivity of the adapted version of the exposure and motivation scales. They found the modified survey scales to be consistent with the original nanotechnology survey when administered to first year engineering students after receiving exposure to a microelectronics context [7]. This paper will discuss the awareness component as it pertains to first-year students and the connections they make to microelectronics. The reliability of the exposure and motivation scales allows us to make more accurate observations with the data that we collected [7]. Exposure to, awareness of, and interest in microelectronics is the focus of the survey questions and responses we analyzed to address our research questions.

Methods

To answer the research questions we surveyed students after receiving multiple context level microelectronics interventions in a FYE programming-heavy course. We conducted a qualitative study of the responses to analyze student awareness of microelectronics as a field. In addition, we utilized the supporting quantitative data to describe student exposure to and motivation for microelectronics.

Context

The course selected for the intervention was the second in a series of two introductory engineering courses. The second course focuses on teaching engineering analysis and computing by using contextual engineering analysis problems and having students solve these problems by programming in MATLAB. In this three credit hour course, assignments usually consist of an introduction to an engineering problem and a related programming analysis task. For this project, we created two interventions and then surveyed the students to understand their exposure, awareness, and motivation regarding the field of microelectronics.

The participants (n=201) were first-year engineering students, transfer students, or students switching majors in two sections of a standard introductory engineering course mainly focused on engineering analysis and computing. As they were primarily general first-year engineering students, they were expected to matriculate into a variety of engineering disciplines at the end of the semester in which our data were collected. By utilizing a population of students in a general engineering course heading into a wide range of majors, the project leadership was hoping to increase the impact for the microelectronics context interventions. We focused on the introductory class because [2] shows that exposure to career fields should happen as early as possible to increase student interest.

The interventions were delivered during a pre-class video and a course assessment and spaced throughout the course. The first intervention was an 18 minute pre-class video used in the flipped-classroom approach to teaching MATLAB coding, which introduced students to user-defined functions in MATLAB using the context of radiation shielding. This microelectronics context occupied 13 minutes of the video with the remaining five focusing on the coding content. The second intervention tested the students' ability to apply conditional statements, while introducing them to the topic of radiation hardening in the context of microelectronics. Students were given a list of microchips and associated radiation hardening values and were tasked with choosing the most appropriate chip for the given conditions. The goal of the interventions was to increase student exposure to the field of microelectronics by embedding the microelectronics contexts, in this case radiation shielding and radiation hardening, to the existing course content. The first intervention occurred in week five of 16. The second intervention happened in the eleventh week. Two weeks later, students were offered to take a survey for extra credit. The survey, adapted by the assessment research team from a study on students in nanotechnology, contains questions about students' exposure, awareness, and motivation in microelectronics [6]. Additionally, Gentry [7] examines the factor structure and sensitivity of the instrument, confirming the validity for use in introductory-level engineering courses.

The survey contains a Likert-type scale for two factors as well as open-ended questions to learn about the connections students could make between the microelectronics context and the work of professional engineers. The Likert-type questions ask students to rank their exposure and motivation related to microelectronics on a 5-point scale from 1-strongly disagree to 5-strongly agree. The first factor consists of five questions which target student exposure and the second factor consists of six questions which target student motivation [7]. The three open-ended questions targeting student awareness will be referred to throughout the study as questions A1, A2, and A3, outlined in Table 1 below. After administering the surveys we collected student responses and proceeded with the analysis process. Through the rest of the paper we will refer to the Likert-type responses as the quantitative data and the open-ended responses as the qualitative data. Since the data were only collected as a post-intervention survey, we will report both the quantitative and qualitative results, but the majority of our analysis and discussion will focus on the qualitative results of the survey.

