Rethinking Electronics Industry Workforce Development: Case Studies on High School and Middle School Students with Semiconductor Design and Advanced Electronics Prototyping

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Abstract: For more than ten years the United States has experienced a major gap in skilled workforce availability with over 100,000 unfilled jobs for the electronics industry, yet the majority of talent pipeline discussions only consider university-level matriculation and overlook the ability of high school and middle school students to learn and contribute to electronics innovation and industry. The large misconception is that students must complete a post-secondary degree or education program to start contributing to electronics innovation or to begin their career. This paper provides two case studies that challenges those assumptions and establishes what high school students and middle school students can accomplish with mentoring, streamlined coursework, and experiential learning through applied engineering projects in semiconductor design and advanced electronics prototyping. By rethinking how to conduct STEM education using observations from these case studies, closing the sustained U.S. electronics workforce gap can become more of a reality.

Keywords: high school, middle school, electronics industry workforce development, printed circuit board design, semiconductor design

INTRODUCTION

The United States electronics industry has experienced a major gap in skilled workforce availability for more than ten years, yet the majority of talent pipeline programs only consider university-level matriculation [1], [2] and overlook the ability of high school and middle school students to learn and contribute to electronics innovation and industry. There exists a misconception that students must complete a post-secondary degree or education program to begin their career and start contributing to electronics innovation. However, a several year delay in new workforce entries is of significant concern given the importance of electronics to society and the broad staffing needs for design and manufacturing of semiconductors, printed circuit boards, advanced packaging, electronics assembly, test, and integration.

This workforce gap has been documented with more than 100,000 domestic electronics industry jobs that have gone unfilled due to lack of sufficiently skilled or knowledgeable workers [3], [4]. Of importance, the U.S. electronics industry has a significant impact on U.S. economy estimated at $246.4 billion GDP [5]. To make matters worse, it is estimated that United States needs at least 50,000 new engineers over the next five years to staff all of the emerging semiconductor fabs and related ecosystem job growth due to domestic on-shoring activities and investments [6], which has also stimulated additional needs for highly skilled technical trades. While the workforce needs increase, employment for electronics industry has stayed relatively flat over the past ten years [7]. These needs are in addition to the diversity, equity and inclusion imperative that is already recognized by the electronics industry (NASIC Code 334 and 335) [8], [9]. With the projected rapid growth in U.S. electronics industry jobs, the significant workforce gap will expand without radical intervention.

STEM Education Gaps

When considering the root cause of the electronics workforce challenge, there simply are not enough interested U.S. candidates entering the electronics industry, it's related post-secondary education programs, and for some employers, workforce retention is a challenge. Simply stated, the needs far exceed post-secondary graduation rates from workforce training programs for technicians or operators as well as related science and engineering degrees [4]. While many electronics industry working groups have attempted to close the workforce gap with focused efforts on improving post-secondary education, they miss a holistic view on a long-term STEM talent pipeline which considers when the next generation make critical decisions on career aspirations or interests: high school and middle school ages.

Yet, many of the secondary education STEM programs, such as [10], only introduce basic knowledge without depth on electronics or other related disciplines. In addition, the introductory material is insufficient to directly build workforce skills and does not capitalize on students' full ability to learn. Even more important, basic knowledge programs do not necessarily inspire students toward solving real-world challenges with an electronics solution nor create a passion for an electronics career. Out of their own interests, some students pursue non-traditional electronics learning pathways such as FIRST Robotics, FlexFactor [11], and others [12], however most occur as extracurricular activities that require students and their families to overcome significant time or financial challenges in order to participate.

While these observations may not represent every academic system, they still highlight significant gaps of inspiring students toward innovation while rapidly obtaining the skills and experience needed for advanced electronics prototyping and semiconductor design. There is a key opportunity to merge the efforts between classroom, extra-curricular, and industry-led workforce development programs.

