NSF DUE: Advancing STEM Instruction: The Impact of Microelectronics Professional Development on Teaching Practices

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Introduction

This study presents outcomes from the Circuit Board Classrooms (CBC): Microlectronics for Teachers professional development (PD) program, designed to support middle and high school STEM teachers in integrating microelectronics into their classroom instruction. The demand for skilled professionals in microelectronics continues to outpace supply; hence, it is utmost important that this talent pipeline be developed early, which requires preparing teachers to introduce students to the field. Accordingly, the CBC program was created to provide PD to teachers in microelectronics while aligning with national priorities to expand domestic semiconductor capacity. This program served as a supplement to the National Science Foundation's Noyce Master Teaching Fellowship program under the Directorate for Undergraduate Education, with the broader goal of contributing to the future microelectronics workforce.

By providing middle and high school teachers with a deeper understanding of circuits and the semiconductor industry, the program sought to better position them to engage and prepare students for related careers. Early exposure during middle and high school is particularly critical, as students' STEM interests, identities, and career trajectories are often shaped during these formative years. By targeting teachers and strengthening their content knowledge, instructional confidence, and ability to connect classroom learning to authentic technological contexts, the program aimed to create sustained impacts on student awareness, engagement, and participation in microelectronics pathways. The outcomes presented in this study focus on teachers' confidence in teaching microelectronics, their growth in content knowledge, and their capacity to engage students through real-world, industry-connected learning experiences.

Literature Review

Microelectronics is foundational to countless technologies, from simple phones to advanced manufacturing, making workforce development in this sector a national priority [1, 2]. As such, national initiatives such as the CHIPS and Science Act emphasize the need to build a pipeline of skilled learners, beginning at the K-12 level, to meet industry demand and sustain innovation in semiconductor fields [3,4]. Integrating microelectronics into K-12 education helps bridge classroom learning with real-world STEM contexts and exposes students to emerging career pathways and foundational technical concepts [5,6].

Tools like Arduino microcontroller kits have emerged as effective educational resources for developing technical competencies, as they combine low-cost, accessible hardware with hands-on, project-based learning that enhances problem-solving, creative thinking, and engagement [7-8]. Research on Arduino in educational settings shows that engaging with these platforms supports students' understanding of programming and electronics, fosters motivation in STEM subjects, and builds practical skills that align with broader workforce goals [7-9].

Given the demonstrated benefits of microelectronics and Arduino-based learning for student engagement and workforce preparation, it is essential that secondary teachers are adequately trained to teach these concepts. However, many educators lack formal preparation in this rapidly evolving field. To address this need, we developed CBC, a professional development program designed to equip STEM teachers with the knowledge, resources, and instructional capacity necessary to integrate microelectronics content into their classrooms.

Context of the Circuit Board Classrooms (CBC): Microelectronics for Teachers Program

Twelve teachers participated in the program, which was structured around two core components: (1) development of content knowledge in microelectronics and (2) pedagogical strategies for classroom implementation. The Rice University faculty who teach undergraduate microelectronics laboratory courses led workshops covering fundamental concepts, including microelectronics, circuit diagram interpretation, basic coding, and troubleshooting, all anchored in hands-on exploration with Arduino microcontrollers. Complementing this, curriculum specialists guided participants in adapting these tools to their existing curricula. Additionally, teacher participants designed new lessons using the engineering design framework, which they can use in their classrooms.

As part of the summer experience, teacher participants also visited Rice University's Cleanroom facility, which provided them with direct exposure to research-standard environments and protocols and deepened their understanding of real-world applications. At the conclusion of the summer program, each participant received a set of 12 Arduino microcontrollers, equipped with a range of sensors for classroom use, as well as an additional unit for instructional modeling.

During the fall semester, participating teachers attended two follow-up sessions designed to support continued implementation and sustained engagement with circuit board content. These sessions focused on completing their engineering design lessons, sharing freely available online resources, introducing potential classroom-ready projects, and providing additional sensors, materials, and no-code build activities. Dedicated time was built into each session for teachers to actively build, experiment, and code, allowing them to further develop and refine their skills.

