Developing Human Capital to Support U.S. Innovation Capacity

Proceedings of a Workshop—in Brief

Domestic and international competition for STEM talent is driving institutions across the research and innovation landscape to consider new policies and partnerships for building and managing STEM knowledge and skills. New levels of investment in human capital to increase U.S. innovation capacity and competitiveness will require coordination and collaboration among academic institutions, workforce development programs, labor organizations, companies, and funders of research and education. The CHIPS and Science Act offers new opportunities for enhancing U.S. human capital; among its many goals, the bill codifies into law the intention of broadening the base of Americans engaged in STEM—from an early age, through formal and informal education and training, and supported by networks of institutions around the country.[1]

On October 18–19, 2022, the Government-University-Industry Research Roundtable (GUIRR) convened a workshop for its membership and invited guests to consider the strategic priority of human capital investment in preparing the future workforce and supporting national innovation capacity. "In the modern era of technological competitiveness, people and, more specifically, their knowledge, skills, education, motivations, and well-being are arguably the most important national security resource. Strategic, long-term investments in human capital are critical to the U.S. economy and a dynamic research enterprise," said GUIRR co-chair **Darryl Pines** (University of Maryland) in opening the workshop. The workshop's discussions examined the state of U.S. workforce preparation and considered trends in supply and demand for human capital to meet the needs of a transforming research enterprise.[2]

INNOVATION ANYWHERE, OPPORTUNITIES EVERYWHERE

In a keynote address, Director **Sethuraman Panchanathan** (National Science Foundation [NSF]) noted three developments that show "it is a potentially transformative moment in the nation for science, technology, and engineering." First, global competition is at an unprecedented level, which he posited motivates the United States to position itself with more intensity and intentionality. Second, the COVID-19 pandemic showed how innovations can meet the moment and deliver solutions. The lag in adoption of some outcomes

[1] H.R. 4346, "The CHIPS and Science Act of 2022," https://science.house.gov/imo/media/doc/the_chips_and_science_act.pdf.

[2] For more information about the workshop, including the agenda, speaker biographies, and presentation slides, see https://www.nationalacademies.org/event/10-18-2022/guirr-meeting-developing-human-capital-to-support-us-innovation-capacity.

demonstrated the importance of collaborations between the sciences and other disciplines to address pressing challenges, such as climate change. Third, he noted that support for science, technology, and innovation to advance the nation's prosperity and security is bipartisan.

"Innovation can and should be anywhere, and opportunities should and can be everywhere," Panchanathan stated. He stressed the need "to lift every ounce of talent across the rich diversity of the nation." He reminded the group that the NSF mission articulated by Vannevar Bush 72 years ago still holds true: to promote the progress of science; advance the national health, prosperity, and welfare; and secure the national defense. To fulfill that mission, NSF has three major priorities: strengthening established NSF programs at speed and scale, inspiring the "missing millions that have been left behind," and accelerating technology and innovation progress. "The DNA of the National Science Foundation is symbiosis," he underscored. "The two strands of curiosity-driven discovery and use-inspired applications feed into each other. This is not one versus the other, but one *and* the other."

Panchanathan highlighted NSF activities in technology areas prioritized in the CHIPS and Science Act. In artificial intelligence (AI), for example, a goal is to "bring out the AI everywhere," such as in agriculture, and with a diverse set of partners in every state and territory. He explained NSF investments in high-performance computing have led to many successful spinoffs—the two founders of Google, for example, received NSF fellowships in 1994. The software company Databricks received critical NSF investments and now has $1 billion in annual revenue and is used by 7,000 organizations. In quantum, NSF is collaborating with the Department of Defense, the Department of Energy, and others to expand accessibility, increase research capacity, and excite people about the quantum revolution.

Advances in robotics include collaborative robots in health care. Using Diligent Robotics as an example, Panchanathan explained that NSF supports a range of efforts, from basic research to the skills needed to launch and sustain a commercial venture. Related to disaster prevention and mitigation, NSF and National Institute of Standards and Technology (NIST) are partnering on Disaster Resilience Research Grants. Programs for advanced communications and wireless technology are investing in the development of new devices, techniques, and networks; enhancing resiliency and performance; and connecting underserved populations.

NSF is investing in talent to strengthen the nation's cybersecurity capabilities, such as through the National CyberCorps Scholarship Program and the National Cybersecurity Training and Education Center (NCyTE), an NSF Advanced Technical Education center at Whatcom Community College in Washington, in partnership with six universities and colleges. In discussing biotechnology, Panchanathan referred to the work of a graduate research fellow funded by NSF in the mid-2000s who received Small Business Innovation Research (SBIR) funding in the 2010s—his company now has $5 billion in funding. "This is the imprint of what NSF makes possible," Panchanathan said, "and there are thousands of examples."

In terms of advanced energy and advanced material science, NSF collaborates with multiple agencies and industrial partners, including its support for the Center for Atomically Thin Multifunctional Coatings (ATOMIC), an Industry/University Cooperative Research Center. NSF has research centers across the nation, including four recently launched Engineering Research Centers. "They are finding solutions to grand challenge problems, societal problems, local, regional, and global problems," he said. "They are funding fundamental research and training the talent of the future, working in partnership with industry."