Our Contributions

The U.S. needs a more integrated approach to electronics workforce education that begins at K-12 school ages and which also capitalizes on what middle school and high school students can actually accomplish. The programs must consider active involvement of industry and educators with targeted electronics education pathways, funded projects, and long-term mentorship commitments in order to be successful. The student opportunities need to be of mixed modalities geared toward experiential learning, along with short didactic sessions for basic knowledge, and active mentoring. By using this approach, our efforts demonstrate that middle school and high school students can rapidly accomplish much more than what many educators and industry members perceive as possible by for younger age participants.

Our paper describes two different pilot programs which establish the feasibility of an alternate approach which capitalizes on the aptitude of high school and middle school students to quickly learn new knowledge and apply their skills toward semiconductor design and advanced electronics prototyping. We offer lessons learned as well as student experiential learning perspectives and discuss strategies to lower the barrier to entry for electronics workforce development at much earlier ages. Most importantly, the two demonstration pilots establish that focused electronics workforce programs of circuit board design and semiconductor design at the secondary level (grades seven through twelve) can quickly build new workforce candidates in a matter of months while inspiring them to continue learning more about electronics.

HIGH SCHOOL SEMICONDUCTOR DESIGN PILOT

The primary goal of the semiconductor design pilot was to provide an opportunity for high school student interns to learn and experience the full set of tasks required to design an application specific integrated circuit (ASIC). This included obtaining background knowledge on semiconductor design and manufacturing process, transistor design parameters, circuit simulation, clock signal propagation, control logic, schematic design, layout design, design verification, and the suite of electronic design automation (EDA) tools. The logistical challenge was that the pilot program needed to fit within an eight-week summer break from school.

The pilot program internship candidates were chosen from a pool of eight returning high school interns and seven new applicants which included an equal mix of both male and female students. The participants were interviewed and selected based on high interest in science, technology, engineering, and math (STEM) and a propensity for curiosity and self-directed learning. These characteristics would be critical for success knowing that most students learning integrated circuit design are university fourth year or graduate-level students. Two high school students, tenth-grade and eleventh-grade, were selected for the semiconductor design pilot. None of the selected candidates had prior exposure to semiconductors or integrated circuit design, although they had some experience with computer systems, basic electronics, and programming.

A technical task was designed for the students to create a transistor-based ring oscillator following both an analog design flow and digital design flow such that the ring oscillator could be tuned to a certain clock frequency. The analog design flow focused on a small-scale ring oscillator (7 stage) and required the students to learn about device physics, transistor geometry sizing, schematic capture, composition of transistors to build digital logic gates, and circuit simulation. The digital design flow focused on full integration of a 115-stage ring oscillator with the goal of creating a 50MHz clock frequency output using the pilot program's semiconductor process development kit (PDK). The digital flow required students to learn about designing integrated circuits with Verilog hardware descriptive language (HDL), digital synthesis, circuit layout, layout vs schematic (LVS) verification, and how to incorporate analog design elements into a larger design.

Efabless Corporation provided mentoring on SkyWater Technology's 130nm Open PDK tool chain process, which was instantiated on an internal network Dell Poweredge server with multiple graphic processing unit (GPU) cards and several terabytes (TB) of RAM to synthesize the design. Efabless also made available the mature cloud-based EDA software suite, Open Galaxy design workspace [13], which was not used during the pilot program.

Mentoring and teaching opportunities were provided to the students on a daily basis during the early weeks of the pilot program to help them get started and introduce several online learning resources. The subsequent weeks had bi-weekly or impromptu meetings with mentors to help the students work through specific design challenges. In addition, weekly and occasional impromptu virtual teleconference calls were established with Efabless throughout the eight-week period to provide opportunities for the students to ask questions or obtain help working through the complexities of integrated circuit design tools.

Below summarizes the phases of the pilot program, each built on the prior stage:

1. Learn foundational knowledge on semiconductor manufacturing and design.
2. Custom transistor design and seven-stage ring oscillator using analog design flow.
3. Custom ring oscillators and layout using digital design flow.
4. Full integration of a 115-stage ring oscillator using the complete EDA tool suite.

