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Using Contexts within Assessments to Increase Student Exposure to Microelectronics

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Introduction

This First-Year Engineering complete paper describes a study using curricular context in a required course to expose students to a specialized engineering career field. Microelectronics are pervasive in everyday life, from smartphones to life-saving medical devices and GPS navigation to home thermostats. Vulnerabilities in U.S. microelectronics workforce capabilities have been a known factor within the industry since the early 2000s [1]. While the demand for microelectronics has surged, the U.S. industrial base has consolidated mainly into a few suppliers [1], [2] with limited technical capabilities in the workforce to scale up. The U.S. is encountering a growing gap between its need for microelectronics design and manufacturing capabilities and its ability to meet these needs domestically, resulting in an undesirable dependence on foreign suppliers. Although several U.S. universities, in partnership with U.S. Defense organizations and private contractors, have become more active in the fields of microelectronics, there is still a challenge in recruiting enough students and workers for this sector. Because areas of microelectronics are crucial to the security and economic growth of the U.S. and its allies, there is a high demand for engineers and technicians skilled [3] in secure communications, vehicles, weapon systems, and other efforts to support the DoD's peacekeeping mission [1], [4]

There are several barriers to achieving a sustainable, secure microelectronics workforce. One significant barrier to meeting the demand is the limited public awareness of the field of microelectronics, i.e., one needs to know about a particular career if one is going to pursue that career path. Chip shortages have become public knowledge through the news media [2], [3], and the COVID-19 pandemic illuminated the general public about severe shortages in microelectronics capabilities (e.g., semiconductors, chips, etc.). However, the general public has little exposure to specific fields of microelectronics, such as radiation hardening and advanced packaging [5]**.** Students entering engineering are typically not exposed to or aware of the field of microelectronics [6]. According to del Alamo and colleagues (2021), undergraduate engineering students who know about it are apathetic toward microelectronics and fail to see the importance of microelectronics in solving significant global problems. For example, previous research found that introductory-level engineering students are largely unaware of the broader role of microelectronics in the U.S. Defense's peacekeeping mission and protection of our society [7]**.** Another significant barrier is that the specific areas of demand are topics that are not introduced until more advanced engineering coursework, long after many students have started having internships and cooperative education experiences. Exposing engineering and technology students to microelectronics early in their academic studies is necessary. Hence, they know about specialized topics in microelectronics while making further educational and career decisions.

One approach to increasing beginning engineering students' exposure and motivation to pursue microelectronics topics is to devote an entire class to microelectronics. However, a fourteen-year study on the effect of an introductory course devoted entirely to microelectronics found that, while a dedicated class exposed students to the field and generated interest in 1/3 of the students in the course, it was also perceived as a boring obstacle for the other 2/3 of students [8]. This finding leaves room for investigating different ways to introduce beginning students to the microelectronics field, attracting those who are predisposed toward interest without the downside of devoting an entire indroductory class to microelectronics.

This study examines a different approach to increasing engineering students' exposure and motivation to pursue microelectronics topics. This approach embeds specialized microelectronics topics as a context in three assessment assignments administered in a fundamental engineering course. The course's learning objectives remain the same, but assignments and other assessment problems have contexts within real-world microelectronics problems, which point to a possible career in microelectronics. This paper examines changes in engineering students' exposure and motivation to microelectronics when microelectronics contexts were integrated into a fundamental first-year engineering course. The research questions are as follows: *To what extent do engineering students recognize their exposure to areas in microelectronics when assignment problems are situated in real-world microelectronics problems? How do students' motivation to pursue a career in microelectronics differ after this limited curriculum intervention?*

