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Board 422: What Does It Take to Implement a Semiconductor Curriculum in High School? True Challenges and The Teachers' Perspectives

Andrew J. Ash, Oklahoma State University

Andrew J. Ash is a PhD student in Electrical Engineering in the school of Electrical and Computer Engineering at OSU and he is a research assistant in Dr. John Hu's Analog VLSI Laboratory. He received his B.S. in Electrical Engineering from Oklahoma Christian University. Andrew's research interests include hardware security of data converters and engineering curriculum development.

James E Stine, Oklahoma State University

I am a Professor at Oklahoma State University interested in pushing the frontiers of computation within digital logic for general-purpose and application-specific computer architectures. I have interests in logic design for high-speed and low-power arithmetic, VLSI, FPGA, memory architectures, divide and square root implementations, computer architectures, cryptographic implementations, and graphics applications.

I have also developed several design flows for use with Electronic Design Automation (EDA) tools, including the FreePDK with my colleagues Rhett Davis from NC State University and those at the Semiconductor Research Corporation (SRC), several Cadence Design Systems (CDS) flows including the GPDK and MOSIS flows for use with CDS, National Science Foundation-funded OpenRAM, and Mentor Graphics and Synopsys EDA flows. I have also developed design flows for Google, Skywater Technology, IBM, trusted foundry, and the US Air Force. I am committed to use my experience to help others learn these tools and help develop them to further research endeavors for everyone involved.

Erin Dyke, Oklahoma State University
John Hu, Oklahoma State University

John Hu received his B.S. in Electronics and Information Engineering from Beihang University, Beijing, China, in 2006 and his M.S. and Ph.D. in electrical and computer engineering from the Ohio State University, Columbus, OH, in 2007 and 2010, respectively. He worked as an analog IC designer at Texas Instruments, Dallas, between 2011 and 2012. He was a Member of Technical Staff, IC Design at Maxim Integrated, San Diego, CA, between 2012 and 2016, and a Staff Engineer at Qualcomm, Tempe, AZ, between 2016 and 2019. In 2019, he joined the School of Electrical and Computer Engineering at Oklahoma State University, where he is currently an assistant professor and Jack H. Graham Endowed Fellow of Engineering. His research interests include power management IC design, hardware security, and energy-efficient computing.

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What Does it Take to Implement a Semiconductor Curriculum in High School? True Challenges and The Teachers' Perspectives

Introduction

In 2022 the Chips and Science Act was passed, which aims to bring more advanced semiconductor manufacturing back to the US while mitigating supply chain risks and maintaining US technological and economic leadership. Billions in federal investments as well as commitments from private companies has revealed the next hurdle; the US is facing a growing workforce shortage in the semiconductor industry [1] with a projected 67,000 unfilled semiconductor jobs for technicians, engineers, and computer scientists by 2030 [2]. The shortage of STEM students is a major contributor to the problem. Perhaps even more important is the lack of high school curricula on semiconductors despite almost eighty years of history.

To address the problem, we proposed a Research Experience for Teachers (RET) site on chip design funded by the National Science Foundation. Ten K-14 teachers were recruited around the state to spend six weeks learning chip design basics. Participants included three teachers from rural high schools serving diverse, predominantly low socioeconomic student populations; one teacher from a rural-serving community college; five high school teachers from an urban charter school serving 85% free-and-reduced lunch and predominantly African American students; and one high school teacher from a highly selective science and mathematics high school that draws students from across the state. As part of the RET, teachers were also required to translate their experience into new curriculum modules suitable for their students. This paper summarizes findings based on qualitative data collected from the first cohort's experiences into three key areas: expanded access to learning resources, peer-to-peer support, and student-centric curriculum. Implementing these changes is expected to improve RET activities and outcomes for future cohorts.

RET Structure

The RET site ran for six weeks from early June to the end of July. Instruction and oversight were primarily provided by three faculty members specializing in digital circuit design, analog circuit design, and curriculum development along with three graduate student mentors.

During Week 1, teachers undertook two workshops on a tri-part framework for curriculum design: cultural relevance; concept-based understanding; and backward design. Cultural relevance emphasizes the need to understand students' linguistic, geographic, gender, racial, and generational, among other cultural, knowledge as assets that can be leveraged for curriculum and teaching [3]. Concept-based understanding prioritizes inquiry-based learning and application and transferability of knowledge versus rote memorization of information or discrete skill acquisition. Backwards design provides an accessible structure for planning assessment and learning activities in ways that center conceptual understanding and student inquiry [4]. Teachers kept reflective journals, analyzed science and mathematics state standards frameworks, and

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participated in group brainstorm activities to identify “big ideas” and “essential questions” that could form the bases of their curriculum design.