Since this pilot was exploratory and focused more on feasibility, a formal assessment tool was not used for measuring effectiveness of the pilot program. Instead, our team sought to answer these fundamental questions related to semiconductor design:

- Is it possible for high school students to learn semiconductor design?
- How much could be accomplished by high school students during an eight-week period?
- What mentorship level of effort was needed to achieve student success?
- What additional opportunities exist to lower the barriers of entry for new electronics industry workforce?

Semiconductor Design Pilot Results

Both of students of the pilot program were able to learn about analog and digital design flows to create custom transistor designs (Figure 1) and a ring oscillator (Figure 2). Due to several variables such as different work starting dates, different work locations, different mentorship engagement, and baseline knowledge on computer systems, physics, and math, one student was able to complete a custom transistor design while the other student was able to fully synthesize and integrate a 115-stage ring oscillator (Figure 3).

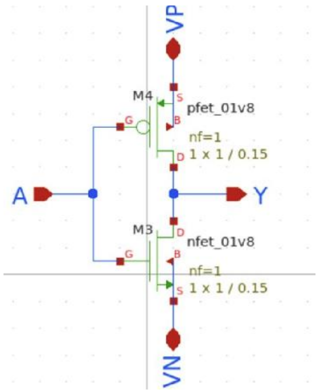

Figure 1: Logic inverter using custom designed transistors.

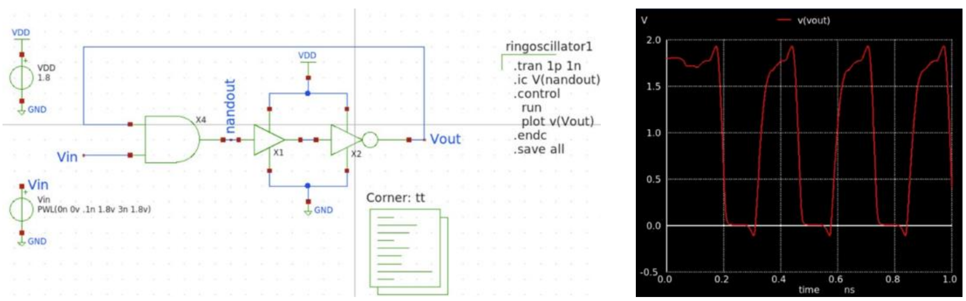

Figure 2: Ring oscillator schematic (left) and the SPICE simulation output (right) showing timing characteristics.

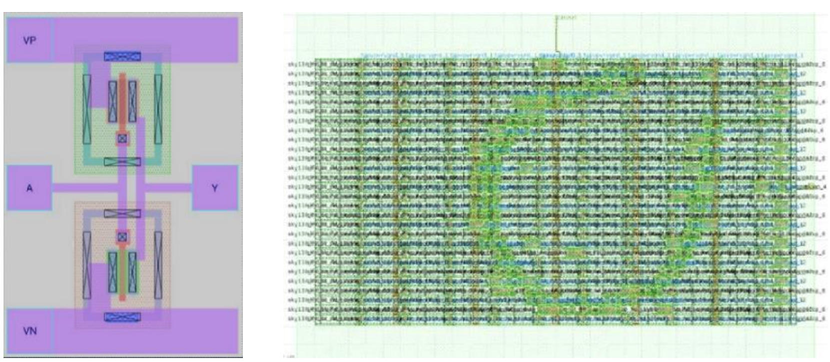

Figure 3: Custom inverter layout (left) and 115-stage ring oscillator layout (right).

Student resourcefulness and mentor interactions were critical to the success of the pilot. The first self-learning initiative was focused on the topics of transistor functionality and basic combinatorial logic but required regular interaction with mentors along with a tremendous amount of online education resources. Of which, the most useful to build strong foundational of knowledge were recorded lectures and free online materials from MIT and other academic institutions. Overcoming the initial steep learning curve was facilitated by daily discussions and whiteboard sessions between students and mentors.

