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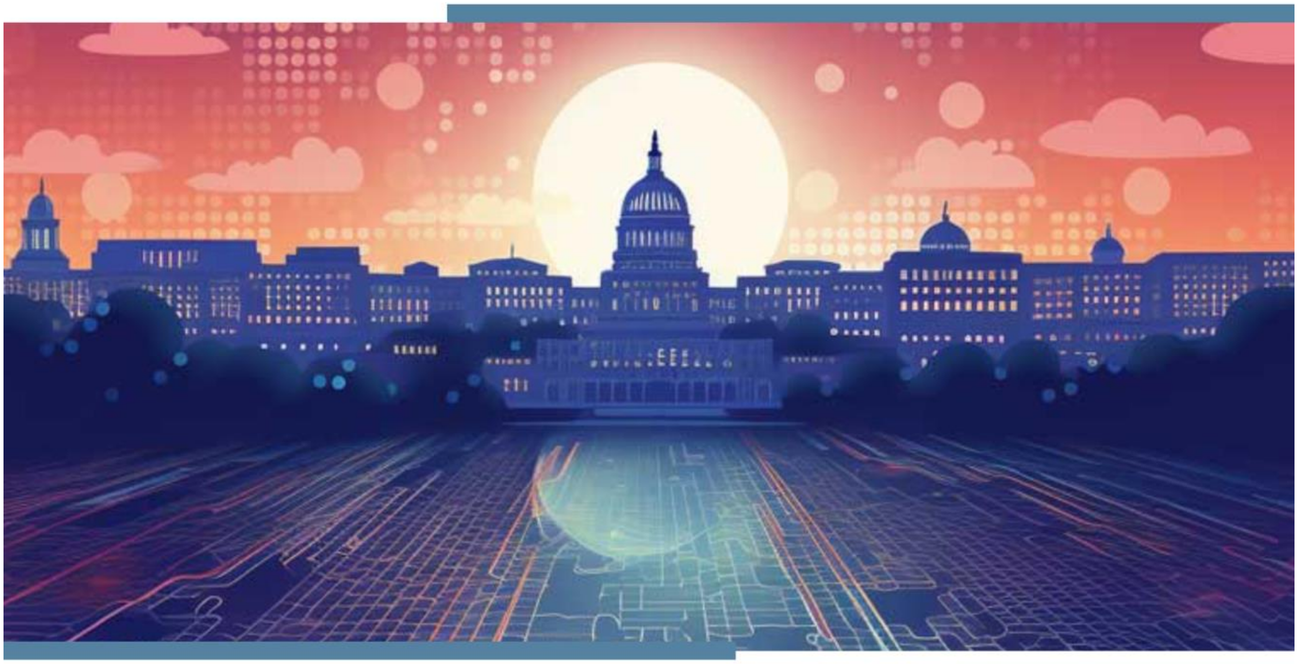
NSF REPORT:

SEMICONDUCTOR EDUCATION & WORKFORCE DEVELOPMENT CONVENING



Pasadena City College

NSF

MNT-EC
Micro Nano Technology Education Center

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The authors would also like to thank countless others who provided insight and feedback.

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Executive Summary

With the 2022 CHIPS and Science Act investing over $50 billion in the U.S. semiconductor ecosystem, it is critical that the U.S. address the workforce implications of this industry expansion. The CHIPS Act is projected to spur the creation of tens of thousands of new positions by the end of the decade, which current enrollment and degree completion rates cannot meet. Educational institutions--K-12, community colleges, and universities--must work in tandem with industry partners and government agencies to bolster the country's workforce development efforts.

This report focuses on opportunities for NSF investment in the semiconductor education and workforce space. It presents a series of recommendations offered by participants in a November 2023 National Science Foundation (NSF) Semiconductor Education and Workforce Convening. Recommendations are divided amongst the convening's four breakout groups: faculty professional development, curriculum development, student recruitment and retention, and infrastructure access. Experts gathered to develop a series of recommendations, including but not limited to: funding faculty summer externships; developing open-source curriculum repositories; prioritizing sustained student engagement activities; and investing in both physical and digital educational infrastructure. Overall, participants agreed that funding must be distributed at speed and with cross-cutting support from educational institutions, industry partners, and government agencies.

Part 1: Introduction

The CHIPS Act and Projected Needs for the U.S. Semiconductor Workforce

The passage of the CHIPS and Science Act in August 2022 allocated billions of federal dollars into the U.S.'s semiconductor ecosystem. As it continues to be implemented, the CHIPS Act will expand the semiconductor industry and drive a great need for technical workers. At present, the U.S. semiconductor workforce cannot meet these demands. According to a report by the Semiconductor Industry Association in July 2023, the semiconductor industry's workforce is projected to grow by nearly 115,000 jobs by the end of 2030, a 33% growth.[2] However, estimates suggest that 58% of these projected new jobs and 80% of projected new technical jobs risk going unfilled. Current enrollment and degree completion rates are not high enough for technicians with two year degrees or engineers with four-year or advanced degrees to fill these roles.[3] If the U.S. semiconductor industry were to become self-sufficient in chip production, around 300,000 new fab workers would be required, a substantial workforce gap.[4]

In efforts to address workforce demands, in November 2023 NSF held the 'Semiconductor Education and Workforce Convening,' facilitated by the Micro Nano Technology Education Center (MNT-EC), a National Science Foundation Advanced Technical Education Center. This convening focused on the workforce challenges spurred by this microelectronics industry expansion and proposed how NSF can strengthen educational institutions--K-12, community colleges, and universities--so that they are equipped to construct this new workforce.