Panchanathan explained that NSF's new Directorate for Technology, Innovation and Partnerships (TIP) will accelerate partnerships and co-investments with industry and other agencies and enable more pathways to entrepreneurship. He called for the inclusion of businesses and institutions of all sizes and in all parts of the country in this effort. For those without the infrastructure to compete for NSF funding, a new opportunity called Growing Research Access for National Transformative Equity and Diversity (GRANTED) has been created as a virtual research office to help in writing proposals, finding partnerships, and budgeting. "If we are serious about expanding diversity, it cannot be done with the existing structure," he stressed.

In discussion, Panchanathan explained that NSF has the responsibility to identify future priority technologies like the ones he covered in his remarks. To do this, NSF is developing a process to gather and synthesize information from industry partners, agency leaders, global trends, and other sources. In discussing how to prevent the "valley of death" in which companies often fall, Panchanathan said NSF works with the Department of Commerce, industry, and the venture capital community. He acknowledged that NSF used to be "pillars of directorates" with little industry collaboration. However, he said, the pandemic created new opportunities for him to engage industry leaders on how to work in partnership with the foundation. Panchanathan concluded by repeating his original message: "Innovation is anywhere, opportunities are everywhere. How can universities, industry, communities, and local governments all come together? How can we unleash the potential of our nation everywhere?" It can be done, he asserted, and invited participants to partner with NSF.

THE STATE OF U.S. STEM TALENT AND WORKFORCE

The first panel, moderated by GUIRR Council member **Zachary Lemnios** (ZJL Consulting), provided an overview of human capital trends across the STEM ecosystem.

Overview of U.S. STEM Workforce Trends

Amy Burke (NSF) drew from recent analytical work conducted by the National Center for Science and Engineering Statistics (NCSES) to highlight five trends related to the state of U.S. STEM talent: (1) U.S. STEM educational trends; (2) foreign-born science and engineering (S&E) doctoral students in the United States; (3) the U.S. STEM labor market; (4) demographic composition of the STEM workforce; and (5) the geographical distribution of that workforce.[3]

First, she said, elementary and secondary STEM education is the foundation for overall STEM knowledge. The data show persistent gaps between racial and ethnic groups in K–12 math assessments, with scores for Hispanic, Black, American Indian or Alaska Native, and Native Hawaiian or Pacific Islander students below those of their White and Asian peers. Moreover, for most groups, the scores in mathematics have remained relatively stagnant for at least the last decade. To understand why, Burke noted that access to experienced STEM teachers (those with at least three years of experience) is an important factor in student performance. The data show schools with high minority or poverty rates and schools in the southern and western United States have less experienced middle school and high school math and science teachers. This disparity carries into post-secondary education when looking at trends in S&E degree recipients by degree level and race or ethnicity. Compared to their presence in the U.S. population, Black degree recipients are underrepresented at all degree levels, and Hispanics, American Indians, and Alaska Natives are underrepresented in all but the associate degree level.

Burke noted the United States awards the most S&E doctoral degrees compared to other countries. In some fields—particularly computer science, engineering, math, and statistics—more than half of U.S. doctoral recipients are foreign-born and on temporary visas, mostly from China and India. Foreign-born workers comprise nearly 50 percent of all workers with doctorates who are in S&E occupations in the United States. Among what she termed "early-career stayers," most are in S&E fields, although she pointed out that a large proportion are not working in the specific area of their doctorates.[4]

NCSES now takes a broader look at the S&E labor market than it used to, Burke said. Traditionally, data were tracked for occupations that require at least a bachelor's degree, such as engineers, physical scientists, or computer scientists, as well as S&E-related occupations in health, education, and management. More recently,

[3] For more information and data, see NCSES.nsf.gov or follow @NCSESgov.

[4] NSF considers early-career stayers as foreign-born, U.S.-trained S&E doctorate holders who had a temporary visa at graduation (2006–2015) and who reside in the United States after graduation. For more information see https://ncses.nsf.gov/pubs/nsf21336.

NCSES has looked at "middle-skill occupations." Burke explained these are occupations that require high levels of S&E knowledge and technical expertise, but not necessarily a bachelor's degree for entry. This expanded set of occupations provides a much more comprehensive definition of the STEM workforce and shows that the workforce is comprised of over 36 million people and constitutes 23 percent of the total U.S. workforce (see Figure 1). "This reflects how innovation and technology have permeated the economy, for example in clean energy," she commented. "To leave out these occupations was skewing our ability to get a full picture of the STEM workforce."

Analysis of the demographic composition of the workforce indicates participation by women and underrepresented minorities (URMs) increased from 2010 to 2019. Looking at the skilled technical workforce, Black workers represented about 10 percent of the workforce in 2019, and Hispanic workers represented about 20 percent. Women represented only about 26 percent of the skilled technical workforce in both 2010 and 2019. About 45 percent of workers with a bachelor's or higher degrees were women, though the distribution is uneven among different STEM occupations.[5]

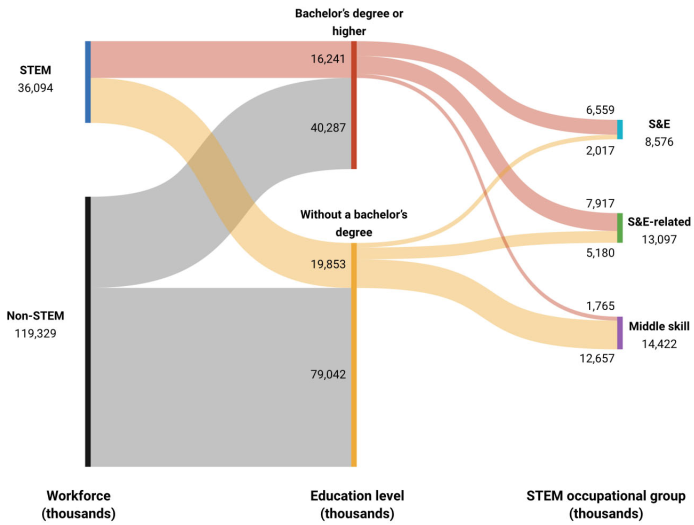

FIGURE 1 U.S. workforce, by STEM occupational group and education level, 2019. SOURCES: NCSES and U.S. Census Bureau. Presented by Amy Burke (NSF) in a workshop of GUIRR on October 19, 2022.