One of the key challenges experienced during the semiconductor design pilot was using the EDA design software and Open PDK within an existing corporate infrastructure. Prior to the pilot program beginning, the team decided to establish a private instance of the software tool suite rather than use the well supported cloud-based version due to unresolved corporate policy issues on cybersecurity and intellectual property protection. Setting up the private instance required a large amount of engineering staff resources and significant custom configuration settings to operate in the private corporate computing environment of the pilot program.

Student useability of the open-source EDA semiconductor design software tools was perhaps the most critical barrier to entry for early workforce development. The students experienced many frustrations with the tool-chain having tight dependencies on a synthesizable design, lack of easy-to-follow documentation, and a graphical interface that used uncommon controls. There was a significant amount of time spent through trial and error as well as engaging with the Efabless EDA team to figure out how to overcome the tool challenges and ultimately accomplish a semiconductor design element.

One positive outcome of the cross-industry partnership during this pilot program was that the students were able to identify issues and complexities to the EDA interface and potential improvements. In response, the design software integration team adapted and took note of opportunities to lower the barriers for potential workforce to participate in semiconductor design. Retrospectively, the cloud-based Open Galaxy environment would have provided a more consistent and stable EDA learning environment since many of the software integration issues had already been resolved.

While there were significant challenges during the eight-week pilot on high school semiconductor design, this effort demonstrates that it is possible for the semiconductor industry to build their workforce pipeline using a focused development program at the high school level. The lessons learned from this pilot helped improve the design infrastructure for an upcoming larger scale high school semiconductor circuit design program for a regional semiconductor ecosystem [14], [15].

HIGH SCHOOL AND MIDDLE SCHOOL ADVANCED ELECTRONICS PROTOTYPING PILOT

For the purposes of this paper, we define an advanced electronics prototype as one that more closely represents a commercially produced electronics systems as an outcome of computer aided design (CAD), design for manufacturing (DFM), design for test (DFT), printed circuit boards, assembly and test using small surface mount components. An electronic prototype of this nature is at the core of innovation to solve real world challenges with a product that can be demonstrated and fielded.

The primary goal of the advanced electronics prototyping pilot was to provide an opportunity for students to learn and experience the full set of tasks required to take a real-world problem and solve it with a custom electronic system. The pilot program was based on a prior course developed to cross train other engineering disciplines in electronics development but was revised to fit high school and middle school levels of knowledge. The participants included three high school students and one seventh-grade student that were recruited through local connections while considering student interests in electronics technology and student availability. The pilot program was conducted over a four-week period in late summer requiring student participation of 40 hours or more depending on the complexity of their design concept.

The pilot program began with several virtual didactic sessions on electronics related physics and math, such as Ohm’s law, and the roles of various electronic components like microprocessors, capacitors, and resistors. The instruction also included presentations and discussion on the process for developing a rapid prototype and how to design or fabricate printed circuit board assemblies. Sample applied math problems were also given to help the students understand how to select the appropriate resistors, diodes, and other discrete components.

To increase motivation of completing the advanced electronics pilot, students had to identify their own real-world challenge and a potential electronics solution. The students could choose to replicate open-source hardware projects with modifications, use existing subsystem designs, or create an entirely new design. As part of the project definition, students also had to research parts, create schematic and board layout designs using KiCAD [16]. They also had to generate a bill of materials with estimated costs and account for supply chain dynamics with parts availability. Mentors performed detailed design reviews considering DFM and DFT principles and worked with students to help them identify any needed corrective pathway.

The next part of the pilot program focused on circuit board assembly manufacturing practices, chemistry, electrostatic discharge (ESD) prevention, and test. Students learned how to identify physical components, work with production packaging (cut-tape, tubes, etc), and set up a hand assembly production flow. After a demonstration session on physical characteristics of solder and assembly techniques, students used solder paste and temperature controlled hot air reflow or soldering irons to assemble surface mount components, through-hole components or flex cable assemblies. Students then visually verified their circuit assemblies with a USB microscope and made any corrections. Finally, students followed a basic test plan using a benchtop power supply and multimeter. Some of the prototypes required test software to be programmed on the embedded processor to activate desired input/output (I/O) interfaces and related subsystems.