The 2022 CHIPS and Science Act
The 2022 CHIPS and Science Act is one of the largest federal investments in decades to advance U.S. global leadership in science and technology, particularly within the semiconductor manufacturing industry. The legislation authorized $280 billion in new funding, with $52.7 billion in direct funding and loan subsidies appropriated, to expand semiconductor research and development and manufacturing in the U.S. Through investments in science and technology, workforce development, supply chains, manufacturing, and education, this landmark legislation aims to boost the U.S.'s domestic semiconductor manufacturing capacity and advance the country's industry leadership.[5]

Key Challenges

[2] "Chipping Away: Assessing and Addressing the Labor Market Gap Facing the U.S. Semiconductor Industry," Semiconductor Industry Association and Oxford Economics, July 2023.

[3] Ibid.

[4] Sujai Shivakumar, Charles Wessner, and Thomas Howell, "Reshoring Semiconductor Manufacturing: Addressing the Work- force Challenge," Center for Strategic and International Studies, October 6, 2022.

[5] Justine Gluck, Kanwalinder Sodhi and Ariel Higuchi. "Community Colleges and the Semiconductor Workforce." Belfer Center for Science and International Affairs, Harvard Kennedy School, June 2023.

NSF grant makers must confront challenges that currently limit the advancement of semiconductor education and workforce development efforts. Key challenges are as follows:

Faculty Professional Development: Instructors, particularly at community colleges and K-12 institutions, are increasingly isolated from industry environments and from access to equipment.[6] There is also a lack of continuously updated centralized forums for educators and industry to share and spread best practices and professional development tools. Faculty recruitment and retention proves to be a challenge, especially at community colleges where qualified faculty are increasingly hired away by private industry offering higher salaries.[7]

Curriculum Development: Current curriculum practices limit interoperability within the transfer process. At present, four year institutions lack confidence that community college graduates are transferring with a curriculum that is calibrated to their teachings. A centralized curriculum repository could help facilitate smoother transfer processes, creating modular content that could assist in alignment between institutions. Additionally, curriculum is often not effectively aligned with present and future industry needs, producing technician and engineer skill deficits as a result of curriculum gaps.[8]

Student Recruitment and Retention: The semiconductor industry as a whole struggles with visibility, with a lack of age-specific literacy and advertising campaigns and student opportunities.[9] In particular, high-paying and visible jobs in the software industry have lured students away from studying microelectronics.[10] Students also need to be incentivized and financially supported to pursue relevant degrees, particularly among underrepresented populations.[11] Increasing recruitment to diverse students is critical for the strength and size of the talent pool, but it is also challenging to find sustainable support for mentorship programs needed to recruit diverse students.

Infrastructure Access: Laboratory equipment and facilities need to be modernized in order to offer relevant experiential learning opportunities for students.[12] There are limited coordinated ecosystems to support infrastructure sharing, both for digital and physical infrastructure. Students need enhanced access to educational Multi-Project Wafer (MPW) services with non-disclosure agreement (NDA) terms that are compatible with academia. Existing educational content needs to be expanded for chip fabrication, packaging, and

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[6] Tsu-Jae King Liu et al., eds., *Fueling American Innovation and Growth: A National Network for Microelectronics Education and Workforce Development* (Milpitas, CA: Semi and American Semiconductor Academy, 2022).

[7] Gluck, "Community Colleges and the Semiconductor Workforce."

[8] Liu et al., eds., *Fueling American Innovation and Growth: A National Network for Microelectronics Education and Workforce Development*.

[9] Gluck, "Community Colleges and the Semiconductor Workforce."

[10] Ibid.

[11] Liu et al., eds., *Fueling American Innovation and Growth: A National Network for Microelectronics Education and Workforce Development*.

[12] Ibid.

testing.[13] Additionally, educational institutions require sustainable support to avoid passing infrastructure usage fees along to students.

NSF Semiconductor Education and Workforce Convening

The Semiconductor Education and Workforce Convening, hosted on November 13, 2023, included 160 registered attendees. Expert participants represented research universities and four year colleges (42 participants), government agencies (33 participants), community colleges (28 participants), industry (26 participants), coalition/ consortium/ consulting organizations (16 participants), non-profits (8 participants), university students (5 participants), and K-12 educators (2 participants). From this group, 16 participants simultaneously represented HBCU/HIS/MIS. Ninety-three attendees and non-attendees submitted pre-surveys answering questions on workforce challenges and posing recommendations to meet these challenges. Each of these groups embody different parts of the workforce and educational system, generating a diverse convening ecosystem.

Participants were divided amongst four thematic breakout groups, discussing faculty professional development, curriculum development, student recruitment and retention, and infrastructure access. Each breakout group was moderated by external facilitators, with NSF representatives acting as observers. Throughout the convening, breakout groups coalesced for consensus on major recommendations and to share out proposals.