[5] For more on the demographic composition of the STEM workforce see NSB Science and Engineering Indicators 2022 report on U.S. and Global STEM Education and Labor Force: https://ncses.nsf.gov/pubs/nsb20221/u-s-and-global-stem-education-and-labor-force.

Looking at geographic differences within the U.S. S&E enterprise to identify areas of capacity building, Burke noted that states with high concentrations of STEM workers with a bachelor's degree tend to cluster in the Northwest and Northeast and in Midwest states with large metropolitan areas. The states with high concentrations of skilled technical workers tend to cluster in the Central, Midwest, and Southern areas of the United States and in Alaska. Within these areas, certain industries dominate, such as motor vehicle production in the Midwest.

Burke concluded that using a variety of indicators provides a more comprehensive view of distribution and concentration of regional innovative capacity. For example, measuring production of output by knowledge- and technology-intensive industries (industries that globally have high R&D intensities like information technology services or car manufacturing) can be used to identify opportunities for broadening and diversifying S&E capacity across the United States.[6]

Sub-Bachelor's Degree STEM Workforce

Harry Holzer (Georgetown University) focused on the STEM workforce without bachelor's degrees. He opened by positing that the long-standing problems in developing a technical workforce—including labor shortages and lack of diversity, and slow implementation and diffusion of technological innovation—hurt the quality of implementation, generate inequality, and limit upward mobility. He noted that among occupations that do not require a bachelor's degree, STEM jobs are often the best compensated.

Concurring with Burke, Holzer said that limitations in K–12 math and science result in fewer students choosing STEM at community colleges. With the exception of health care, these programs are underenrolled. For example, the City Colleges of Chicago recently created a number of workforce programs, including one on advanced manufacturing, but students are not choosing to enroll. Perceptions persist that these occupations have race and class issues, he opined.

[6] See NSB Science and Engineering Indicators 2022 report on U.S. and Global Science and Technology Capabilities: https://ncses.nsf.gov/pubs/nsb20221/u-s-and-global-science-and-technology-capabilities.

Holzer said workplace learning is weak in the United States—there is no apprentice system as in Europe, and career and technical education (CTE) tends to be stigmatized. "There has been progress, but enrollment is low and quality uneven," he said. In addition, community college completion rates are low and many students get degrees in fields that are "low value" as a terminal degree (e.g., an associate's degree in a humanities field compared to a STEM field). The overall amount of debt taken on by students at community colleges is generally lower than the debt amounts of bachelor's degree–seeking students, but small debt loads can lead to high default rates, if students go into low-compensation fields or do not finish their degrees.

Several reasons account for this mismatch, according to Holzer. Community colleges are underfinanced, underincentivized to boost completion rates, understructured (e.g., to provide adequate counseling to students), and undersupported (e.g., to provide mentoring or child care assistance). Noncredit programs are nimble but often not well funded. He said some do not want to work with community colleges because they perceive the community colleges move too slowly. The outcomes at for-profit colleges are not as good on average, he added. The Workforce Innovation and Opportunity Act (WIOA), signed into law in 2014, has had little funding and thus weak results, which creates a cycle in which the lack of results means little funding. The pandemic, he added, saw a decline in students' academic performance, rising inequality for children, dropping enrollment in higher education, and tight labor markets that exacerbate worker shortages in certain fields.[7]

Holzer offered some new developments that—in his view—seem promising. First, several CTE models have been evaluated and show impact, including career academies and technical/hybrid high schools such as the Pathways in Technology Early College High School (P-Tech) in New York City. Second, apprenticeship programs are on the rise. Third, research in community colleges shows the benefits of strong support programs. Fourth, sector-based programs, while too small, are effective, including Project Quest, Per Scholas, Year Up, and the Wisconsin Regional Training Partnership.

Holzer concluded with policy suggestions, including improving math and science teaching by increasing the quantity of well-trained teachers; supporting effective work-based learning models; providing financial aid to community colleges (and their students), and scaling sector-based training. He also urged resources to remediate losses from the pandemic.

Understanding and Addressing the STEM Talent Shortage

Matt Sigelman (Burning Glass Institute) offered data that he suggested may explain the STEM talent shortage. To start, he agreed with Holzer's discussion of a "misaligned pipeline" related to community college and CTE pathways. Only 18 percent of credentials earned in CTE programs are in demand by industry, while many needed certifications are undersupplied by higher education institutions. In many fields, such as logistics, supply is not keeping up with rising demand. He urged looking at the data behind the increases in STEM talent. While engineering conferrals have grown over the past 50 years, virtually all the increase is attributed to computer science. "Computer science has swallowed up engineering," he said. "We need engineering talent in other fields."