Below summarizes the phases of the advanced electronics pilot program, each built on the prior stage:

1. Introduction to electronics prototyping, basic physics, and related math.
2. Specifying and buying components, including parts research and bill of materials.
3. Circuit board design with CAD software and design for manufacturing (DFM) principles.
4. CAD verification and design review.
5. Soldering with through-hole, surface mount, solder paste, and hot air reflow.
6. Student project assembly lab.
7. Verification and test of prototypes including test software for processor components.

Similar to that of semiconductor design, this pilot was exploratory and focused more on feasibility rather than a formal assessment on effectiveness of the program. Likewise, our team sought to answer these fundamental questions related to electronics design and prototyping:

- Is it possible for high school and middle-school students to learn advanced electronics development?
- How much could be accomplished by students during a 40-hour class?
- What mentorship level of effort was needed to obtain student success?
- What additional opportunities existed to lower the barriers of entry for new electronics industry workforce?

Advanced Electronics Prototyping Pilot Results

Students as part of this pilot were successful in designing and creating their own advanced electronics prototype device. Each of the students chose to design custom devices from their personal interests (Figure 4, Figure 5, and Figure 6). Mentorship on developing their ideas was important to help students learn different ways to solve the design problems and introduce them to online electronics knowledge base repositories, reference designs, or DIY electronic communities. Reference designs provided in the component datasheets or offered by the open-source hardware community were extremely helpful for the students to quickly learn electronic circuit designs that achieved real-world functions. Regular mentor discussions helped students understand the nuances of integrating the various subsystems or complex assemblies.

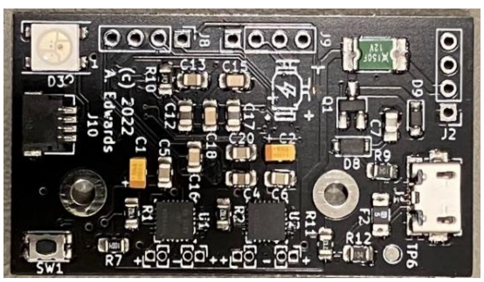

Figure 4: Tenth-grade student designed and assembled a DC motor controller.

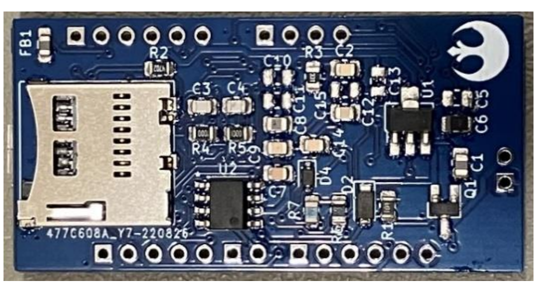

Figure 5: Seventh-grade student designed and assembled a soundboard for a custom lightsaber.

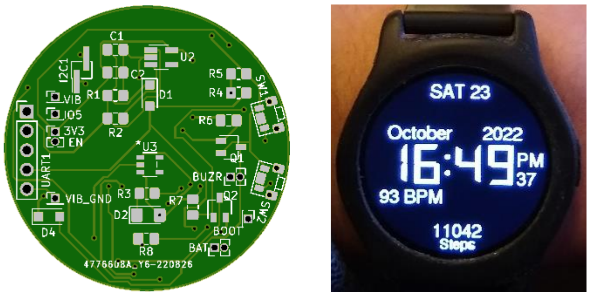

Figure 6: Tenth-grade student designed smartwatch circuit board layout (left), completed project with a 3D printed enclosure (right).