Literature Review

The Role of Interest in Career Development

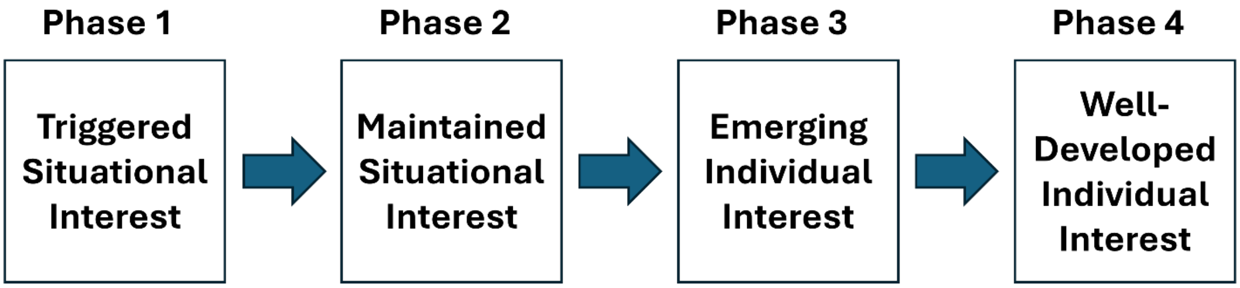
Social Cognitive Career Theory (SCCT) [9] is an overarching conceptual framework that guides all of the decisions of the Scalable Asymmetric Lifecycle Engagement (SCALE) project. SCCT emphasizes the role of relevant interests in career development. Within SCCT's Choice Model and Interest Model, interest directly links self-efficacy, outcome expectations, and career-related choices [9]. Because of this, many studies seeking to affect student's interest in engineering careers focus on increasing student self-efficacy and outcome expectations. In SCCT, interests directly relate to choice goals, and self-efficacy and outcome expectations directly and indirectly (through interests) relate to choice goals [10].

Contextual Influences mediate the relationships between different factors of SCCT and choice goals. SCCT posits that career-relevant interests are mediated by a person's interaction with events in their environment, including their academic environment. Factors in the educational environment can shape learning experiences that "fuel personal interest and choices" [11]. According to Lent et al., who use the terms contextual and environmental factors interchangeably when referring to career-relevant influences [9], environmental influences play a crucial role during the educational phase of career development. Lent, Brown, and Hacket state, "it is essential to study those aspects of the environment … that can facilitate career choice and development." [9] Lent et al. distinguish between distal and proximal environmental factors. Proximal factors, which play a role at "crucial choice junctures," include students' experiences in the academic environment [9]. This study focuses on one proximal factor in the first-year engineering educational experience: the context of curricular problems.

Contextual Factors Influence Interest

This study uses curricular contexts within a first-year undergraduate engineering classroom to foster knowledge of and interest in microelectronics as a career field. SCCT provides the broad framework for our decision to use the environmental factor of curriculum to affect students' interest in microelectronics. However, within SCCT, interest is driven by self-efficacy and outcome expectations. Because students in this study are first-year engineering students, increasing students' engineering self-efficacy, outcome expectations, and interest in engineering (in general) is not our goal in this study. Our conception is that these students already have a base level of self-efficacy, outcome expectations, and interest in engineering by virtue of their matriculation into an undergraduate engineering program. They already have a general base level of interest in engineering and an engineering career. This study aims to affect undergraduate students' knowledge of and interest in microelectronics careers early in their academic journey, which is a more fine-grained level of interest generation. We are specifically interested in whether or not and how the curriculum intervention affects student knowledge of and interest in microelectronics. Students can not become interested in a field they lack knowledge of. For this reason, we look to a second theory that more directly addresses interest development, The Four-Phase Model of Interest Development [12], show in Figure 1. For this study, we take direction from the first three phases of the model: Triggered Situational Interest, Maintained Situational Interest, and Emerging Individual Interest.

Figure 1: Four-Phase Model of Interest Development



The first phase in the Four-Phase Model of Interest Development is Triggered Situational Interest. In Phase 1, instructional conditions, learning environments, and environmental or textual features can provoke situational interest in a topic. The role of environmental or textual features in the learning environment and instruction holds promise for our brief curriculum intervention's ability to spark students' situational interest in microelectronics. In the academic environment, an instructor directly influences the context in which learning activities occur. Instructors can use this influence over contextual learning to generate interest in specific careers. One contextual learning technique instructors can use is to embed concepts into a fictional scenario, such as a homework problem. Embedding concepts into fictional scenarios can yield both the instructional and motivational benefits of contextual learning [13]. Instructors can direct students' interest toward a topic by making the purpose for which they are reading crucial to them. When a reader views the information as vital to their purpose for reading, it becomes more interesting to them [14]. In such cases, interest becomes another "contextual (environmental) constraint" [14].

There does not need to be a deep level of context to generate interest. Situational interest can be generated with only moderate exposure to a topic, leading to students developing individual (topic) interest [13]. Additionally, moderate exposure to a topic increases topic knowledge, which is associated with high cognitive interest and recall of information [13]. Instructors can increase cognitive interest and recall in a topic by providing a small amount of background knowledge [15]. Students, through participation in a semester-long class on programming, develop a level of background knowledge needed to understand the realm of microelectronics. The subjects covered in the first-year engineering class provide background knowledge relevant to microelectronics, thus laying the groundwork for increased cognitive interest.