Table 1. Open-Ended Questions

Questions Targeting Student Awareness	
A1	Please list an example of how work in microelectronics directly impacts your life
A2	Please list an example of how work in microelectronics benefits society or humanity
A3	Please list an example of how work in microelectronics may directly impact your life in the future

Analysis

The survey data were de-identified and cleaned based on several elimination criteria. Data were removed if students did not correctly respond to a filter question which prompted students to select “somewhat agree” if they were reading the survey. If students selected any other option besides “somewhat agree” to the filter question their survey data was removed as we interpreted this response to mean the students did not read the survey questions as they responded. Data were also removed if students did not respond to the open-ended questions as this was the main focus for the analysis. Once data were cleaned and de-identified, there were 178 student responses to be analyzed. Regarding the Likert-type scale, descriptive statistics were calculated for the two factors. To understand student awareness of microelectronics, two undergraduate researchers and one graduate researcher undertook a thematic analysis of the student’s open-ended responses. First, we used open coding individually which we then applied to the responses, establishing a preliminary code book. After this initial analysis, we discussed how to group similar codes in an iterative process to obtain a more refined codebook. Using the refined codebook one undergraduate and one graduate researcher both coded the student responses separately. We then discussed any mismatched codes to consensus then identified central themes emerging from the codes. The codebook and corresponding thematic analysis of the open-ended awareness questions will be described in more detail in the next section.

Students' responses to question A1 centered around four themes. It was also noted that 11 students indicated work in microelectronics had no impact on their lives and three students referenced the context of the microelectronics intervention. Analysis of question A2 yielded three themes as well as five responses referencing the context of the intervention. When coding question A3, six themes emerged along with two responses of students indicating microelectronics would have no impact on their lives in the future. The themes used in the qualitative analysis are shown in Table 2 below.

Table 2. Thematic Codes

Question A1	
Career development	A focus on future endeavors and classroom preparation for a career
Electronics	Using devices like phones, laptops and gaming systems or referencing more efficient, compact technology
Education	Accomplishing tasks for school often grounded in the context of remote learning often due to the pandemic
Health	Referencing the medical field or medical devices which include microelectronics
Question A2	
Innovative technology	Technological development specifically more compact, efficient, inventive devices
Quality of life	Improved quality of life including accessibility, safety, security, sustainability, and economic stability
Societal shift	Transformative periods of change including large scale production, automation development, and other societal advancements
Question A3	
Career focus	Mentioning the microelectronics field as a career path of interest
As a tool	Using microelectronics in day to day job life or as a microelectronics embedded technology
Evolving technology	Incremental changes to already existing technologies
Revolutionary technology	New of cutting-edge technologies that would greatly impact society
Quality of life	Improved quality of life including healthcare, safety, accessibility & sustainability

It is important to note that some responses received multiple codes, as they incorporated multiple different themes together. The frequencies of each code were then analyzed and graphed to better visualize the trends emerging from the themes. Next we will summarize and discuss the results.

Results & Discussion

In this section we will summarize what we can learn from the quantitative results about student exposure and motivation but mainly focus on what we can learn about student awareness from the qualitative results. The quantitative analysis shows that on average, student motivation to engage with microelectronics is 34% higher than student exposure to microelectronics related activities. From these results we conclude that students are motivated to learn about microelectronics and there are opportunities to increase student exposure to the field. The qualitative analysis shows that student responses vary greatly when asked how work in microelectronics impacts their life, society and their future. The vast range of student awareness of microelectronics applications gives educators many opportunities to expose students to the field in ways that target a variety of student interests.

Quantitative Analysis

The first step in understanding student data was to find the sum of student responses within each scale. These sums make up student scores for the exposure and motivation scale. Analysis of the student scores from the Likert-type data is displayed in Figure 2 below.