Summary of Workforce Recommendations

The following report presents the key challenges and recommendations identified by convening experts. Recommendations are divided amongst the four breakout groups: faculty professional development, curriculum development, student recruitment and retention, and infrastructure access. Each section highlights *gaps* agreed upon by participating experts and offers expert recommendations for how NSF might bridge these gaps. Gaps must be filled in order to meet the workforce challenges that will be spurred by the CHIPS-induced microelectronics industry expansion.

[13] Matthew Guthaus et al., "NSF Integrated Circuit Research, Education and Workforce Development Workshop Final Report," National Science Foundation, 2022.

Part 2: Workforce Recommendations

Faculty Professional Development

Gap: Instructor experience and knowledge diverges from current industry practices.

1. **With the support of NSF funding, universities, community colleges, and K-12 school districts can facilitate paid summer externships for faculty within industry environments**. Capitalizing on summer recess, faculty nationally can gain experiences on state-of-the-art industry equipment to improve instructional practice. Hosted at national laboratories or within industry partner sites, externships offer the chance for faculty to learn technical topics such as multiscale/multiphysics modeling, verification & validation, field programmable gate arrays (FPGAs) development boards, and electronic design automation (EDA) tools. NSF should consider requiring output implementation for this funding, in which faculty must implement their learnings within their classroom curriculum upon the program's conclusion.

2. **Offer incentives for industry technician exchange with community colleges**. NSF can help facilitate the exchange of industry technicians--including those entering retirement--to conduct learning modules within community colleges and K-12 schools alongside instructors. While there are opportunities for industry personnel to teach students, it's critical that industry practitioners receive training on teaching pedagogy for industry experience to translate to effective classroom teaching. As a result, industry exchange may be most effective in the form of professional development workshops hosted for an audience of community college faculty.

3. **Funding opportunities should support the creation of short-term professional development (PD) programming: seminars, workshops, training modules, and faculty mentor programs.** Time and funding constraints often prevent faculty from attending more robust summer training programs. Professional development must also include short-term training opportunities in a hybrid format, both online and in-person, to broaden the scope of PD participation. Programming should be offered on a repeated and scheduled basis and should focus on a.) strengthening faculty knowledge of industry practices and b.) developing a curriculum aligned with workforce goals. These modules/ workshops should also enhance instructional and classroom practices, such as technical communications and pedagogical theory.

4. **As an immediate action, online PD resources can be corralled and made centrally available for enhanced access by faculty and institutions**. At present, a number of PD resources are available online. However, these resources are dispersed and often inaccessible for institutional access. Plans for NIST's future National Semiconductor Technology Center (NSTC) include a "Center of Excellence" to expand training and retraining for the semiconductor ecosystem. Coordination and communication should be

undertaken with NIST to ensure that NSTC's Center of Excellence centralizes and makes publicly available faculty PD resources.

5. **Sponsor meetings and conventions, both regionally and nationally, that convene industry representations and educators**. Akin to this Semiconductor Education and Workforce Convening, there are opportunities for NSF to fund future gatherings coalescing representatives from industry, education, and government. Such gatherings offer the chance to build partnerships, gather knowledge, and spread models and best practices. Meetings can be hosted nationally and also within regional jurisdictions.

Models for Faculty Professional Development

Paid Summer Externships:

Lawrence Livermore National Laboratory Faculty Mini Sabbatical Program. This program brings academic faculty across the U.S. onsite to the Laboratory for one- to three- month paid exchanges. Faculty are able to use Laboratory resources and advance skills.

Northeast Advanced Technological Education Center (NEATEC) Experiential Learning. NEATEC offered PD courses to high school teachers, learning how to use atomic force microscopes and various electronics, and receiving hands-on kits to teach nanotechnology. While these were short courses, this program could be effectively extended into a summer externship.

NIST K-12 Neutron Research Summer Opportunities. NIST runs the Research Experiences for Teachers, RET, which gives high school teachers the opportunity to do a summer research project under the direction of an NCNR scientist or engineer, providing unique insights to pass along to students. NIST also runs the NIST Summer Institute for Middle School Science Teachers, which provides middle school teachers with resources and instructional tools for teaching math and science.

Short-term PD Programming:

Penn State Center for Nanotechnology Education and Utilization (NACK) PD Workshop. Funded by an NSF grant, NACK offered both live-streamed and hands-on workshops for educators to gain introductory information on nanotechnology and learn to implement nano-concepts into their classrooms.

Code.org Teacher Training on AI. Code.org announced a new program to offer specialized teacher training workshops and online webinars to help faculty learn about AI and effectively incorporate AI into their classrooms. This example could be transferred to nanotechnology.

Centrally Available PD Resources:

The Center for Excellence in Education (CEE). CEE is a nonprofit organization that may act as a model for NSTC's Center of Excellence and other future resources. The organization runs a Teacher Enrichment Program that connects high school STEM teachers to industry PD workshops. It also runs Lab Bench, which provides access to STEM education materials and labs for teachers.

Curriculum Development

Gap: Gap between existing curriculum repositories and centralized access to these materials, which would help facilitate interoperability of transfer processes.