As such, evaluation surveys were conducted at two points during the program (*at the end of the summer institute and at the end of the program in the fall*) to examine its effectiveness [See Methodology for details]. The guiding research question for this study was: *What is the impact of the Circuit Board Classrooms (CBC): Microelectronics for Teachers professional development program on middle and high school teachers' confidence, content knowledge, and instructional practices related to microelectronics?*

Methodology

Participants

Twelve STEM teachers, specifically five middle school and seven high school teachers, participated in the program. Teachers came from varied backgrounds; some had taught for 1 or 2 years, while others had been in teaching for more than 10 years. All participants completed a *post-summer survey* after completing the summer PD program focused on microelectronics. The same group of teachers was invited to complete a *fall follow-up survey* to assess the extent to which they incorporated summer program activities into their classroom instruction. Nine of the twelve teachers completed the *fall follow-up survey*.

Instruments

Two in-house built evaluative surveys were used for data collection: a *post-summer survey* and a *fall follow-up survey* (See Appendix A for questions). The surveys were designed based on a review of the evaluation literature, which informed the selection and phrasing of items commonly recommended for effective program evaluation [10]. Since the purpose of the survey was to inform program improvements and to determine its impact and effectiveness on teachers' instructional practices, it was not piloted beforehand.

The *post-summer survey* consisted of 19 questions, including 13 quantitative and 6 qualitative items. The quantitative questions measured teachers' perceived gains in microelectronics-related skills, their overall program satisfaction, and their satisfaction with specific program activities. The qualitative questions solicited open-ended responses regarding (1) the most beneficial aspects of the summer program, (2) suggestions for program improvement, and (3) teachers' plans for implementing what they learned into their curriculum.

The *fall follow-up survey* consisted of 5 questions, which focused on curriculum implementation and sustained impact. It included questions examining how useful teachers found the fall sessions and how they had incorporated their learning gains and summer activities into classroom instruction during the fall semester.

The post-summer survey was administered at the conclusion of the two-week summer program, whereas the fall follow-up survey was administered approximately one week after the conclusion of the fall sessions to assess the usefulness of the sessions and how teachers were applying their learning in the classroom. Participation in both surveys was voluntary.

Data Analysis

Quantitative survey responses were analyzed using descriptive statistics to summarize teachers' perceived skill gains and satisfaction with the program. Qualitative responses from both surveys were analyzed thematically to identify common benefits, challenges, suggestions for improvement, and patterns of classroom implementation [9].

Findings

<u>Post-summer evaluation survey</u> (see Table 1) indicated that 100% of participants "agreed" or "strongly agreed" that they gained practical experience in semiconductor manufacturing and cleanroom practices. Moreover, 100% of participants "agreed" or "strongly agreed" that they felt confident incorporating microelectronics into their teaching practice. Lastly, 92% of teachers reported having a solid understanding of microelectronic fundamentals (i.e., microcontrollers, sensors, and circuits). These findings suggest that targeted professional development that

combines technical content with pedagogical support can significantly enhance teachers' readiness to integrate emerging technologies into STEM education.

Table 1. Evaluation Survey Statements and Percentage of Teacher Responses (N = 12)

	Strongly Agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree
I have a solid understanding of microelectronics fundamentals (e.g., microcontrollers, sensors, circuits).	5 (42%)	6 (50%)	1 (8%)	0	0
I feel confident in incorporating microelectronics into my classroom lessons.	4 (33%)	8 (67%)	0	0	0
I gained practical experience in semiconductor manufacturing and cleanroom procedures.	7 (58%)	5 (42%)	0	0	0
The training in Arduino programming and CAD tools was effective.	7 (58%)	4 (33%)	1 (8%)	0	0

Per the open-ended responses, teachers consistently identified hands-on learning as the most beneficial aspect of the program. In particular, direct practice with Arduino kids, including circuit building, breadboard activities, and project development, was frequently cited as having immediate classroom applicability. For instance, one teacher stated, "[*the most beneficial aspect] was the Arduino kits for [our] classroom and the direct instruction on using them*." Teachers also valued the clear instructional support, including faculty lectures, explanations that accompanied each activity, and guidance on developing their lessons. For instance, a teacher appreciated the "*hands-on practice & struggles with the Arduino circuits, plus the comprehensive overview of the overarching themes in microelectronics*."