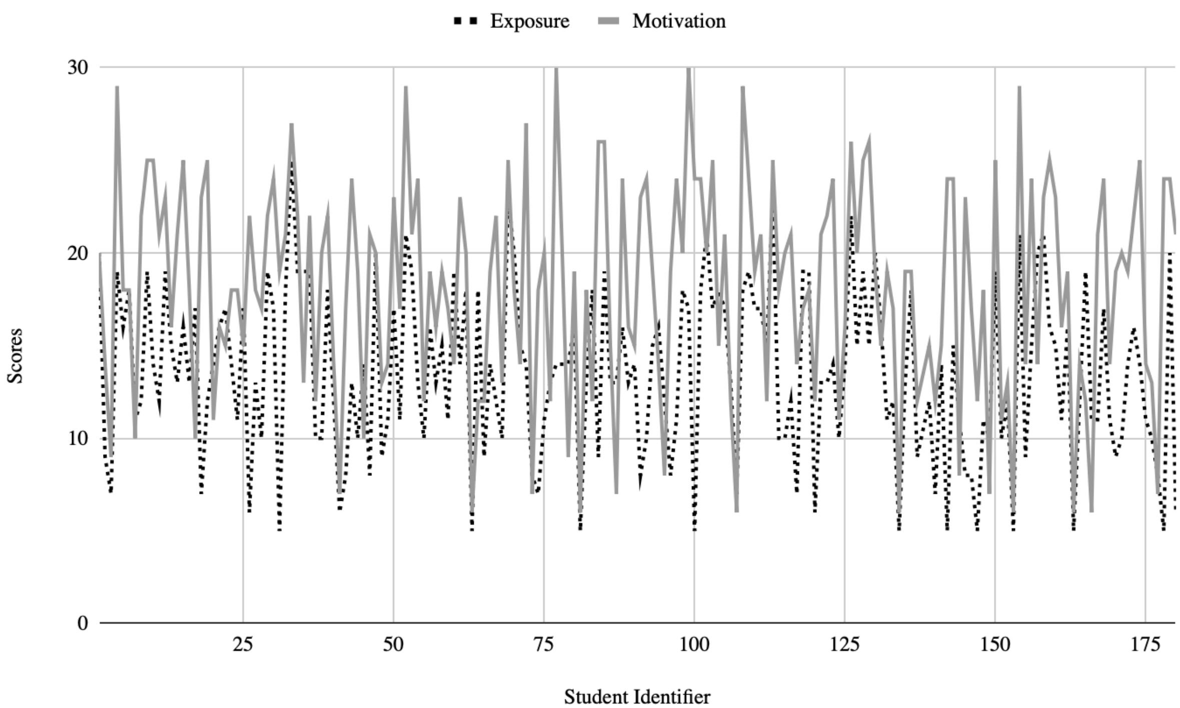

Fig. 2. Student Scores for Exposure and Motivation

As shown in Figure 2, student motivation on average is higher than student exposure to microelectronics. This is supported with the descriptive statistics of each average score. The mean of the student scores for the exposure scale is 13.5 where the mean for the exposure scale is 18.11. The standard deviations for exposure and motivation are 4.52 and 5.82 respectively.

The quantitative results can be used to understand the trends and differences between student exposure and motivation in microelectronics. As average student motivation is 34% higher than average student exposure, we can see there is an opportunity to increase student exposure to meet existing student interest in microelectronics. There is sufficient motivation among students in introductory engineering courses to advocate for microelectronics context-related interventions which aim to increase student exposure.

Qualitative Analysis
In this section we will first use the coding frequencies as displayed in Table 2 to introduce the trends in student responses to questions about their awareness of microelectronics as a field. We will also expand on the qualitative analysis of microelectronics awareness using examples from student responses to each question. Finally, we will summarize the trends across the questions to describe overall student awareness of the field of microelectronics.

Table 3. Percentage of Students with Occurance of Code

Codes	Total Code Occurrences	Percent of Students Per Code
Question A1		
Career development	16	8.99%
Electronics	150	84.27%
Education	22	12.36%
Health	3	1.69%
No impact	11	6.18%
Reference context	3	1.69%
Question A2		
Innovative technology	143	80.34%
Quality of life	86	48.31%
Societal shift	34	19.10%
Reference context	5	2.81%
Question A3		
Career focus	20	11.24%
As a tool	69	38.76%
Evolving technology	80	44.94%
Revolutionary technology	22	12.36%
Quality of life	43	24.16%
No impact	2	1.12%

Question A1: "Please list an example of how work in microelectronics directly impacts your life"
Answers to A1 generally showed that most students are aware of the impact of microelectronics on their lives. Most responses focused on consumer electronics like phones and computers. Other prominent themes include discussion of their impact on education, healthcare and careers. Roughly six percent of students indicated that microelectronics has no impact on their lives.