1. **There is a funding opportunity for a neutral, third-party host to help adjudicate and curate new insertions into a centralized open-sourced curriculum repository.** Successful curriculum repositories exist, including Purdue's NanoHUB and curriculum hosted by ATE-Central. However, these repositories like NanoHUB primarily serve graduate students and engineering students, pointing to a need for open-source repositories for all education levels, from K-12 to graduate students. Another major gap is that content development in existing repositories is usually constructed by individuals or small teams. Extending these sites would allow for more collaborative methods to develop curriculum modules and provide a strong basis for follow-on adaptation and development. As a result, a public domain with a facilitating organization, like MNT-EC or ATE-Central, may be best to house this content, further centralizing curriculum and simplifying institutional access. In the future, NSTC's Center of Excellence may act as a host for this curriculum repository. There is an opportunity for NSF to communicate with NIST preemptively during NSTC's creation and expedite the development of an effective semiconductor curriculum repository. As a first step, NSF may want to release a funding opportunity to research and compile existing open-source curriculum in preparation for inclusion in a future centralized repository.

2. **Incentivize the development of short, modular content to include on open-source repositories.** Curriculum development, especially curriculum created by industry sources, is often constrained by intellectual property regulations and the inclusion of proprietary information. While industry content does not need to be excluded, it also does not meet all the needs for a modular curriculum repository. Due to these limitations, it is helpful to invest in the development of fresh or repackaged curriculum geared towards public use. Short modular content that can be included within broader courses is preferred over the development of full learning plans. Instead of requiring a full course restructuring, modules are able to be adapted and integrated into different courses across educational levels. Subsequently, these curriculum materials can be published on public websites instead of keeping them in closed learning management systems (e.g. Blackboard, Canvas).

3. **A centralized curriculum repository must also incorporate existing knowledge, skills, and abilities (KSAs) roadmaps aligned with current & future requirements of the industry workforce**. Student KSAs roadmaps, like those developed by MN-TEC and the Semiconductor Research Corporation's (SRC) Microelectronics and Advanced Packaging Technologies (MAPT), should be housed in the same location as curriculum repositories to highlight curriculum alignment with industry needs. These KSA roadmaps can be extended and divided into multiple tracks based on technical areas (e.g. process engineer versus chip designer). There should be a national thrust for executing KSAs roadmaps for educational purposes and to facilitate industry recruitment pathways.

Gap: Divergence between creation of new curriculum and implementation within classrooms.

1. **NSF can provide summer funding opportunities for faculty to develop lesson plans and labs.** Developing and integrating curriculum is a time intensive project for faculty. By reserving time during summer recess to undertake curriculum development, faculty are more apt to generate up to date lesson plans aligned with industry practices, workforce needs, and improved pedagogy. *See also Faculty Professional Development Page 8, summer externships.*

2. **Fund virtual and in-person sessions for curriculum developers to prepare educators for carrying out curriculum changes in their classrooms.** Creators of curriculum modules and videos can bring their curriculum to life by hosting workshops. These workshops will help promote faculty understanding and confidence to effectively deliver new curriculum.

3. **Support paid opportunities for graduate students to provide classroom support for faculty during periods of new curriculum usage**. While graduate students often assist university faculty, there are also opportunities for graduate students to support community college and K-12 instructors by acting as classroom aides or as adjuncts. Graduate students can help teachers communicate technical topics to students, enriching STEM instruction and providing assurance for faculty to approach new lesson plans.

4. **Promote a dedicated funding stream for faculty grant application support.** Many faculty applying for NSF grants (e.g. grants geared towards curriculum development or other relevant grants hosted by NSF) face limitations navigating the federal grant application process. At many community colleges, the lack of designated grant facilitators and institutional knowledge on grant strategy constrains the ability of faculty to take on grant-funded projects, like adapting classroom curriculum. NSF should consider expanding successful grant mentorship programs, such as ATE's Mentor Up, that support community college faculty in developing grant proposals. NSF should also consider other funding opportunities that raise awareness for supplemental funding requests (including inviting

supplemental funding requests from more awardees) and offering early-stage training for community college faculty within the grant application process.

Gap: Disparity between industry needs and industry involvement within existing curriculum.

1. **Promote semiconductor industry-approved certifications, particularly for K-12 career and technical education programs.** Industry-recognized credentials provide a standardized measure for competency and performance in work-related tasks. Certificates achieved by K-12 students would be accepted by local industry for entry-level technician positions, or put towards an associate degree at a regional community college. Implementing industry-approved certificates in the semiconductor industry offers a key opportunity for NSF to direct funding to meet local workforce demands.

2. **Fund hands-on-learning experiences for students directly integrated into the curriculum.** Both shadowing programs and summer- or semester-based internships can upskill students with knowledge and tools appropriate for the needs of a future workforce. To recruit a diverse and inclusive talent pool, it is critical for these internships to be funded, offering wages at a rate higher than fast food, retail, or hospitality industries. Funding grants should prioritize integration of hands-on-learning opportunities. Simultaneously, there is an opportunity for NSF to facilitate the creation of a guide to help institutions strengthen industry partnerships and student experiential learning. At present, there are a number of strong industry partnerships within the semiconductor ecosystem. This guide, for both national and regional levels, would compile and advertise these models of industry involvement, in order for additional institutions to identify effective methods of collaboration.