Phase 2 of the Four-Phase Model of Interest development, the Maintained Situational Interest phase, involves sustained interest after an initial trigger. This sustained interest can either persist or re-occur over a period of time. Instructional modes such as project-based learning and group work that provide an engaging environment contribute to developing and maintaining situational interest [12]. Intermittently placing the microelectronics context problems throughout the semester facilitated re-occurring exposure to microelectronics over the sixteen-week course.

In Phase 3, Emerging Individual Interest, the learning environment and instruction also enable students to transition from situational to emerging individual interest. In this phase, students indicate positive feelings, stored knowledge, and stored value for the topic. Understanding that topic knowledge and interest are "reciprocally related" [16], we can begin to infer a change in interest by measuring changes in students' knowledge of microelectronics. The level of knowledge we seek to measure is shallow, considering the limited nature of the interventions. Therefore, it is sufficient that students go from little or no exposure to recognizing their exposure. This exposure to electronics may generate motivation. Students who show increased recognition of exposure to microelectronics after the interventions indicate that they have gained and retained some knowledge about microelectronics.

The link between topic exposure, individual interest, and topic recall provides the basis for an approach that instructors can use to influence the context in which they introduce materials. By measuring any changes in exposure to the topic, instructors can capitalize on this link between exposure and interest to facilitate greater interest in the desired subject. An increase in student recognition of exposure can help us surmise whether or not we have potentially affected student interest in microelectronics.

Background of Curriculum

For this study, we define our environmental support within the context of curriculum interventions.

Contexts:

1. The curriculum must motivate students to want to participate in the learning activity.
2. The curriculum must allow for personal meaning to the student in some way or another [17].
3. The curriculum needs to connect to the reality of being an engineer [18]
4. From a workforce development aspect, the curriculum needs to introduce students to the microelectronics area related to the problem.

We used context-based problem-solving to design curricular innovations that meet the above criteria for contexts.

The course in which the curricula were implemented is an introductory course on computer programming and engineering analysis using MATLAB as the computer tool. MATLAB is required for all first-year engineering students in the university's College of Engineering. This course is the second in a two-course sequence needed for all first-year engineering students at the university.

The learning objectives of this course help students learn the fundamentals of programming, including understanding and implementing user-defined functions, sequential structures, selection structures, repetition structures, and nested structures while using professional programming standards. One goal of the course is to expose students to various contexts, fields of engineering, and significant efforts relevant to the times. Therefore, the programming skills are applied while students solve engineering analysis problems situated in real-world contexts.

The course is a two-credit-hour studio course structured such that the first ten weeks are dedicated to learning the fundamentals of programming in the MATLAB environment using both skill-based problems with no context and small engineering context problems as weekly individual homework. The last six weeks are dedicated to applying their programming knowledge within a complex engineering analysis project with four milestones completed in a team of three or four students. Each class meeting was 110 minutes, and met two times per week. During the first ten weeks of the course, each class session was divided into two approximately equivalent time blocks, with the first block dedicated to instructor-facilitated, hands-on, active learning to deepen their understanding of the content and develop the ability to integrate the ideas with other programming structures and apply them to engineering problems. The second time block was dedicated to students having unstructured work time to outline the context-based homework problems with their team and then solve them individually. At the same time, the instructor and teaching assistants were available to answer questions and provide guidance. The curriculum uses multiple real-world applications from electrical, materials, aeronautical, and mechanical engineering domains; however, this study only focused on the results of introducing new problems situated in a microelectronics context.

Specific Microelectronics Contexts in the Curriculum

Knowing the need to add a microelectronics context to the class, the curriculum design team wrote many MATLAB coding problems utilizing this context. To do this, they looked for microelectronics articles that they could connect to the learning objectives and content of the class. Of the many problems devised by the team, the course instructor picked three problems to implement during the Fall semester. The total number of problems for the class appears in Table 1. The ratio of microelectronics context problems to all course problems was 3/95. The time for students to complete all three problems set in a microelectronics context was less than two hours across the semester.

The SCALE project's focus on microelectronics provided contexts for the curricular innovations developed for the programming course. We designed and implemented three context-based problems in the course: one context problem for individual homework, one video module problem, and one context problem for one of the three take-home exams in the course. Table 2 outlines the nature of these three microelectronics contextual problems. The students had no other class-based interventions or lecture discussions of microelectronics throughout the course. The purpose of using these particular contexts within the first-year programming course was to increase student exposure to the field of microelectronics, particularly in radiation effects and system-on-chip.