Responses in this section overwhelmingly focused on ubiquitous electronics like smartphones, computers and gaming consoles. Most of these answers contained no more substance than simply stating that microelectronics are essential to the functioning of a specific device, however some responses went into more technical detail. One such student wrote "Microelectronics are everywhere, for example accelerometers in your phone are normally microscale electronics. As other technology and sensors decrease in size, things like phones can have more space for batteries or can take up smaller footprints." The responses show the spectrum of awareness that students have about microelectronics, with the former demonstrating a basic acknowledgement of the importance of microelectronics and the latter indicating a deeper understanding of the ways that microelectronics helps technology progress. It's also important to note that many responses of this type also were given codes in other categories such as healthcare or education.

Students also focused on the downstream effects of microelectronics to other parts of their life, such as their education, healthcare and their career. As the survey was taken after the onset of the SARS-CoV-2 pandemic, remote and technology-assisted education became common-place. Many students understood the effect that microelectronic devices have on their ability to complete their schoolwork and participate in class in this paradigm. Other students mentioned the use of microelectronics in medical and health-related devices, such as step counters and blood-sugar monitors. Finally, a portion of the students indicated that they have used or been exposed to microelectronics in a career development setting, such as in a classroom or internship. All of these examples indicate the students' awareness of niche applications of microelectronics.

Eleven students stated that microelectronics has no impact on their lives. Interestingly, one of these students referenced the context of one of the interventions, radiation hardening of microelectronics, but did not tie it into their own life. Overall the analysis of responses to A1 shows student awareness of the roles microelectronics plays in daily life specifically in devices like phones and laptops which they often attribute to improved efficiency.

Question A2: "Please list an example of how work in microelectronics benefits society or humanity"
Student responses to A2 indicate a general awareness of how microelectronics benefits society as a whole. We used the codes described in the methods section to group student responses into innovative technology, quality of life, and societal shift. Most students referenced an innovative technology, half of students mentioned an increase in quality of life and a smaller group of students alluded to societal shifts. In addition to these codes, five students referenced the context of one of the microelectronics interventions.

Over 80 percent of student responses touched on technological development either through refinement of existing technology or through invention of new devices. Student responses coded as innovative technology often mentioned microelectronics aiding the design of more efficient, compact devices. Just under half of the student responses included how microelectronics can increase quality of life. Responses coded as quality of life often included components like increased accessibility, safety, sustainability, and economic stability. The final code which was only identified in about 20 percent of student responses includes mention of large-scale societal shifts as a result of work in microelectronics. Student responses often included transformative periods of change like large-scale production or automation as well as other impactful societal advancements.

There was frequent overlap between multiple codes in which many students mentioned technological innovations to make devices more compact therefore using less materials which leads to better sustainability ensuring increased quality of life. Some students took this logic a step further alluding to past and possible future societal shifts due to fundamental changes in production and automation of the more compact, sustainable devices.

Question A3: "Please list an example of how work in microelectronics may directly impact your life in the future"

Students' responses to A3 also demonstrate good awareness of the impact of microelectronics. Responses focused on themes such as the use of technology as a tool in a job, choosing microelectronics as a career path, the incremental evolution of technology, the advent of revolutionary technologies and future effects to quality of life.

About half the students reference their future career in their response, with some forecasting their use of microelectronics as a tool and others indicating their intention to choose microelectronics development as a career. Answers about the use of microelectronics as a tool focused heavily on engineering applications, such as using microcontrollers as components in larger systems and relying on simulation and computer-aided design software. These responses reveal that many students are aware that they will need to use microelectronic products in their job. Students that indicated a career focus in microelectronics described their career aspirations in varying levels of detail. These students are not only aware of the effects of microelectronics, but have a high enough interest in the field to pursue it as the focus of their career.