Although he agreed with broadening definition of STEM occupations discussed by Burke, he noted an "artificial constraint" related to the rise in the percentage of computer/math occupations that require a bachelor's degree. "This runs counter to a broader market embrace of skills-based hiring," he said. Overall, the percentage of job postings requiring a bachelor's degree declined by 27 percent between 2012 and 2021, but it increased by 17 percent in STEM fields. "Degree inflation is on the rise, leaving no path for non-degreed workers," he said.

Emerging technologies are feeding rapid growth in some areas, such as AI, machine learning, cloud computing, and product management, but people are not being trained in these areas. "Emerging sectors demand a curriculum rethink," he suggested. It is not so much a "talent shortage" as a "skills

[7] For more information on the impacts of the pandemic on children and their families see National Academies of Sciences, Engineering, and Medicine. 2023. *Addressing the Long-Term Effects of the COVID-19 Pandemic on Children and Families*. Washington, DC: The National Academies Press. https://doi.org/10.17226/26809.

shortage." Even those in long-standing occupations, such as mechanical engineers, need new skills to stay relevant and valuable. In addition, jobs across sectors increasingly demand STEM skills, such as data analysis. "STEM skills are foundational for economic opportunity," he concluded.

DEMANDS FOR HUMAN CAPITAL: THE PRESENT AND FUTURE OF STEM WORK

In the next panel, moderated by Pines, three engineering professionals shared how their organizations are focusing on the human needs to build talent and improve U.S. competitiveness.

The End of "Unskilled, Un-STEMed Labor"

Stephen Welby (Institute of Electrical and Electronics Engineers [IEEE]) recounted that when he served as chief technology officer at the Department of Defense, it became clear that to achieve technological objectives, "it had to start with talent." In his role at IEEE, he engages globally on the changing nature of work. He welcomed NSF's inclusion of "middle skill" STEM occupations in its analysis, but suggested an even broader view. "There is no such thing as unskilled or un-STEMed labor," he stated. Increasingly, he added, even "non-STEM" employers expect their workers to have numeracy, systems thinking, comfort with computing devices and automated systems, mechanical reasoning, and ability to achieve competency with complex tools. So-called "unskilled labor" must, in fact, be highly skilled in STEM applications, he asserted. However, looking at OECD data, the digital skills of the U.S. workforce do not line up with demand, and the gap is broadening.

Among the degreed workforce, the model of a STEM career is also changing, Welby continued. Because of shorter tenure with individual employers, accelerated introduction of white-collar automation, and a shorter half-life of technical skills, individuals must take ownership of and accountability for their personal career trajectories. The average tenure in engineering roles is 5.7 years, or half of what it was 20 years ago. At the same time, engineers will have extended careers and retire later in life.

Welby noted the three current models to develop skills have limitations. While traditional degrees provide a base of knowledge and critical thinking, they are expensive and slow to change. Continuing education does not adapt quickly enough to industry needs. Certifications are primarily motivated by safety compliance requirements or are product-specific. Thus, he suggested a role for engineering societies to deliver lifelong learning. He noted, "learning throughout professional life is no longer optional; it's necessary to sustain because of the changing nature of job-relevant knowledge." He summarized what he sees as four implications for the STEM workforce. First, changing the way STEM careers are framed and conceptualized—with new markers, measures, and milestones for career progression. Second, providing professional career support for the STEM workforce independent of one's employer. Third, new models to support refreshed skills. Fourth, accommodations for the impacts of human-machine learning and transformation on STEM professions and the research enterprise.

Manufacturing and STEM

Jeannine Kunz (Society of Manufacturing Engineers [SME]) reported that SME, an association impacting over 750,000 manufacturing professionals, educators, and students, wants to increase partnerships to advance its core belief that manufacturing is key to economic growth and prosperity. Reflecting on the theme of the workshop, she stressed, "we need to advance people—not just technology—for innovation. We need to remember the people." To illustrate this point, she referenced the Global Competitiveness Index, which considers access to talented workers as the top indicator of a country's competitiveness, followed by a country's trade, financial and tax system, and cost of labor and materials.[8]

When SME partnered with CESMII, the Smart Manufacturing Institute, to survey the top challenges to achieve smart manufacturing, lack of skilled talent was

[8] 2016 Global Manufacturing Competitiveness Index, Deloitte Touche Tohmatsu Limited (DTTL) Global Consumer & Industrial Products Industry Group and the Council on Competitiveness, https://www2.deloitte.com/content/dam/Deloitte/global/Documents/Manufacturing/gx-global-mfg-competitiveness-index-2016.pdf.

identified as the top challenge.[9] Despite this recognized need, 76 percent of companies surveyed said their company does not have a talent development strategy for their manufacturing employees.[10] Only 41 percent said their company trains people to develop the right knowledge and skills, 51 percent evaluate critical job tasks with structured evaluations, and 28 percent provide employees with training that meets the organization's needs for the future. She commented that one of the reasons behind this gap is that companies face multiple other pressures.