Alongside these curriculum development workshops, in the first two weeks of the RET, teachers were given introductions to both digital and analog design. After this, teachers were split into smaller groups based on their interest in digging deeper into analog or digital concepts. In weeks 3-5, teachers trained in resources to introduce their students to analog or digital circuit design. The digital design group learned to use open-source tools to fabricate integrated circuits through Tiny Tapeout [5][6]. The analog design group received training on LTspice (a lightweight, free SPICE simulator distributed by Analog Devices [7]) to verify expected behavior of circuits before creating them and learned to use the ADALM1000 (a two-channel signal generator and oscilloscope capable of 100,000 samples per second [8] see Fig. 1) for physically testing circuits. During the first five weeks, teachers engaged in weekly reflection on the development of their curriculum ideas.

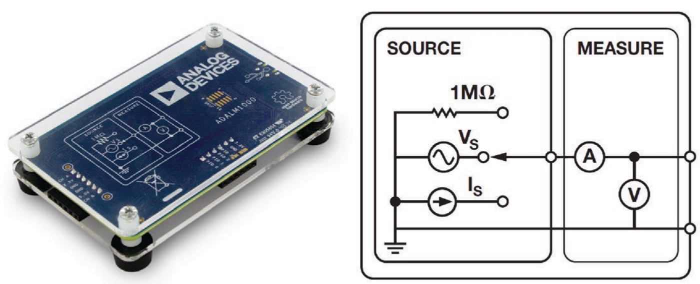

Fig. 1: The Analog Devices Active Learning Module (ADALM1000) and basic schematic of the circuit

In Week 6, teachers focused specifically on curriculum design and were mentored to forefront cultural relevance. They had opportunities to discuss and reflect in more depth on the social, academic, and cultural contexts of their student communities. In doing so, teachers also reflected on and across their own cultural backgrounds, teaching philosophies, and challenges. They also supported one another in creatively navigating the challenges they faced in curricular innovation (e.g., limited curricular autonomy, workload constraints). All participating teachers developed unit curricula through a scaffolded, iterative approach with peer and mentor feedback. By the end of Week 6, teachers formally presented their curriculum unit designs, which ranged in focus from the use of second order linear differential equations for analysis of RLC circuits (calculus course) to the chemistry of semiconductors and doping process and their significance for chip design (chemistry course).

This RET site’s focus on circuit design with the intention of improving workforce development in the semiconductor industry makes it a unique addition to the efforts of RET sites across the country; however, this site does share structural similarities with other recent RET sites. The ten K-14 educator cohort and six-week model are part of the RET program requirements [9], making them common to many sites. Much like [10], the first two weeks of our program put participants through a theory-heavy “boot camp” to bring them up to speed on the relevant topics needed for research activities. Many recent RET sites do curriculum development activities in parallel with research activities through the whole RET schedule without a time for teachers to *completely* focus on curriculum development [10]-[13]. At our site we found that including some curriculum development activities throughout the schedule and devoting the final week solely to curriculum (a schedule like that of [14]) gave teachers time to decompress from the intense focus of research and learning activities to fine-tune curriculum ideas into fully fledged lesson plans.

Data Collection

While the larger evaluation employs a mixed methods approach, this paper draws on constant comparative analysis of qualitative data collected during the 6-week research experience. Qualitative data included participants' weekly written feedback (the form details are shown in Table 1), reflective midterm and cumulative research posters, participants' iterative curriculum design drafts and peer feedback, and RET mentors' midterm and cumulative reflections. Qualitative research is commonly used in educational and practitioner research because it allows the study of "the reciprocal, recursive, symbiotic relationships of research and practice, ... generating local knowledge of practice while at the same time making that knowledge accessible and usable in other contexts" [15].

Likert-scale [16] (1-Strongly Disagree to 5-Strongly Agree) with space for comments below each question	My faculty mentor is helpful
	I am learning a lot in this research program
	I am enjoying the experience in this program
	I am able to see connections to my classroom through program activities
Short Response Questions	3 things I learned this week...
	2 things that I am still wondering about are...
	1 thing that I would like to learn more about is...

Table 1: Weekly teacher feedback form.

Data Analysis

Qualitative data was analyzed utilizing an ongoing constant comparative method within an interpretivist paradigm [17]. Coding of qualitative data occurred in stages. First, data underwent initial open coding, centering participants' meanings and perspectives. Initial coding involved multiple, iterative readings of the data over time and in relation to the project's aims, developed the researcher's familiarity with the data, and created cursory interpretations and categories. The second stage of analysis entailed in-depth focused coding, which is more "directed, selective, and conceptual" [17], and refines and clarifies codes, categories, and their significance.