Slightly less than half of the students gave an answer related to the incremental progression of technology. These answers detailed how as microelectronics improved, engineers could create better versions of the things we already have, such as faster and smaller processors. This demonstrates that the students are not only aware of the current state of microelectronics, but understand how the industry might develop. Additionally, some students detailed cutting-edge technologies that would be highly disruptive if made commercially viable. The feasibility of these technologies varied from teleportation devices to brain-computer interfaces to quantum computers, but nevertheless, these ideas show that students are aware that the field's rapid pace of innovation allows for things that were once thought impossible to be done.

Some students identified that microelectronics will affect their lives by increasing their quality of life. Responses of this type explained how microelectronics might make society healthier, safer, more accessible, and more sustainable. Students often brought up medical devices or the possibility of increasing small microelectronics in our body to demonstrate specific ways that microelectronics could make people healthier. Students also focused on the increase in safety brought by the advent of autonomous vehicles and others commented on how work in microelectronics might make them more sustainable. These students have demonstrated that they are aware not only of the uses of microelectronics, but also how those uses might be benefiting people. Lastly, just over one percent of students indicated that they thought microelectronics would not impact them in their future.

The qualitative results can be used to understand student awareness of microelectronics and the connections they may make within the field between themselves and society as a whole. We can use the differences observed between questions to make recommendations about the types of interventions to include in future workforce development opportunities. Responses to A1 and A3 were more focused on the student individually while responses from A2 were applicable to groups of people and society as a whole. From A1 to A2 students shifted from talking about technological devices to discussing the purpose of technological development in microelectronics. From A1 to A2 to A3 students generally shifted from microelectronics affecting their daily life on a small scale to viewing microelectronics as a career option with a purpose to justify their response.

Throughout the analysis we have worked to understand how students conceptualize microelectronics after the interventions and how they connect their interest in microelectronics to their future careers. We can see that depending on the awareness question, students' concepts of what work in microelectronics means can change. Students are able to connect to possible careers in the field and show motivation for continued exposure to microelectronics. In the investigation of student exposure, awareness, and motivation related to microelectronics we can use our qualitative analysis with quantitative support to provide evidence for increasing student exposure to microelectronics as well as recommend criteria for possible microelectronics interventions.

Limitations & Implications

Limitations to the Study

Students were not given a traditional pre-post survey, so we are not able to conclude if their exposure and interest in microelectronics was changed by the intervention. This was considered acceptable because the goal of this study was to give exposure to an advanced topic, and not immediately try to assess student progress. The same thinking is also the reason that this study did not look at the accuracy or correctness of student performance on the knowledge assessment that this survey was paired with. In the future, this may be an interesting relationship to examine to see if proficiency in the programming topic has any correlation to the interest in the advanced topic as a career choice.

Student demographics such as gender and socioeconomic background were also not collected as part of this study. We are able to reach no conclusions about these metrics as having an impact on exposure, motivation, and awareness toward microelectronics or to advanced topics in general. As equitable curriculum development and workforce retention is of the utmost importance, demographic metrics should be included in future studies especially when investigating the relationship between the content knowledge and awareness of the microelectronics context.

Implications
We can conclude that there is ample student interest in microelectronics and capacity for growth in the amount of exposure FYE students experience to microelectronics as a field. When asked to reflect, these students are able to make connections to their future career and consider what work in microelectronics means for society as a whole. Even with relatively minimal exposure some students were able to make connections back to the context of the interventions. This is affirming for instructors of FYE students who are interested in giving more opportunities for student exposure to the field of microelectronics. We plan on incorporating more interventions of upper-level material as contexts in introductory coding courses. These new exposures will also be thoroughly studied so that we may get a better view of their cumulative impact.

A potential avenue for future work includes examining more sections of this course with pre-post surveys to investigate the intervention's effectiveness and suggest changes if necessary. Incorporation of assessments to investigate student knowledge and self-efficacy could offer some insight into how the program can be adapted to both serve student success and increase interest in microelectronics, with potential application for other niche fields. Although the integration of a novel context in existing course content is an accepted practice in engineering education it would be interesting to see how this works in FYE programs with fields outside of microelectronics.

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