Technology and the work environment are changing, Kunz continued, with 40 percent of current skills projected to change within five years.[11] Because it is not possible to provide all the skills needed beforehand, training is required when onboarding new employees—but it does not all have to happen in a traditional classroom. Digital training incorporating eLearning and virtual reality are improving scalability and on-demand availability. Kunz noted the top 10 skills needed in 2025 as identified by the World Economic Forum: analytical thinking and innovation; active learning and learning strategies; complex problem-solving; critical thinking and analysis; creativity, originality, and initiative; leadership and social influence; technology use, monitoring, and control; technology design and programming; resilience, stress tolerance, and flexibility; and reasoning, problem-solving, and ideation.[12]

Kunz suggested considering the whole ecosystem of roles, education institutions, and communities, setting clear specifications on what knowledge and skills are needed, and ensuring the ecosystem can support those specifications. Through innovation and collaboration, she urged, "Think nationally, act locally, and scale aggressively."

Space Workforce 2030

Ed Bolton (Aerospace Corporation) reported on an effort called the Space Workforce 2030 (SWF2030) Executive Leadership Pledge, to broaden participation in the U.S. space industry. In April 2022, executives from 25 leading space companies signed a pledge to advance diversity through action in four areas: (1) significantly increase the number of women and employees from underrepresented groups in their collective technical workforce; (2) significantly increase the number of women and employees from underrepresented groups who hold senior leadership positions in their collective technical workforce; (3) work with universities to increase the percentages of women and students from underrepresented groups receiving aerospace engineering degrees to levels commensurate with overall engineering programs; and (4) sponsor K–12 programs that collectively reach over 5 million underrepresented students annually.[13]

"Why space and why now?" Bolton posed. In addition to the inspirational aspects of space exploration, he identified pragmatic reasons. Globally, the industry is expected to generate revenue of $1 trillion or more in 2040, up from $350 billion in 2021. Demand for employees is high. Average salaries in aerospace are more than double the average salary for all U.S. private-sector jobs and 27.3 percent higher than for other STEM occupations. At the same time, he said, "the current state of diversity is abysmal, but also an opportunity." According to Bolton, only 28 percent of aerospace and defense industry executives are female and only 9 percent are Black or Hispanic. The numbers of underrepresented minority students have grown, but a large percentage switch majors or leave higher education entirely.

A current focus is an SWF2030 internship program, developed with the White House Office of Science and Technology Policy and announced by Vice President Harris.[14] It is based on data that a person who has at least two internships is more than two times more likely

[9] For the full survey, see https://www.cesmii.org/smart-manufacturing-sustainability-study/.
[10] For the full report, see https://learn.toolingu.com/globalassets/tooling-u-sme/resources/white-papers/cost__of__turnover__report__v3.pdf. For further analysis, see https://www.toolingu.com/images/pdf/ToolingU-SME-Manufacturing-Insights-Report.pdf.
[11] The Future of Jobs Report 2020, World Economic Forum, https://www.weforum.org/reports/the-future-of-jobs-report-2020/in-full.
[12] See https://www.weforum.org/reports/the-future-of-jobs-report-2020/in-full.
[13] To read the full pledge see https://swf2030.org/read-the-pledge/.
[14] "FACT SHEET: Vice President Harris Announces Commitments to Inspire, Prepare, and Employ the Space Workforce," U.S. White House, September 9, 2022, https://www.whitehouse.gov/briefing-room/statements-releases/2022/09/09/fact-sheet-vice-president-harris-announces-commitments-to-inspire-prepare-and-employ-the-space-workforce/.

to graduate, Bolton related. A university partnership program and social media accounts have been created, and SWF2030 seeks like-minded organizations to join the effort. He emphasized that annual reporting of workforce data, promotion of shared success at the annual Space Symposium, and strengthened diversity, equity, and inclusion (DEI) efforts will support accountability.

During the discussion an attendee asked about why people leave the STEM workforce. Bolton posited one common reason people leave is they report not feeling respected, which points to the importance of supervisors. Kunz suggested better ways to onboard and to "put humans in the center of all we do." She added that younger people in particular need to understand the connection between their jobs and societal priorities. One attendee noted that the statistics from the first panel about representation in engineering and other STEM fields might suggest a challenge around communicating the value of a STEM degree—for some students, high-salaried careers might be the more motivating value proposition, and for others the motivation might be in the societal impact and problem-solving capabilities that a STEM degree can enable.

SUPPORTING THE SUPPLY OF HUMAN CAPITAL BY BROADENING PARTICIPATION IN STEM EDUCATION AND WORK

Looking at promising ways to build capacity for the STEM workforce, three presenters discussed efforts to broaden participation through regional STEM ecosystems, at Historically Black Colleges and Universities (HBCUs), and at community colleges.

Connecting the STEM Ecosystem

Before describing programs in northeast Ohio, **Kirsten Ellenbogen** (Great Lakes Science Center [GLSC]) urged participants to learn about existing STEM learning ecosystems in their locations.[15] She explained that formal STEM ecosystems connect schools, higher education, nonprofits, libraries, businesses, science centers, and many other organizations in a city or region to harness the unique contributions of each to work in symbiosis. GLSC is part of the Northeast Ohio STEM ecosystem to broaden the supply of local human capital, particularly in manufacturing and aerospace. GLSC houses the NASA Glenn Visitor Center; a project-based, year-round school; and a digital fabrication lab, among other resources.

Ellenbogen shared ideas about what has made the STEM ecosystem in northeast Ohio work. Alignment is key, she stressed—each partner has had to be willing to set aside some things it was working on that others were doing more efficiently. Industries in the area are eager to provide funding, staff time, and feedback. For example, she related a comment from one industry partner who said to deal with complex systems, they need "problem identifiers," not just problem solvers.