While analysis drew on a range of qualitative data amid and post RET activities, we provide exemplar comments from feedback forms in Table 2 to illustrate key findings. First, due to the complex nature of semiconductors and circuit design, it is easy to overload participants with too much information to fully process; this led to the finding that more time should be included in the schedule for participants to ask questions of facilitators. Second, a common theme in feedback throughout the cohort was the positive experiences of group networking and collaboration times. Finally, throughout the first half of the RET, and even at times in the later weeks, teachers expressed concerns with connecting the RET content to their classroom and students. More time should be spent preparing teachers for the challenges of developing student-centric curriculum relating to their semiconductor and circuit research topics.

Finding	Feedback
"Expanded Access to Learning Resources" Participants will benefit from more access to faculty and graduate student facilitators for Q&A on complex topics	• "Still need to improve and solve more examples with [facilitator]." (Week 3) • "Need more practice with professor" (Week 4) • Four participants requested more time for facilitator-led times to work through examples as a cohort during the exit interview.
"Peer-to-Peer Support" Participants will benefit from additional time for socializing and networking with each other	• "Unexpected personal development learning by interaction with individuals and groups in this type of setting are what I look forward to in this type of professional development environment." (Week 3) • "Have one day a week where the class eats lunch together provided by the program." (Week 3) • "Lunch as a class once a week or the last week at the very least" (Week 5) • Three participants requested more scheduled times for group collaboration during the exit interview
"Student-Centric Curriculum" Participants will benefit from resources that help develop student-centric curriculum tailored to each participant's school context	• "How can one simplify deep concepts into high school student level activities without losing the content?" (Week 1) • "[I would like to learn more about] Workforce opportunities for high school graduates, tech center (VoTech), and community College grads in the industry." (Week 1) • "[I am still wondering] how to embed analog IC design into my classroom" (Week 2) • "[I would like to learn more about] Technician jobs within the industry, as the majority of my students will be more interested in that level...at the beginning." (Week 2)

Table 2: Summary of key findings from weekly teacher feedback forms.

Finding One: Expanded Access to Learning Resources

A common subject during weekly feedback forms, reflective discussions, and the exit survey was the need for a wider variety of support mechanisms while learning semiconductor and circuit topics. To better guide learning during the RET, facilitators will schedule additional one-on-one meetings with teachers to discuss subject matter currently confusing teachers and set achievable timelines for weekly research activities. Facilitators can then use the topics discussed during one-on-one meetings to guide large group discussions, further cementing unfamiliar concepts through additional insights into the topic. Teachers also requested access to other information sources to help in their learning. Requests ranged from guidance on finding training videos on software tools and research topics to more time with graduate student mentors for additional Q&A. The regular request for access to instructional resources is indicative of the continuous learning required for these complex topics. To accommodate continuous learning, teachers are given access to repositories of all learning materials used during the RET and remain in contact with facilitators throughout the school year.

Finding Two: Peer-to-Peer Support

A six-week dive into the world of electrical engineering can be an overwhelming experience for teachers with diverse STEM education backgrounds, teaching areas, and teaching experience. To keep the momentum required for learning complex topics and developing curriculum based on these topics, teachers requested times to step back from research and get to know others in the cohort. Rest times to network with other teachers can help to build the camaraderie needed for peer-to-peer learning during the RET. A common request was for group lunches with facilitators. Two of these lunches were scheduled during the RET and the events proved to be helpful both as a time for teachers to take a step back from their research and curriculum development together and as an additional time for teachers to discuss difficult semiconductor topics with the faculty facilitators. Group lunches and other times for collaboration and socializing led teachers to foster partnerships in curriculum development that have extended beyond their time at the RET. The success of these group lunches indicates the value of exploring additional avenues for future cohorts to collaborate and network outside research activities.

For example, halfway through the program a special session was offered to the math educators on how to introduce circuit and semiconductor topics into various levels of high school mathematics. This session led to insightful discussion between teachers and facilitators on how to present the *math applications* of engineering (typically relegated to science classes) in a way relevant to the *math theory* school administrators expect of math classes. Concerns about school districts' acceptance of new units incorporating semiconductor and circuit topics into the classroom were common among the teachers. The special session with math teachers and the results of exit surveys demonstrated the expected effectiveness of allotting more time specifically for collaboration in small groups based on similar teaching topics and/or research interests. Considering these administrative difficulties early will allow teachers more time to collaborate on effective plans to meet their district's expectations and achieve their goals from the RET.

Finding Three: Student-Centric Curriculum

Weekly feedback forms early in the RET indicated teachers were unsure of how to integrate their new knowledge on semiconductors and circuits into the classroom. Discussion with teachers revealed their concerns came from a variety of areas; for some it took time to find connections between the subjects they teach and the content they were learning, for others it was difficult to find hands on lessons to introduce theory heavy topics, there were also concerns of irrelevancy for students planning to get technical certifications rather than pursue a college degree. Through working with other teachers and facilitators these concerns were addressed and quality curriculum relevant to each classroom was developed.