Parts availability was a challenge since the electronics industry had not fully recovered from supply chain impacts of the COVID-19 pandemic. When attempting to purchase components from the student's bill of materials, some were not available, and students had to redesign the affected subsystem to work with a new component. The dynamic supply chain and subsequent design modifications exposed students to real world challenges in the electronics industry.

The advanced electronics pilot participants experienced a significant sense of accomplishment and learned many new tools to solve real world problems with electronics devices. All students described that their success was from extensive research on reference designs, components and specifications, creativity in design, time, and commitment to accomplish a project goal. They appreciated that planning, multiple design reviews, mentor discussions, careful attention to assembly details, and testing were also critical to making their systems work. The students also felt that many people could create a custom electronic device by learning the process and techniques in this pilot, however it requires motivation as a key to success.

FINDINGS

One key to the success of the pilot programs was to rapidly establish the essential knowledge prerequisites and then apply them. Foundational knowledge in physics, electron conduction, electronic devices and components, semiconductor and circuit board manufacturing, chemistry, and related algebraic math were important to establish while completing the advanced electronic designs. However, the participants did not need several years of coursework before applying the new knowledge. In essence, the education and workforce development were streamlined towards the student identified real-world challenges and potential electronics solution.

Another key to the success of this electronics workforce development model was active engagement by industry. This includes mentors, industry developed reference design content, and industry use-cases that provided students additional insights on how to solve their engineering problems. Daily or weekly access to industry mentors was critical to help explain advanced topics, provide additional learning resources, or to help quickly resolve design tool challenges so that the students could continue their innovative learning and creativity in engineering design. To summarize, industry plays a key part in the success of a rapid workforce development program, especially with the untapped workforce pipeline at middle school and high school levels.

Student Perspectives on Electronics Workforce Preparation
Following completion of the pilot programs, each student was asked about their perspectives on existing high school and middle school education programs as preparation for the electronics workforce development pilot programs. The following summarizes their candid responses:

Did middle school and high school experiences introduce you to the idea that you can learn and contribute to technical innovation (in electronics) well before a college degree?

None of the students felt that their school experiences considered early age innovation and technical contribution. Similarly, none of the students had in-school opportunities to learn and apply advanced technical knowledge to real-world engineering problems. Most of their inspiration for curiosity and engineering came from outside of their school experiences. One student commented that high school and middle school students can engineer solutions despite not having complete knowledge or skills; they still had great ideas on how to solve real problems.

Did middle school and high school experiences prepare you for electronics or semiconductor design (including EDA tools, complex computer environment, problem solving, research, etc)?

All students had consensus that existing STEM oriented courses or extra-curricular programs in their schools did not have enough depth or breadth of topics that would allow them to create end-to-end electronics solutions for real-world engineering problems. In other words, their current school systems have insufficiencies in establishing foundational knowledge needed to prepare them for the electronics industry.

How might industry and schools partner to prepare students for electronics and other engineering industries?

When asked this question, each of the students reflected on their experiences and generated several creative ideas on how industry and school systems can partner to be more effective at preparing a needed workforce for the electronics industry talent pipeline. High school career fairs could help students explore different STEM industry careers; many of the pilot participants felt that they lacked knowledge of all the opportunities available. Regular engagement with industry members would also allow students the chance to learn sooner about what they may want to pursue in life and help them identify a pathway towards that. Another concept was to create science or engineering focused middle schools and high schools (much like a charter school) but for specific STEM careers. They would learn what is required for state-level education requirements but with heavy focus on applying the science and engineering which directly prepares them for certain career fields after high school graduation.

Another concept that student participants thought would be extremely valuable was to conduct industry specific STEM camps or industry-led short courses like the advanced electronics prototyping pilot program. These would introduce students to more specific topics that translate directly to workforce preparation. One of the pilot program participants described a recent example of a student-led week long camp with the goal to inspire individuals to pursue the emerging artificial intelligence (AI) field [17]. The students attending the free camp were from lower-income districts and had no background in software coding. By the end of the week, the instructors not only saw many students develop skills but also develop a passion for AI software, similar to [18].