Table 1: Assessment/Instruction Assignments for the Semester

Type of Assessment/Instruction	**Description**
Homework	Students are given approximately 45 homework problems across the semester. This is broken down into 10 homework assignments, each with approximately four problems.
Exam	Students are given three exams during the semester. Each exam has approximately six questions. The final exam is a take-home exam with eight questions.
Code-along video tutorials	Students are given 31 code-along video tutorials as part of a flipped learning environment. In these tutorials, students are given portions of code to imitate.

Table 2. Microelectronics Context Problems

Week Introduced	Type of Problem	Description
Weeks 2 - 3	Homework	The homework was context-rich and covers the plotting content in MATLAB. The context of this problem is integrated circuits in the system-on-chip area of microelectronics, focusing on data regarding interconnect delay and gate delay. This question was designed to take approximately one hour out of a 2.5 hours homework assignment for the week.
Week 5	A Video module in a flipped class format	The video was designed to introduce students to the concept of user-defined functions (UDFs) in MATLAB. The 18-minute video was used as a pre-class introduction to the content in a flipped-classroom format. Within the video, the problem focused on the context of radiation shielding, with 13 minutes of the video dedicated to the problem (the other five minutes devoted to syntax and structure related to UDFs). The video is available here: https://youtu.be/kHXM0EZZpOI?si=2NI1XWQJRiZK6x4H
Week 11	A context problem for a take-home exam	The context problem assessed students' ability to apply conditional statements in an online take-at-home exam in the eleventh week of the course. For this problem, students were provided a catalog of microchips and their associated radiation-hardening values. They then had to develop code to parse the proper chips based on a particular parameter. The entire exam was designed to take approximately two hours to complete. The microelectronics context question was designed to take approximately twenty-five minutes to complete.

Methods

KAM Survey Instrument

A survey tool for measuring exposure to nanotechnology [19] was adapted to measure exposure to microelectronics [7]. The Knowledge Awareness & Motivation (KAM) survey tool measures two microelectronics scales: exposure and motivation. Prior iterations of this instrument also included knowledge measurement questions specific to the class being taught, designed to assess students' deep knowledge acquisition. Given the limited touch points provided by the three curricular problems in the course, developing a deep level of knowledge about microelectronics was not expected.

In our adaptation of the KAM, we were not concerned about assessing students' deep knowledge acquisition. We were interested in determining whether or not students recognized their exposure to microelectronics topics. We were interested in whether or not students increased their recognition of their exposure to microelectronics and their motivation toward microelectronics.

The KAM survey [7] included five Likert scale questions (range 1 = strongly disagree to 5 = strongly agree) to measure students' perception of their exposure to microelectronics. The questions were:

1. I have read something about microelectronics.
2. I have had one or more instructors talk about microelectronics.
3. I have watched a video about microelectronics.
4. I have participated in an activity involving microelectronics.
5. I have taken at least one university class about microelectronics.

The scale yielded an alpha coefficient of .83 for the full sample. Each student's ranking across the five questions was totaled (minimum 5, maximum 25).

The KAM survey included six Likert scale questions (range 1 = strongly disagree to 5 = strongly agree) to measure students' motivation to learn more about microelectronics. The questions were:

1. I plan to read about microelectronics.
2. I plan to take a class about microelectronics.
3. I plan to investigate fields of study in which I can learn more about microelectronics.
4. I plan to pursue a research opportunity in microelectronics.
5. I plan to pursue an internship in microelectronics.
6. I plan to pursue a career in the field of microelectronics.

The alpha coefficient for this scale was .91. Each student's ranking across the six questions was totaled (minimum 6, maximum 30).

Participants

The course is typically given in the Spring semester of students' first year. For this research study, the course was offered during the Fall semester. Participants were recruited from the first-year introductory course offered in the Fall 2021 term at a large Midwestern land grant institution. Students enrolled in the course were invited to complete the pre- and post-KAM survey instrument to gain extra credit in the class; however, the students were not required to participate in the study and were not penalized for non-participation. An alternative extra-credit assignment was offered for students who chose not to participate in the study. 201 students were enrolled across 2 sections, with a maximum of 120 students allotted per section. The first section had 105 students enrolled, while the second section had 96 students enrolled. The pre-survey was administered during week 2 of the semester and gathered 190 student responses across both sections. The post-survey was distributed during week 16 of the course, and 198 student responses were gathered. Table 3 contains demographic information for the survey respondents.