In some cases, the solution was simply to keep pressing forward into more competency with circuits and semiconductors. Weekly feedback from the teachers indicated a shift in perspective from feeling overwhelmed with information at the beginning of the RET to seeing connections to their classrooms. A greater mastery of the material led to enough understanding to create lessons tailored to their students. For example, early in the RET experience, teachers in rural school communities where agriculture is centrally important culturally and economically brainstormed ways to engage students in understanding how the semiconductor industry has impacted agricultural technology. Other teachers took it upon themselves to find career statistics so they could talk with their students about exactly what semiconductor jobs would be available to them in our state with various levels and types of post high school education. The teachers' efforts during the first five weeks of the RET gave them a good starting point for discussion with each other and facilitators in the final week of the RET focused solely on curriculum development.

Discussion

Scalability and Sustainability: When the Chips and Science Act was passed, the semiconductor industry employed approximately 277,000 people and was projected to reach 319,000 by 2027 [18]. The industry's growth has outpaced this original projection, achieving approximately 345,000 jobs by 2023 and the current growth rate leads to a projected 67,000 unfilled jobs for technicians, engineers, and computer scientists in the semiconductor industry by 2030 [2]. The semiconductor industry's need for skilled workers and workforce development is constantly changing. As companies and institutions across the country ramp up their own workforce development efforts [19]-[21], the unfilled needs in the industry will change. As part of our RET site's strategy, we will monitor the current needs and upcoming projected needs of the semiconductor industry from the Semiconductor Industry Association and other industry experts. As needs change, we will modify our training materials accordingly. The intensive learning environment required to complete an RET can be a heavy burden for teachers. Summer is typically a time to recuperate from the prior year of teaching and prepare for the. To better accommodate future cohorts, we are modifying our research schedule to include two days each week to work from home. This will reduce the total time teachers must spend commuting to and from our campus during the RET while still leaving three days each week for in-person Q&A, networking, and socialization within the cohort. In addition, we are shifting the timeline of our RET to run from the beginning of June to mid-July. We believe these two changes will reduce the demand for teachers' valuable time during the RET while also giving them more time to speak with administrators about their new curriculum before the school year begins.

Fairness and Inclusion: In addition to the racial/ethnic and economic diversity of teachers' school contexts, participants were diverse along the lines of gender, race/ethnicity, immigrant status, religion, language, culture, and educational background. For example, six participants emigrated to the U.S. to teach, are multilingual, and had various experiences teaching in other global contexts. The RET structure sought to create an inclusive environment for diverse participants in numerous ways to model the kinds of student- and inquiry-centered and culturally relevant pedagogy we encouraged them to engage in their curriculum design. We conducted interviews and communications prior to the RET start date to learn more in-depth about our participants, their backgrounds, interests, and contexts and used this information to develop the structure of the RET. For example, in their pre-site training, mentors learned about teachers' specific backgrounds and contexts. During orientation and curriculum workshops, participatory group activities were intentionally arranged so teachers could share their knowledge, resources, and experience with one another and mentors. As another example of bringing cultural relevance and inclusion to the forefront in the structure, we adjusted the schedule to accommodate observing Eid ul-Adha, a Muslim holiday, and provided Halal options for meals.

Future Work

The results of weekly feedback and exit surveys are far from the end of our interaction with the first cohort. Our future work will focus on two aspects: classroom visits and student outcomes. Throughout the spring semester, we will visit teachers to speak with them about the successes and challenges they have faced in implementing the semiconductor and circuit curriculum so far this year. We plan to collect more qualitative data through surveys with the teachers regarding the response to modules based on RET efforts. These visits will allow us to observe changes in the teachers' mindsets over time and provide further vectors for improving the experience for our next cohort. We will also consider additional ways to collect student data as a robust way to gauge the long-term impact of our teachers' efforts and the RET program. Future work will draw insights from the larger mixed methods, multi-year evaluation to understand the scope of teachers' chip design learning and the impact of teachers' curriculum implementation on student learning. A more complete understanding of the teachers' perspective and the challenges they have faced implementing these new modules is critical to the success of our future RET cohorts.

Conclusions

This paper presents improvements to enhance future RET cohorts' experiences based on feedback from our first cohort. (1) Expand access to learning resources, participants will benefit from more access to subject matter experts for Q&A on complex topics. (2) Peer-to-peer support, additional times to network and socialize will help participants develop long lasting collaborations with each other. (3) Student-centric curriculum, participants will benefit from resources that help develop student-centric curriculum tailored to each participant's school context. If we want to expand semiconductor education in K-14 classrooms, these findings should be implemented at our RET site and, more importantly, in other semiconductor workforce training and curriculum development programs.

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