In a collaboration with the Cleveland Metro School District, GLSC agreed to guidelines to integrate its programming with the district's needs. "The field trip of time-gone-by is no longer acceptable," Ellenbogen described. "We are integrated into the curriculum." GLSC participates in teacher training, principals' meetings, and even has access to the district's software to schedule school busses to transport students to GLSC. Based on results from national test scores, the school district identified areas of needed curricular support (in energy science, alternative energy, and emerging technology) and a target age group (middle school) and worked with GLSC to facilitate the programming.

She called attention to a National Academies report that described how science learning can take place in science centers and other informal environments, including helping young people develop a science identity.[16] Coaches, ministers, athletes, and other influential adults are involved, along with parents and caregivers. She also stressed the power of giving youth authentic tasks to perform, such as when students learned skills for their robotics club by creating prosthetics for other students.

Broadening Participation in Data Science

Diversity among data scientists is critical to prevent bias, said **Talitha Washington** (Atlanta University Center [AUC] Data Science Initiative), who reported that only 3 percent of data and analytics professionals are Black. The AUC encompasses four co-located HBCUs in Atlanta with 9,000 students in total: Clark Atlanta University, Spelman

[15] See https://stemecosystems.org/.

[16] National Research Council. 2009. *Learning Science in Informal Environments: People, Places, and Pursuits.* Washington, DC: The National Academies Press. https://doi.org/10.17226/12190.

College, Morehouse College, and Morehouse School of Medicine. Nationwide, she added, the approximately 101 HBCUs make up 3 percent of all U.S. higher education institutions and enroll 10 percent of Black students. They graduate 24 percent of Black students with STEM degrees, and HBCUs are the institutions of origin of almost 30 percent of Black students in STEM doctorate programs. Thus, the initiative hopes to leverage this production of Black STEM professionals at HBCUs to enhance data science across all disciplines.

The specific goals of the AUC Data Science Initiative are to develop new talent and create new knowledge through curriculum development, research, and engagement. Industry partners help build the talent pipeline by co-developing programs, providing guest lecturers, and designing real-world applications. Faculty undertake research, expand pathways, and develop curriculum. Students participate in research, training, and workforce development. UnitedHealth Group was the initial sponsor, and other companies have since become sponsors to create opportunities across the curriculum.

Washington stressed the need to build sustainable institutional capacity with faculty and staff with training, small grants, and workshops. A Data Science and Analytics minor framework was developed that can prepare students to obtain, process, analyze, and present complex data, including data related to the African diaspora. Workshops on using data have been offered to students from AUC and other HBCUs, such as on using data to drive reform related to the legal system and to health equity. A data science course for all students, data science club, a one-week summer experience for entering students, and several symposia and seminar series further empower and connect students, faculty, and researchers. Clark Atlanta, in collaboration with the AUC Data Science Initiative, has an NSF Research Experience for Undergraduates (REU) site that offers a supported summer program on the interface between chemistry and data science.

Washington said the initiative is now expanding its work across HBCUs. She shared examples of current efforts at HBCUs, including a six-school Data Science Consortium led by Florida A&M University, a Data Science and Cybersecurity Center at Howard University, and a Center for Applied Data Science at Winston-Salem University. The NSF INCLUDES program also recently funded the establishment of a National Data Science Alliance, led by Washington, to build a national network of HBCUs to advocate for the building of institutional data science capacity "to transform data science discoveries into tangible societal benefits that advance equity for all."

Praising programs like the AUC Data Science Initiative, a participant observed that Black S&E students at Predominately White Institutions (PWIs) also can benefit from these programs and asked how they can participate. Washington commented that some opportunities come to HBCUs because a sponsor or funder has a "diversity box to check." She underscored partnerships must be mutually beneficial, including institution-to-institution relations with PWIs that facilitate open communication and exchange of ideas.

Advanced Technical Education Program

Celeste Carter (NSF) described the Advanced Technological Education (ATE) program within NSF's Directorate for STEM Education as another resource to prepare a skilled technical workforce to improve U.S. competitiveness. As noted by her NSF colleague Burke earlier in the day, when NCSES started to collect data on this segment of the workforce, also known as "middle-skills" occupations or "blue-collar STEM," it showed that the country's STEM workforce was twice as large as previously thought. Nearly 20 million people without a bachelor's degree are in the STEM workforce.

Citing data from the American Association of Community Colleges, Carter said community and technical colleges represent a way to educate these future workers and broaden participation. Two-year institutions enroll 10.3 million students, 60 percent of whom are women. They enroll a large number of underrepresented minorities (27 percent Hispanic, 12 percent African American), many of whom are first-generation students. The average age is 27.[17]

[17] For more Fast Facts from the American Association of Community Colleges, see https://www.aacc.nche.edu/research-trends/fast-facts/.

The ATE workforce readiness program puts two-year institutions at the forefront. Public-private partnerships are developed with industry to keep pace with real-world industry needs. Career pathways are forged with high schools and four-year institutions. Carter referred participants to several publications on building the skilled technical workforce, including a National Academies consensus study,[18] a National Science Board report,[19] an NSF-CORD report on cross-disciplinary STEM skills,[20] and the ATE Impacts Report.[21] She also suggested CareerOneStop at the Department of Labor as a resource.[22]

There are 389 active ATE Projects, 27 Centers, and 6,408 resources archived on an ATE central repository, many related to advanced manufacturing.[23] Examples include the National Center for Autonomous Technologies and the National Electric Vehicle Consortium. Industry partners have provided monetary and in-kind support. Referring to the earlier discussion about the time lag for educational institutions to change curriculum offerings, Carter countered with the example of the Convergence Tech Center in Texas that can change and roll out curriculum to 80 programs across the United States quickly. She also noted 50 ATE projects have developed or maintained articulation agreements that have allowed 640 students to matriculate to higher-level institutions. Carter called attention to an NSF "Dear Colleague" letter from ATE and Industry-University Cooperative Research Centers (IUCRC) on supplemental funding for Skills Training in Advanced Research & Technology (START) to support training in hyperspectral sensing for community college students and faculty.