3. **Facilitate ways for industry to be involved with periodic curricular review.** Develop and distribute a regular industry survey to stay aware of emerging issues within the semiconductor ecosystem, adjust student KSAs, and gain direct feedback on curriculum priorities. Curricular review could also take the form of advisory committees made up of regional manufacturing industries, who audit and provide feedback for curriculum improvement. Ensure that this process is carried out throughout community college, university, and even K-12 ecosystems.

Models for Curriculum Development
Development of Short Curriculum Modules: NSF PD for Teaching High School Physics. This grant funded the research and development of instructional materials and PD for teachers to better educate students on energy flow, aiming to create a model for PD that could be widely utilized across institutions. Similar funding opportunities could be structured around instructional materials for students.

Co-Designing Curriculum for Middle School Data Literacy. EDC's Oceans of Data Institute is operating an NSF grant to develop curricula and tools with middle school teachers on data literacy. The project aims to develop digital tools and learning activities, especially those that can be used in diverse classroom contexts. NSF may consider funding other curricula development grants for modular nanotechnology content.
Graduate Student Classroom Support: **NSF Graduate STEM Fellows in K-12 Education.** Funded by NSF until 2011, this program supported fellowships for STEM graduate students who spent one to two years partnering with K-12 teachers while enrolled in school. These fellows helped to enrich STEM content and instruction for K-12 teachers.
Industry Approved Certifications: **WakeTech BioWork Process Technician Certification**. This program is a 136 certificate course that can lead high school graduates in North Carolina into an entry-level position as a process technician or put towards an associates degree in Biopharmaceutical Technology. This certificate offers a model for future nanotechnology certificates. **ASTM International Stackable Certificates for Micro Nano-Technology Workforce Education**. This program, developed in partnership with The Nanotechnology Applications and Career Knowledge (NACK) Network funded by NSF's ATE Program, offers a series of assessment exams for individuals to earn ASTM industry-endorsed stackable certificates for entry-level positions in the nanotechnology workforce. Three certificates have been developed: ASTM Workforce Certificate for Health and Safety in Nanotechnology; ASTM Workforce Certificate for Nanotechnology Characterization; ASTM Workforce Certificate for Nanotechnology Fabrication and Related Infrastructure. NSF may want to consider expanding these certificates' pilot programs and developing similar credential programs with other industry partners.
Industry Survey and Curricular Review: **IPC Study of Quality Benchmarks for Electronic Assembly.** A yearly study that provides data on 59 electronics companies of all sizes. Includes measurements and information on product type production and applications, amongst other benchmarks to stay aware of emerging issues. This survey may offer a model for an industry survey that delivers information to institutions to inform curriculum modifications.

Student Recruitment and Retention

Gap: Discrepancy between increased funding for semiconductor workforce development and awareness and visibility of the industry by students and the general public.

1. **Funding must prioritize continuous, repeated engagement with students across their educational timeline, including informal education opportunities that engage both students and parents and promote community awareness.** There are a number of different types of engagement activities/ awareness campaigns that can effectively enlist students into the semiconductor ecosystem. However, the specifics of the activity should be left up to a particular school or region to implement, as the effectiveness of approaches may vary amongst communities. Consequently, community colleges should also be recipients of funding for informal education campaigns, as they are able to tailor opportunities directly to their immediate area. NSF funding should prioritize engagement campaigns that encompass the following four characteristics:
    a. Activities provide basic knowledge of the semiconductor ecosystem for both families and students.
    b. Campaigns/ activities are structured as sustained touchpoints for students. They build continuous awareness of the industry, as opposed to offering one-time exposure.
    c. Recruitment efforts are attached from the outset to academic offerings. Funding is best spearheaded by community colleges or universities with semiconductor education programs, who develop informal campaigns and activities built around these existing education programs. As students are made aware of the semiconductor industry, they are simultaneously pointed towards academic opportunities to extend informal learning opportunities.
    d. While engagement activities should ideally capture students at all levels of the educational pipeline, funding should prioritize engaging high school seniors and students within the first two years of college. These years are pivotal within a student's career decision pathway.

Suggestions for Student Engagement Activities
1. Partner with local museums and learning centers to build semiconductor exhibits/ learning days that engage the community. 2. Host nanotech demonstrations at local schools: a. Fund a multi-college collaboration to host speaker events on "Nanotech in Popular Media."

b. Partner with popular media sources, like SciShow, to create video series on nanotechnology.

3. Offer immersive classroom experiences hosted by industry representatives (e.g. bringing clean-room suits and silicon wafers to classrooms).

4. Organize region wide career expos for middle school/ high school students, in which semiconductor companies are visible.

5. Hold Semiconductor Day events at regional community colleges and universities, together with industry partners, to introduce students to the entire ecosystem of the semi industry - and invite students and faculty from all relevant programs to attend.

6. Host student competitions in nanotechnology, which may include partnerships with industry.

7. Distribute inexpensive electronics kits that can be given to students for hands-on activities.

Gap: Disparity in enrollment of diverse students, limiting the size and strength of the talent pool.