Exposure to microelectronics concepts was another key benefit, especially for teachers who had limited prior experience in the field. Teachers highlighted gains in understanding microcomputers, circuit design, and microelectronics. For instance, one teacher stated, "*I had no idea what microelectronics was; now I am exposed to it, so I can take that back to my students*." Classroom-ready materials and supplies further supported teachers' confidence in implementing activities with students.

Additionally, experiential components such as the clean room tour and collaborative group presentations enhanced learning by connecting the topic to real-world applications. For instance, one teacher stated, "*Clean room walkthrough put everything on the back end into perspective.*" Overall, teachers reported that the combination of theoretical grounding, hands-on practice, and practical resources made the program highly impactful and transferable to their classrooms.

Despite these strengths, teachers suggested areas for improvement. Common recommendations included reducing the pace and length of lectures and providing additional support during hands-on sessions, such as more troubleshooting support for common issues. For instance, one teacher mentioned that "*the lecture portions of the program were a bit advanced for [her], I think maybe more expansion on the content for middle and high school as it relates to the Arduino could be* *more beneficial*." Moreover, another stated, *"I think having a couple of helpers for [CBC program lead] to quickly troubleshoot some common mistakes would improve efficiency. Just a couple of students would work out just fine*."

9 out of 12 teachers responded to the fall follow-up survey. Most teachers (67%) indicated that they had already begun implementing CBC concepts in their classroom and referenced using circuits and Arduino kits with their students. One teacher stated, "*they are using the Arduinos to create a usable tool for astronauts going to Mars*." Another mentioned that she has "*used some of the beginning activities, such as blinking an LED on and off by having the kids complete a circuit diagram and then connecting them to get the outcome*." Those who had not yet begun implementing the CBC concepts (33%) stated they would begin in the Spring semester but did not elaborate on how they would do so.

Discussion

The findings from this evaluative study demonstrate that the microelectronics-focused CBC PD program had a meaningful impact on participating teachers' content knowledge, instructional practices, and confidence in teaching microelectronics-related content. Teachers reported gains in both conceptual understanding and practical skills, particularly through hands-on Arduino activities and experiential learning opportunities such as the clean room tour. These experiences supported teachers' ability to translate abstract concepts into classroom-ready activities, reinforcing the program's effectiveness in promoting authentic, applied learning. These findings align with prior studies, such as Strimel et al. (2025), a case study of four middle school engineering teachers, which found that hands-on, iterative instructional units supported student engagement in their classrooms [11]. Although that study examined classroom-level integration and student experiences, this present evaluative study illustrates how targeted PD helps build foundational teacher knowledge and confidence to implement within their classrooms. Increased teacher confidence, in turn, is associated with a greater likelihood of integrating the material into instruction.

Additionally, the results highlight a clear need for targeted PD in emerging technical fields such as microelectronics, which aligns with other researchers' systematic review of PD programs focused on Arduino technology [6]. Based on their study, they found that well-designed Arduino PD programs were effective in promoting deeper learning, strengthening computational thinking and robotics self-efficacy, and increasing teachers' content knowledge. In our present study, the majority of the participants entered the program with limited prior exposure to the subject, yet reported increased confidence and readiness to implement new content and activities with their students. Thus, well-designed, hands-on PD using Arduino can help address gaps in teacher preparation and support the integration of microelectronics in K-12 curricula [5, 6, 9].

Feedback on areas for improvement, namely the need for more time on hands-on activities and additional instructional support for troubleshooting, will help guide and refine future iterations of the program. Overall, the results of our evaluation underscore the importance of sustained, practice-oriented professional development programs in equipping teachers with the knowledge, resources, and confidence necessary to bring complex, high-impact STEM content into their classrooms.