Carter reflected on some "take-homes." First, given their demographic composition, two-year institutions can support DEI. Quoting recently retired Portland Community College President Mark Mitsui, she stressed, "Talent is universal, opportunity is not." Second, Carter noted the education of the skilled technical workforce relies on use-inspired research developed in authentic, mutually beneficial partnerships with industry. Third, she said hands-on training is critical in developing skills and competencies, with augmented and virtual reality training as a way to introduce students to new skills and competencies. And lastly, Carter emphasized that lifelong learning is also critical for up- and reskilling. "We have to change the narrative on what these jobs look like," she said. Carter noted that NSF supports development of the STEM workforce in other ways, such as a new solicitation through the Improving Undergraduate STEM Education (IUSE) program aimed at improving pathways between two-year and four-year engineering programs.

EMPOWERING THE INNOVATIONS OF TOMORROW TO ENHANCE U.S. INNOVATION CAPACITY

The final panel focused on the role of entrepreneurship and innovation throughout STEM educational and career pathways.

Building a Technology Ecosystem in Higher Education

Lance Collins (Virginia Tech) explained how investing in technology to foster innovation through higher education, pioneered by Mayor Michael Bloomberg through Cornell Tech in New York City, is envisioned at Virginia Tech's new Innovation Campus in northern Virginia. "In the digital economy, talent and technology are *the* drivers of national and global competitiveness," he stated. "Universities are well positioned, because we contribute to both." In its bid to serve as an Amazon headquarters, Virginia included plans to invest in housing, transportation, and higher education to grow tech talent that Amazon will need.

The Innovation Campus, which is under construction, is envisioned as "both a place and a culture that unlocks the power of diverse people and ideas," Collins said. He stressed that in building something new, "getting the culture right is 99 percent of the game." In this respect, the Innovation Campus's defining culture is bold, outward-facing, and committed to living up to the term

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[18] National Academies of Sciences, Engineering, and Medicine. 2017. *Building America's Skilled Technical Workforce*. Washington, DC: The National Academies Press. https://doi.org/10.17226/23472.
[19] National Science Board. 2019. The Skilled Technical Workforce: Crafting America's Science & Engineering Enterprise; NSF and Center for Occupational Research and Development. 2021. https://www.nsf.gov/nsb/publications/2019/nsb201923.pdf.
[20] *A Framework for a Cross-Disciplinary STEM Core*, https://www.preparingtechnicians.org/wp-content/uploads/A-Framework-for-a-Cross-Disciplinary-STEM-Core.pdf.
[21] Advanced Technological Education Impacts 2022-2023: Strengthening the Skilled Technical Workforce, https://ateimpacts.net/flipbook/#p=1.
[22] For more information, see https://www.careeronestop.org.
[23] For a full list of ATE centers, projects, and resources, see www.atecentral.net.

"innovation" along every dimension, he said. "If there is a better way of doing things—we are starting something new, and we can do the work to do it that better way." It also has a commitment to be the most diverse graduate tech program in the nation. He noted this commitment is measurable and galvanizing to everyone working on the campus.

The program focus is on computer science and computer engineering. The Master of Engineering will be the largest degree, built around project-based education sourced from industry. PhD/MS programs will operate in a "use-inspired environment" and post-doc appointments will also be on campus. At full build, enrollment will be 750 students undertaking 100 or more projects a year to solve problems for industry, government agencies, education, and others. Purpose-driven research is organized around two main areas: advancing the art of the possible and improving the human experience. Twelve initial faculty who worked elsewhere at Virginia Tech have been named to the Innovation Campus, with a goal of 50 faculty at full build. Companies are providing a tiered system of support. He noted there is also an increase in computer S&E enrollment at the Blacksburg campus.

The schedule to grow is aggressive, with a lot of hard work to increase enrollment of women and underrepresented minorities. The goal at full build is that women comprise 50 percent of the student body and underrepresented minorities 30 percent.

New Priorities in the Economic Development Administration

The Department of Commerce is invested in the importance of a skilled workforce, said **Eric Smith** (Economic Development Administration [EDA]) in explaining EDA's mission and programs to achieve it. With a mission to lead the federal economic development agenda, EDA programs increase America's global competitiveness, support community-led economic development, and help communities develop resilient and agile local economies. Workforce development ties together infrastructure and community needs. Smith agreed with previous speakers' emphasis on win-win collaboration and "hyper-partnerships" to enhance competitiveness. EDA has seven investment priorities: (1) equity, (2) recovery and resilience, (3) workforce development, (4) manufacturing, (5) technology-based economic development, (6) environmentally sustainable economic development, and (7) exports and foreign direct investment.[24]

Smith highlighted several EDA programs. Technology-based economic development and workforce development tie into several EDA efforts. They include regional programs to support entrepreneurs and build STEM talent pipelines, support to University Centers, Public Works and Economic Adjustment Assistance to improve infrastructure, and Communities of Practice. One Community of Practice focuses on workforce development. The premier program within the Office of Innovation and Entrepreneurship is a Build to Scale Challenge. It is comprised of a Venture Challenge to support regional innovation systems and a Capital Challenge to increase access to capital, particularly in communities with limited access to equity capital.[25]

EDA's cross-agency collaborations, such as with the Department of Energy and NIST, align investments that strengthen entrepreneurial ecosystems related to particular missions. A new EDA program, the STEM Talent Challenge, funds projects to establish or grow training systems that align with STEM worker demand in a given region. Governance is important, he stressed, to ensure that partnerships are durable. STEM workforce development underlies all EDA priorities, he concluded.