The below list summarizes several themes from the pilot programs that had direct impact on each student's success:

- Inspire curiosity and self-directed learning.
- Streamline foundational knowledge for each task, this gives students a jump start on engineering design.
- Apply engineering to real-world problems for significant experiential learning.
- Specific skills-training sessions (didactic and practicum) may be necessary.
- Ensure that design and verification tools are easy to use while providing advanced capability.
- Reference architectures and pre-developed design elements aid in learning how to solve certain problems with electronics.
- Encouragement and knowledge help overcome complex challenges.
- Longer-term industry mentor relationships with regular engagements.

IMPLICATIONS – RETHINKING ELECTRONICS INDUSTRY WORKFORCE DEVELOPMENT

Integrated Approach to Electronics Workforce Education

The U.S. needs a more integrated approach to electronics workforce education that begins at K-12 school ages while they are forming ideas on career pathways during middle school and high school, rather than focus explicitly on post-secondary education. The integrated approach also needs to capitalize on what students can accomplish and teach them the advanced electronics knowledge and skills that are employable several years earlier than post-secondary education venues. The programs must consider significant involvement of both industry and educators with a focused electronics education pathways, funded projects, and active long-term mentorship commitments to be successful.

Inspire Curiosity, Self-directed Learning, and Purpose

Inspiring curiosity, self-directed learning, and purpose may be the most important goals for an early STEM workforce development program. These three aspects were observed as critical to each student's success. During future engagement with high school and middle school students, it will be key to inspire curiosity and teach them how to become independent learners as part of their foundation while providing them resources and specific skills. Additionally, STEM workforce development programs and personnel must also consider that the next generation of workforce may be seeking purpose in what they do [19]. That statement is also reflected by several author interviews with technology companies on the topic of workforce recruitment, retention, and development. A potential employee's purpose can be derived from understanding how their work positively impacts a humanitarian or defense mission or can be driven by internal motivations for technology innovation and solving the real-world problems.

Meet Students Where They Are
A less apparent implication is that early workforce development programs must meet students where they are. There are a number of barriers to learning advanced STEM topics including lack of awareness of career pathway options, competing time commitments, and financial difficulties in addition to the diversity, equity, and inclusion challenges. One of the easiest ways to overcome several of these challenges is for early STEM workforce development activities to occur on-campus at high schools and middle schools. This approach alleviates several areas of student difficulties; however it requires a partnership between industry members and educators to ensure successful career fairs, electronics industry short courses, focused project-based learning opportunities, and long-term mentorship. While more work is required to scale this approach and address all student barriers, on-campus workforce development activities can help make significant progress towards what can be achieved for electronics industry and broad STEM workforce preparation.

CONCLUSIONS

The results of both pilot programs establish that semiconductor design and advanced electronics prototyping can be achieved by high school and middle-school students as part of an early workforce development program. While the student participants may not necessarily represent all U.S. student demographics or socio-economic challenges, it does set a high bar for what can be accomplished in a relatively short period of time with significant industry-based mentoring. The pilot programs also demonstrate that key design and engineering tasks for electronics and semiconductor segments can be performed by younger students on focused topics, and do not require college degrees to begin contributing to the electronics innovation ecosystem.

Ultimately this "shift left" perspective towards high school and middle school workforce development can significantly contribute to building a more robust talent pipeline for the electronics industry, and perhaps can be broadly applied to all science and engineering fields. The two case studies and discussion presented in this paper highlight ways to overcome current STEM education gaps while reducing barriers for STEM education and meet students where they are at on-campus. By rethinking how to conduct STEM education using observations from these case studies combined with existing diversity, equity and inclusion imperatives we can inspire the next generation of innovators and rapidly close the sustained U.S. electronics workforce gap.

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REFERENCES

[1] U.S. Department of Defense, “DoD STEM.” https://dodstem.us/participate/opportunities/?audience=Students (accessed Feb. 24, 2023).