Table 3. Pre- and Post- Survey Demographics

Week	Total Responses	Female	Male	Hispanic	Black	Indian	Mixed Race (other)	Asian	White
Week 2	190	21	112	2	4	4	22	34	67
Week 16	198	26	114	2	1	6	40	24	67

Using Qualtrics, we distributed the KAM survey instruments during weeks 2 and 16 of the introductory course. During the second week of the introductory course, the instructor distributed the pre-survey on the course's learning online platform, Brightspace. Students could complete the survey any time during the three-day window allotted by the research team. After the pre-survey was closed, the team transferred all student responses to a spreadsheet software to clean the data. During week 16 of the introductory course, the instructor distributed the post-survey via Brightspace. Due to the students' final exams schedule, the research team decided that providing students with more time to complete the survey was appropriate. The students received a seven-day timeframe to complete the post-survey. After seven days, the research team closed the post-survey, and all survey responses were transferred to spreadsheet software for data cleaning.

In cleaning the data, we eliminated responses where the student did not grant permission to use the data for research purposes. We eliminated careless responses to our screening questions (Meade & Craig, 2012). Fifty-seven student responses were discarded due to consent denial, less than 50% completion, or incorrect response to the filter question, resulting in 133 total student responses for pre-survey. Similarly, post-survey, student responses were screened and eliminated based on our screening process (Meade & Craig, 2012). Fifty-seven student responses were discarded after survey screening, resulting in 141 student responses for the post-survey.

Analysis

KAM Survey Item Results

Because of the discrepancy between pre- and post-respondent numbers, the Mann-Whitney U test was used to examine the difference between the pre-exposure, post-exposure, and pre-motivation, post-motivation survey data. After the three SCALE interventions, students showed a significant increase in exposure measures (U=6902, p<.001, r=.23) for the entire sample. No significant difference was seen in the measure of motivation. Table 4 contains the pre- and post-exposure and motivation survey measures and descriptive statistics for the mean and standard deviation for the entire sample and for each demographic.

Table 4. Pre- and Post-Exposure and Motivation Survey Means

Group	Pre-Exposure *M (S.D.)*	Post-Exposure *M (S.D.)*	Pre-Motivation *M (S.D.)*	Post-Motivation *M (S.D.)*
Total/Entire	14.06 (5.67)	16.73 (3.84)	19.02 (5.77)	19.00(5.67)
Asian	14.11 (5.75)	17.48 (3.66)	21.86 (4.32)	21.61 (4.45)
Black	13.25 (6.7)	20.33 (1.53)	19.00 (3.74)	20.33 (3.06)
Indian	14.25 (6.99)	18.83 (4.22)	21.00 (2.45)	23.17 (6.34)
Latino	15.25 (4.92)	18.50 (3.70)	18.50 (3.11)	18.50 (1.00)
Other/Mixed	13.19 (5.88)	17.67 (2.90)	18.88 (5.92)	18.75 (4.56)
White	14.20 (5.67)	15.96 (3.95)	17.48 (6.25)	17.75 (6.04)
Men	14.26 (5.50)	16.61 (3.79)	19.19 (5.64)	19.26 (5.76)
Women	13.00 (6.54)	17.23 (4.23)	18.10 (6.52)	17.85 (5.85)

Pre-Survey sample size, Total *n* = 133. Post-Survey sample size, Total *n* = 141

Discussion

We sought to understand the extent to which engineering students increased their knowledge of exposure to and interest in areas of microelectronics when assessment assignment problems were situated in real-world microelectronics contexts. We introduced three problems with a microelectronics context into the curriculum of a first-year engineering course on MATLAB. The week before the first intervention, we administered the KAM survey to gauge students' exposure to and motivation toward microelectronics. At the end of the semester, we administered the same survey. We performed a Mann-Whitney U test to measure any change in student exposure and motivation.

The small curriculum interventions that placed problems within a microelectronics context effectively increased students' knowledge of microelectronics as measured by their exposure recognition. One out of fourty-four homework problems, one out of twenty exam questions, and one out of thirty-one teaching videos contained specialized microelectronics context. Therefore, students could recall exposure to microelectronics when just 3/95 assessment questions were situated in a microelectronics context during the semester. These three questions consumed less than two hours of student learning and assessment time during the semester.

Instructors do not have to offer an entire class devoted to specialized topics like microelectronics, risking a time drain on those students who will not be interested enough to warrant a whole semester of learning. By embedding microelectronics context in the assessment problems of a required standard engineering course, students can receive enough knowledge of the topic to generate situational and, possibly, emergent individual interest. When students are introduced to microelectronics or other specialized topics early in their academic journey, they have a greater opportunity to pursue emergent interests in this specialized topic as they progress through school.