Labor Implications of Technology Change

Moving from specific programs to insights on labor and technology, **Christophe Combemale** (Allegheny County Department of Human Services) summarized research he and others conducted at Carnegie Mellon University on how technological characteristics map to workforce implications, and how technology change impacts inequality.[26] He noted previous presenters discussed

[24] To learn more about EDA's Investment Priorities, see https://eda.gov/about/investment-priorities/.
[25] For more information on Build to Scale, see http://eda.gov/oie/buildtoscale.
[26] The presentation was based on two papers: Combemale, Ales, Fuchs, and Whitefoot. 2022. "How it's made: A general theory of the labor implications of technology;" and Combemale, C. 2022. "New technology, new hierarchy."

building STEM pipelines and meeting the demand for specific skills, and expressed hope that his work connects these two areas in a strategic way to inform technology innovation and adaptation.

“Technological changes in the last 100 years have been multidimensional,” he stated. He called attention to the literature on skill-based technological change, including findings related to different levels of skills required and the wages that result. His research tries to answer the question, “What characteristics of technology lead to different effects on labor demand, and what choices do we get to make about those effects?”

Combemale presented a general theory of how technology changes work. First, the effect of technology is mediated by two tradeoffs: (1) rate versus complexity, and (2) division of labor. Technology changes the characteristics of performers (humans or machines) and production by changing how sensitive the performers are to the rate of production, their sensitivity to complexity, the cost of reassigning them to utilize full capacity, and the cost of fragmenting production.

Combemale highlighted his research modeling the rate-complexity tradeoff, specifically in the area of automotive welding. In that research, tasks are broken up into steps and performers are assigned to each step. In this model, longer steps involve higher complexity, and fragmentation costs depend on the tasks. The differences in ability demand come from steps of different lengths. Working faster requires a higher level of ability to complete the steps successfully. A firm can apply this theory to determine whether a human or a machine is best suited to perform each step. A machine may be able to perform a task quicker than a human, but it does not have the flexibility of a human to be “reassigned” when a task is completed.

Combemale called attention to the “cone of automation” in the model. An upper bound of automation is driven by complexity. “Humans are better at handling complexity than machines, and are cheaper than machines in these situations,” he explained. With simple tasks, the lower bound is driven by underutilization of inflexible machines. Empirical data from the 1890s, when decisions about human versus machine production were made, back up this theory, he said. Today, he continued, the constraint on automation drives a polarizing effect on skill demand, as shown in the semiconductor industry. People with the highest and lowest skill levels are less affected by automation than those in the middle.

Combemale then applied the theory to another application: the consolidation of parts. In many industries, parts that had been discretely fabricated and assembled are consolidated into one piece. “While the consolidation of parts is key to U.S. competitiveness, it merges many short, simple steps and shifts demand away from the lowest-wage workers toward the middle,” he explained. At the same time, the overall complexity of the process is reduced, and skills converge toward the middle. Thus, he said, not all technological change needs to result in inequality.

Combemale suggested this model as a map of the labor implications of technology. He reiterated that the division of labor realizes gains from this rate-complexity tradeoff. Technology change acts on skill demand by shifting this tradeoff. This theoretical approach, grounded in empirics, supports a taxonomy to explain and plan for the effects of new technology, and an integration between technology development and the STEM workforce pipeline, he concluded.

CONCLUDING REMARKS

GUIRR co-chair Pines closed the workshop by summarizing points that emerged from the presentations and discussions. He noted the dire statistics about the U.S. STEM enterprise related to the workforce and to diversity in the STEM pipeline, including the lack of growth in traditional engineering disciplines. Workers with “middle skills” are increasingly needed by industry, he continued, and he welcomed the attention to this priority. He also called attention to the efforts to broaden participation, with science centers, two-year institutions, and HBCUs among the places where innovation is happening. Turning to the final panel, he noted the role of the broader innovation ecosystem to grow talent. Undergirding these ideas, Pines recalled NSF director Panchanathan's motivating remarks showing how advances across STEM fields can occur at speed and at scale.

DISCLAIMER This Proceedings of a Workshop—in Brief was prepared by **Paula Whitacre** as a factual summary of what occurred at the workshop. The statements made are those of the rapporteur or individual workshop participants and do not necessarily represent the views of all workshop participants; the planning committee; or the National Academies of Sciences, Engineering, and Medicine.

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REVIEWERS To ensure that it meets institutional standards for quality and objectivity, this Proceedings of a Workshop—in Brief was reviewed by **Bryant Moore,** University of North Carolina at Chapel Hill, and **Pamela Norris,** The George Washington University. **Marilyn Baker,** National Academies of Sciences, Engineering, and Medicine, served as the review coordinator.

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