[2] National Science Foundation, “NSF Directorate for STEM Education: Funding search,” *NSF - National Science Foundation*. https://beta.nsf.gov/funding/opportunities (accessed Feb. 24, 2023).

[3] S. DuBravac, “The Current Sentiment of the Global Electronics Manufacturing Supply Chain.” IPC, Sep. 2021. [Online]. Available: https://emails.ipc.org/links/0921Current-Sentiment-GEMSC.pdf

[4] Semiconductor Industry Association, “SIA Workforce Rountable March 16th, 2018 Summary Report: Challenges and Opportunities Facing Semiconductor Workforce,” May 2018. [Online]. Available: https://www.semiconductors.org/challenges-and-opportunities-facing-semiconductor-workforce/

[5] Semiconductor Industry Association and Oxford Economics, “Chipping In: The Positive Impact of the Semiconductor Industry on the American Workforce and How Federal Industry Incentives Will Increase Domestic Jobs,” May 2021. [Online]. Available: https://www.semiconductors.org/chipping-in-sia-jobs-report/

[6] J. Whalen, “Economic future of U.S. depends on making engineering cool,” *Washington Post*, Oct. 23, 2022. [Online]. Available: https://www.washingtonpost.com/technology/2022/10/23/engineer-shortage-us-chips/

[7] U.S. Bureau of Labor Statistics, “All Employees, Semiconductor And Other Electronic Component Manufacturing,” *FRED, Federal Reserve Bank of St. Louis*, Feb. 03, 2023. https://fred.stlouisfed.org/series/CES3133440001.

[8] U.S. Census Bureau, “2020 ECNSVY Annual Business Survey AB2000CSA01: Statistics for Employer Firms by Industry, Sex, Ethnicity, Race, and Veteran Status for the U.S., States, and Metro Areas.” [Online]. Available: https://data.census.gov/table?n=334:335&tid=ABSCS2020.AB2000CSA01

[9] Intel Corp, “Intel Global Diversity and Inclusion,” *Intel*. https://www.intel.com/content/www/us/en/diversity/diversity-at-intel.html.

[10] Project Lead The Way, “PLTW Engineering,” *PLTW*. https://www.pltw.org/our-programs/pltw-engineering.

[11] NextFlex, “FlexFactor: K-12 Advanced Manufacturing Training Program.” https://www.nextflex.us/learning-portfolio/flexfactor/ .

[12] U.S. Department of Education, “Science, Technology, Engineering, and Math, including Computer Science,” *You Belong In STEM*, Jan. 2023. https://www.ed.gov/stem .

[13] Efabless Corporation, “Full-Chip design with Chiplicity (part 1),” Jun. 29, 2017. https://efabless.com/kb-articles/full-chip-design-with-chiplicity-part-1.

[14] *Redemption Christian Academy STEM Pilot Program*, (Dec. 20, 2022). [Online Video]. Available: https://www.youtube.com/watch?v=lTQDgc2a6Kc

[15] “STEM Program - Redemption Christian Academy,” Aug. 23, 2022. https://redemptionchristianacademy.org/stem/ .

[16] “KiCad EDA.” https://www.kicad.org/ .

[17] A. Nashikkar and S. Zhou, “All In AI.” https://www.all-in-ai.org/ .

[18] P. Bhounsule, L. Claeys, B. Harmon, C. Lima, and E. Young, “Coding Camp for Middle School Girls Helps Improve Awareness of Science/Engineering Careers and Pathways,” presented at the 2022 ASEE Illinois-Indiana Section Conference, Apr. 2022. [Online].

Available: https://peer.asee.org/coding-camp-for-middle-school-girls-helps-improve-awareness-of-science-engineering-careers-and-pathways
[19] J. W. Mitchell, “Fire Your Hiring Habits: Finding and Keeping the Best Talent is Fundamental to Building Electronics Better,” presented at the IPC APEX EXPO 2023 Keynote, San Diego, CA, Jan. 25, 2023.

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