1. **Funding opportunities should encourage applications that incorporate mentorship programs.** Mentorship networks have a positive impact on drop out rates and academic achievement. Offering individualized guidance and support--in the form of peer-to-peer models or by pairing industry professionals with students--can boost underrepresented student achievement and retention. Industry and universities receiving CHIPS funding have the opportunity to integrate mentorship programs within their proposals. When disseminating funding, NSF can promote proposals that make a concerted effort to weave in mentorship within their stated strategic goals.

2. **Fund bridging programs that support the transition from K–12 to college programs, along with internships and co-ops that are conducted after the first year of college.** Bridging programs and internships act as pipelines into the workforce- teaching, guiding, and supporting students in the hopes of building a wider, more diverse labor pool. Proposals that support students after their first year at university or community college can preemptively capture students who might drop out of this pipeline due to lack of financial resources and learning opportunities. *See also Curriculum Development page 12, certifications and hands-on-learning experiences.*

3. **Fast track programs that help with student aid and fund programming around campus anchor groups.** Supportive wraparound services--childcare, transportation, and housing assistance--are critical for retaining a diverse student population. NSF has the

opportunity to direct funding towards student aid and scholarships, including scholarships distributed by campus groups that historically engage marginalized populations.

4. **Support funding opportunities within K-12 education to address gaps in fundamental math and science preparedness curriculum**. NSF can support K-12 institutions and community colleges in addressing student fears of under-preparedness, which can limit recruitment of engineering students from underserved communities. Funding might support colleges in developing effective supplemental math and science courses for enrolled students or take existing NSF programs and broaden them out to include students who are not as academically competitive.

Gap: Barrier between available student opportunities and resources that bring awareness to these opportunities.

1. **Build a centralized repository and/or promote existing repositories that provide career roadmaps for students.** Career roadmaps include information on: academic programs, certificates, job opportunities, and salary estimates. The National Talent Hub, funded by the National Institute for Innovation and Technology (NIIT), offers potential for institutions to help their students connect with job opportunities and resources. NSF may consider ways to advertise and encourage institutions of higher learning to join the National Talent Hub. There may also be opportunities under the forthcoming NSTC to consolidate career roadmaps and simplify the pathway for students interested in both technician and engineering positions.

Models for Student Recruitment and Retention
Internship and Mentorship Programs: **Purdue SCALE.** Led by Purdue University, funded by the Department of Defense and managed by NSWC Crane, SCALE provides research projects, internship matching, and mentoring for college students interested in microelectronics. Notably, this program utilizes DOD funding to support internship placement at government and industry partners and to build year round virtual and in-person mentorship opportunities. NSF may consider funding opportunities for similar multifaceted retention programs. **SEMI Mentoring Program.** SEMI, a microelectronics industry association, facilitates one-on-one mentoring relationships for free online to connect students and young professionals with industry professionals. SEMI also runs the SEMI Career and Apprenticeship Network (SCAN) which utilizes grants to run a registered apprenticeship program, as well as advertise other internships and early career opportunities.
Scholarship and Bridging Programs:

Biotechnology A2M Scholars Program. Funded by NSF, this program provides scholarships to students pursuing associate, bachelor's, or master's degrees in biotechnology. The program partners scholarship funding with academic, career, and support services, including mentorship components, to retain students throughout their academic pathway. This multi pronged model can be replicated within the nanotechnology field to support students.

GEM Fellowship Program. This program provides scholarship funding for students pursuing engineering master's programs. This funding is coupled with practical engineering summer work experiences at employer sponsor sites, touting the benefits of both scholarship funding and experiential learning.

Louis Stokes Alliances for Minority Participation (LSAMP). This NSF program promotes student retention by increasing STEM bachelor's and graduate degrees awarded to underrepresented populations. With a focus on constructing Alliances, including between community colleges and four-year institutions and entry into college, there is the opportunity for NSF to pursue project types under this program focused on the semiconductor ecosystem.

INCLUDES National Network. With the goal of broadening participation of underrepresented students in STEM, NSF INCLUDES network also offers a space for NSF to pursue nanotechnology-focused projects.

Infrastructure Access

Gap: Sustainable and equitable access to medium-scale and large-scale physical infrastructure.

1. **Regional access models need to be developed for educational institutions to sustainably utilize off-site large-scale semiconductor EWD infrastructure, creating a community of stakeholders that can share semiconductor equipment and facilities.** Community colleges can benefit from access to university clean rooms and universities can benefit from access to industry fab facilities. NSF should fund regional consortia or partnerships to coordinate student and faculty access to this large-scale semiconductor EWD infrastructure. Funding would support logistics of coordination and reduce user fees. To support this endeavor, NSF might also consider developing a national inventory of large-scale, education-accessible semiconductor fab and packaging infrastructure to enable regional coordination networks for institutions. Lab-scale equipment is also important to increase the training capacity of community colleges and universities and expand programming, so NSF should also consider funding and supporting partnerships for acquiring lab-scale equipment.

2. **NSF should consider writing support and maintenance of infrastructure into grant budgets.** There is a risk of infrastructure usage fees being passed along to students, impacting the financial viability of student engagement. By offsetting costs associated with maintenance of large-scale infrastructure access, NSF would limit possible fee exchanges.

NSF could also consider making certain research grants available only to eligible institutions that support this infrastructure.

Gap: Limited access to open-source educational content and design tools, particularly cloud based infrastructure and AR/VR tools.