We found that the brief curriculum interventions surrounding a specialized topic examined in this study were able to increase students' knowledge of microelectronics. Students' recognition of their exposure to microelectronics grew. We did not find any increase in students' motivation toward microelectronics. The results of this study hold promise for exposing first-year engineering students to a greater breadth of real-world contexts and triggering interest in little-known careers. Exposing first-year engineering students to specialized, obscure, but highly needed career fields can trigger interest and allow time for undergraduates to pursue relevant topics further before graduating. This exposure can be effectively carried out via contextualized problems in the curriculum of general engineering courses without requiring an entire course devoted to the topic. When interest is generated early, through a general engineering course, students have time to consider a specialization and pursue topic-specific courses and pathways for the next 3-4 years as undergraduates. We have included the microelectronics questions as a part of every first-year engineering course since our initial intervention, as described in this study.

Limitations

The surveys were anonymous, and we could not uniquely identify and match pre- and post-respondents' answers. However, the class enrollees did not change significantly during the semester. Therefore, we reasonably infer that the pre-and post-test takers were from the same group of students. Another limitation of the current study is that we do not know how students who chose to participate differ from those who did not. The IRB office responsible for reviewing this study required that students were given a choice of extra credit options, one from the researchers and an alternative assignment. We were only allowed to analyze data from students who chose to participate; thus, we do not know how they differ from those who chose not to participate. However, this is a limitation in all human subject research, as it is difficult for researchers to know how study participants differ from those who declined. Lastly, the sample size for this study was smaller than ideal. While the effects are significant, the small *n* may warrant more research using a larger population of students.

Conclusion/Summary

Modern society has become dependent on microelectronics in almost every aspect of life and, with further advances, has the potential to be part of solving some of the biggest problems around the globe [5]. Nevertheless, few beginning-level engineering students are exposed to or aware of specific topics in microelectronics or their significance to society. Furthermore, they are unaware of particular microelectronics needs crucial to the defense industry, such as system-on-chip and radiation hardening. To meet the pressing workforce needs, multiple approaches must be taken to introduce students to microelectronics areas and train them with the knowledge, skills, and abilities to enter the workforce.

This work aimed to examine how providing students with the context of microelectronics-related problems would enhance students' recognition of their exposure to the field and motivation to learn more about it. We found that by using the context of real-world microelectronics problems in three assessment problems for a required first-year MATLAB class, student scores significantly increased in exposure. Similar to other research, we found that motivation did not increase by the end of the semester[20]**;** however, future research should look more longitudinally at students' motivation to pursue additional learning related to microelectronics after this type of exposure. A longitudinal study might provide further insight into how Phases 1 and 2 of Situational Interest generated by the intervention develop into Phases 3 and 4 of Individual Interest.

The level of intervention studied is relatively small, consisting of only 3 out of 95 problems – the instructor did not give any specific instruction related to microelectronics. However, by providing students with real microelectronics-related problems to solve with their programming knowledge, students could recognize their exposure to microelectronics. Small curricular interventions that use real-world microelectronics for assessment problems can potentially increase student knowledge about microelectronics and lay the early groundwork for their further interest in microelectronics. While undergraduate engineering programs are packed with broad, foundational topics and content such as programming, our results show that students recognized their exposure to microelectronics when curriculum designers intentionally integrated microelectronics as context in assessment problems.

Our main goal was to study whether a minimal change to the context of an assessment assignment is enough to increase students' awareness of exposure to microelectronics and motivation to study microelectronics. While students need many opportunities to interact with and learn about topics related to microelectronics in order to meet the workforce needs, this research demonstrates that beginning engineering students have had almost no exposure to these topics and that a small context change for a a few assignments gives students enough content such that they recognized their exposure to microelectonics. Practically speaking, first year engineering programs have many learning objectives with a variety of stakeholders, many of whom do not wish to make large sweeping changes to curriculum in order for specialty fields like microelectronics to take a more central role in the course. Yet, to meet the rising workforce needs, all engineering students will need to have some level of exposure to microelectronics. Thus, a small curricular change can provide opportunities to do that within existing required courses. Based on this work, as new fields emerge and become more crucial to U.S. workforce demands, small contextual curriculum interventions may serve to generate interest in these fields early enough in students' undergraduate careers for them to pursue deeper study and specialization before entering the workforce.

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