To provide appropriate context for these findings, it is important to acknowledge the study's limitations, which may influence the interpretation and generalizability of the results. First, the sample size was small, consisting of only 12 participating teachers, which limits the generalizability of the results to broader teacher populations. Second, the data relied primarily on self-reported survey responses, which may be subject to response bias or overestimation of perceived gains and classroom implementation. Third, while the fall follow-up survey provided insight into short-term implementation, the study did not examine long-term impacts on teaching practices or student learning outcomes. Another survey administered a year later could serve as a future research opportunity to examine the program's long-term impacts on teachers' instructional practices. Finally, the absence of a comparison or control group limits the ability to attribute observed changes solely to participation in the program. Future research could address these limitations by including larger samples, multiple data sources, and longitudinal measures of impact.

Conclusion

This study provides evidence that the microelectronics-focused CBC professional development program positively influenced teachers' instructional practices, confidence, and readiness to integrate microelectronics concepts into their classrooms. Through hands-on Arduino activities, practical resources usable right away, and authentic learning experiences, teachers gained the knowledge and tools needed to translate complex technical content into meaningful student learning opportunities. The findings highlight a clear need for continued and expanded professional development programs in emerging microelectronics and related fields, as such initiatives play a critical role in supporting teachers and strengthening classroom instruction. Continued refinement and sustained support will further enhance the impact of these programs and their potential to broaden student exposure to high-impact technologies.

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Appendix A

Post-Summer Feedback Survey

Open-Ended Questions

1. How satisfied are you with the overall quality of the CBC program?
2. What were the most beneficial aspects of the program?
3. What aspects of the program could be improved?
4. How likely are you to recommend the Circuit Board Classrooms program to a friend or colleague? [Scale from 0 – 10]

For the following statements, the scale is: *Strongly Agree, Agree, Neither agree/disagree, and Strongly Disagree.*

5. I have a solid understanding of microelectronics fundamentals (e.g., microcontrollers, sensors, circuits).
6. I feel confident in incorporating microelectronics into my classroom lessons.
7. I gained practical experience in semiconductor manufacturing and cleanroom procedures.
8. The training in Arduino programming and CAD tools was effective.

Please rate the following program activities:

	Excellent (1)	Good (2)	Average (3)	Poor/Needs Improvement (4)	N/A (5)
Introduction to Microcontrollers & Electronics Basics (9)	○	○	○	○	○
Sensors & Interfacing with Microcontrollers (10)	○	○	○	○	○
Clean Room Visit & Semiconductor Manufacturing Tools (11)	○	○	○	○	○
Semiconductor Fundamentals & Solar Cells (12)	○	○	○	○	○
Microcontroller Integration & STEM Lesson Planning (13)	○	○	○	○	○
Final Project Development & Presentation (14)	○	○	○	○	○

15. How likely are you to incorporate microelectronics and microcontrollers into your classroom? [Scale – Very likely, likely, unsure, unlikely, very unlikely]

Open-Ended Questions

16. Which specific activity or day was most valuable to you, and why?

17. Were there any activities that you found less helpful? Please explain.

18. What additional support or resources would help you successfully implement these skills in your teaching?

19. Do you have any additional comments or suggestions to improve the CBC program?

Fall Post-Program Survey

1. What grade do you teach?
2. What subject(s) do you teach?

To what extent were the fall sessions useful to you?

	Extremely useful (1)	Very useful (2)	Moderately useful (3)	Slightly useful (4)	Not at all useful (5)
Meeting Topics/Discussions (3)	○	○	○	○	○
Timing/Scheduling (4)	○	○	○	○	○
Available Resources (5)	○	○	○	○	○

6. What are your main takeaways from your participation in the program?

7. Have you begun implementing the concepts you learned in CBC in your own classroom? [Options: *Yes or No*]

If yes, how have you implemented Microelectronics in your classroom? If possible, feel free to share a picture, student artifact, or lesson plan from your classroom.