1. **NSF should partner with software vendors and fund annual licenses, especially for K-12 and community colleges.** Ideally, critical training software would be kept available within an open-source ecosystem. However, there remains sophisticated nanotechnology educational software with steep licensing fees and upgrade costs. There is an opportunity to alleviate cost barriers for institutions to access software-defined products. Alternatively, NSF might consider ways to facilitate toolsets that provide K-12 and community colleges with some training abilities for little to no cost (as compared to annual license costs).

2. **NSF should support AR/VR tools that can be made widely available.** The U.S. needs widely available, open-source textbooks and learning resources, especially for younger learners. This includes AR/VR learning resources and complex semiconductor equipment or process 'digital twins.' Digital twins are virtual models of a system currently under development, which enables the design to be explored and analyzed before finalization. In the semiconductor ecosystem, digital twins offer the potential for students to simulate and optimize operations within a fab or of physical devices. NSF might consider investment in AR/VR technology and digital twin technology to facilitate infrastructure training and enhance educational offerings.

3. **Programs should support expanded access to process design kits (PDKs) and open-source design tools.** PDKs are typically specific to a foundry, and offer a model for the generic fabrication process used to design an integrated circuit. Many PDKs are proprietary and subject to NDAs. However, NSF should fund programs and solicit proposals to develop and increase open source PDKs.

Gap: Cost and logistical barriers of student access to instructional tapeouts.

1. **Programs should promote sustainable and equitable access to chip tapeouts and MPW runs across the educational spectrum, from K-12 through graduate institutions.** NSF should support multi-tier MPW programs to enable students (starting at K-12) to complete multiple tapeouts during their educational careers, nurturing the development of engineering skills. A tapeout is the critical final stage of the design of electronics, before design information is sent to manufacturing at a fabrication facility. Students should complete multiple tapeouts during their educational careers to develop engineering skills. In order to do so, NSF should help to make MPWs broadly available. MPWs enable students to tapeout their designs, reducing costs through sharing wafers with other MPW participants. There are different types of MPWs that can be funded for student access. K-12 students can receive access to low-cost processes using larger transistors, which do not require NDAs to access, and have a quicker turnaround. These processes often include many pre-generated designs, which makes system design easier for younger student learners.

Mid-level and advanced learners, such as undergraduates and early graduate students, should be provided access to more advanced MPWs that offer opportunities for open-ended design with cutting-edge performance. NSF might consider creating and funding a new program to solicit proposals to enable low-cost multi-project wafer and packaging services for a wide audience.

2. **U.S. commercial fabs should have a requirement to support broad MPW access for semiconductor education.** There are currently a number of logistical barriers for accessing instructional tapeouts through commercial foundries. Consider communications with the U.S. Department of Commerce and the CHIPS Act office to set recommendations for how CHIPS funding recipients can support broad MPW access for semiconductor education.

Gap: Limited development of new and expansion of existing educational content for advanced packaging.

1. **NSF should encourage the development of curricula and credentials--within community colleges and universities--for advanced packaging**. Packaging refers to the material that encapsulates finished chips, connects them to their environment, and protects against damage and contamination. In recent years, there have been developments in advanced packaging, which uses sophisticated technology to combine components from different types of semiconductor processes into a singular, superior device. Advanced packaging is becoming increasingly utilized to meet the global boom in demand for semiconductors, making it critical that students learn how to utilize advanced packaging technologies. NSF should create funding opportunities to develop curriculum geared towards advanced packaging. Additionally, resources should be set to help community colleges gain accessibility and connections to packaging facilities. Finally, NSF might consider funding the development of a nationally accessible multi-project packaging service with standardized chiplet/interposer/PCB offerings (and an associated assembly design kit). Standard components should be used so that student-designed chiplets would be integrable with standard components to return a full packaged system suitable for validation.

Gap: Divergence between new infrastructure and its effective use within classrooms.

1. **Fund training for faculty and students to operate new infrastructure.** Access to infrastructure, design tools, validation and testing does not equate to usage. Both faculty and students--K-12, community colleges, and universities--require ongoing support and training to maximize the usefulness of new infrastructure. It is critical that infrastructure be accessible to newer learners and that there are no substantial barriers to access (e.g. extensive paperwork or NDAs). NSF should prioritize funding opportunities, like training, that will lead to effective infrastructure engagement.

Models for Infrastructure Access

Access to Physical Infrastructure: **Center for Advanced Technology in Nanomaterials and Nanoelectronics (CATN2) Matching Investment Program (MIP).** MIP is designed to enhance on-site infrastructure and capacities through collaborations between New York State businesses and University of Albany faculty. Through its mission to enhance workforce development, MIP supports infrastructure investment and collaboration and offers a model for public-private partnership. **National Nanotechnology Coordinated Infrastructure (NNCI).** NSF supports 16 facility sites through NNCI, which provide students and professionals access to university user facilities with fabrication tools and other nanoscale science infrastructure. Enables the coordination of nanoscale research and development activity.
Access to Digital Infrastructure: **Purdue NanoHub.** The NanoHub has been a model for shared academic cloud resources. NanoHub has a subsite, Chipshub, that acts as a centralized place to access expert-level tools for the chip design process. These include software educational packages, 2/D and 3/D simulators for electronic devices, and other forthcoming tools. **Remotely Accessible Instruments for Nanotechnology (RAIN) by the NACK Network.** RAIN allows students to access and control microscopes remotely, from classrooms or at home. Students can schedule remote access sessions with experienced engineers. **CMC Microsystems Cloud Design Environment.** A Canadian company, CMC Microsystems offers access to digital and development resources accessed via a research subscription. The system is free for all Canadian academics, presenting a similar model for the U.S. **EUROPRACTICE IC Service**. EUROPRACTICE offers academia in Europe affordable access to industry-standard and state-of-the-art design tools. They offer affordable access to a wide range of CAD tools, training courses and state-of-the-art fabrication technologies, similar to the above service within Canada.

Conclusion

Participants in the 'Semiconductor Workforce Development Convening' identified key challenges and recommendations within four spheres: faculty professional development, curriculum development, student recruitment and retention, and infrastructure access. All participants agreed that funding must be rapidly distributed across the semiconductor ecosystem to address pressing workforce development limitations. By merging perspectives from education, industry, and government partners, the convening highlighted the fundamental need for these actions to be cross-cutting and inclusive. Suggestions for next steps vary, but underscore the need to draw from currently successful models (within nanotechnology and other STEM fields) and to capture diverse students throughout the educational pathway through consistent outreach, effective curriculum, strong faculty teaching, and experiential opportunities.

Appendix: Report Summary

	Gap	Funding Recommendations
Faculty Professional Development	*Instructor experience and knowledge diverges from current industry practices.*	With the support of NSF funding, universities, community colleges, and K-12 school districts can facilitate paid summer externships for faculty within industry environments. Offer incentives for industry technician exchange with community colleges. Funding opportunities should support the creation of short-term professional development (PD) programming: seminars, workshops, training modules, and faculty mentor programs. As an immediate action, online PD resources can be corralled and made centrally available for enhanced access by faculty and institutions. Sponsor meetings and conventions, both regionally and nationally, that convene industry representations and educators.
Curriculum Development	*Gap between existing curriculum repositories and centralized access to these materials, which would help facilitate interoperability of transfer processes.*	There is a funding opportunity for a neutral, third-party host to help adjudicate and curate new insertions into a centralized open-sourced curriculum repository. Incentivize the development of short, modular content to include on open-source repositories. A centralized curriculum repository must also incorporate existing knowledge, skills, and abilities (KSAs) roadmaps aligned with current & future requirements of the industry workforce.

	Divergence between creation of new curriculum and implementation within classrooms.	NSF can provide summer funding opportunities for faculty to develop lesson plans and labs. Fund virtual and in-person sessions for curriculum developers to prepare educators for carrying out curriculum changes in their classrooms. Support paid opportunities for graduate students to provide classroom support for faculty during periods of new curriculum usage. Promote a dedicated funding stream for faculty grant application support.
	Disparity between industry needs and industry involvement within existing curriculum.	Promote semiconductor industry-approved certifications, particularly for K-12 career and technical education programs. Fund hands-on-learning experiences for students directly integrated into the curriculum. Facilitate ways for industry to be involved with periodic curricular review.
Student Recruitment and Retention	*Discrepancy between increased funding for semiconductor workforce development and awareness and visibility of the industry by students and the general public.*	Funding must prioritize continuous, repeated engagement with students across their educational timeline, including informal education opportunities that engage both students and parents and promote community awareness.
	Disparity in enrollment of diverse students, limiting the size and strength of the talent pool.	Funding opportunities should encourage applications that incorporate mentorship programs. Fund bridging programs that support the transition from K–12 to college programs,

		along with internships and co-ops that are conducted after the first year of college. Fast track programs that help with student aid and fund programming around campus anchor groups. Support funding opportunities within K-12 education to address gaps in fundamental math and science preparedness curriculum.
	Barrier between available student opportunities and resources that bring awareness to these opportunities.	Build a centralized repository and/or promote existing repositories that provide career roadmaps for students.
Infrastructure Access	*Sustainable and equitable access to medium-scale and large-scale physical infrastructure.*	Regional access models need to be developed for educational institutions to sustainably utilize off-site large-scale semiconductor EWD infrastructure, creating a community of stakeholders that can share semiconductor equipment and facilities. NSF should consider writing support and maintenance of infrastructure into grant budgets.
	Limited access to open-source educational content and design tools, particularly cloud based infrastructure and AR/VR tools.	NSF should partner with software vendors and fund annual licenses, especially for K-12 and community colleges. NSF should support AR/VR tools that can be made widely available. Programs should support expanded access to process design kits (PDKs) and open-source design tools.
	Cost and logistical barriers of student access to instructional tapeouts.	Programs should promote sustainable and equitable access to chip tapeouts and MPW

		runs across the educational spectrum, from K-12 through graduate institutions. U.S. commercial fabs should have a requirement to support broad MPW access for semiconductor education.
	Limited development of new and expansion of existing educational content for advanced packaging.	NSF should encourage the development of curricula and credentials--within community colleges and universities--for advanced packaging.
	Divergence between new infrastructure and its effective use within classrooms.	Fund training for faculty and students to operate new infrastructure.