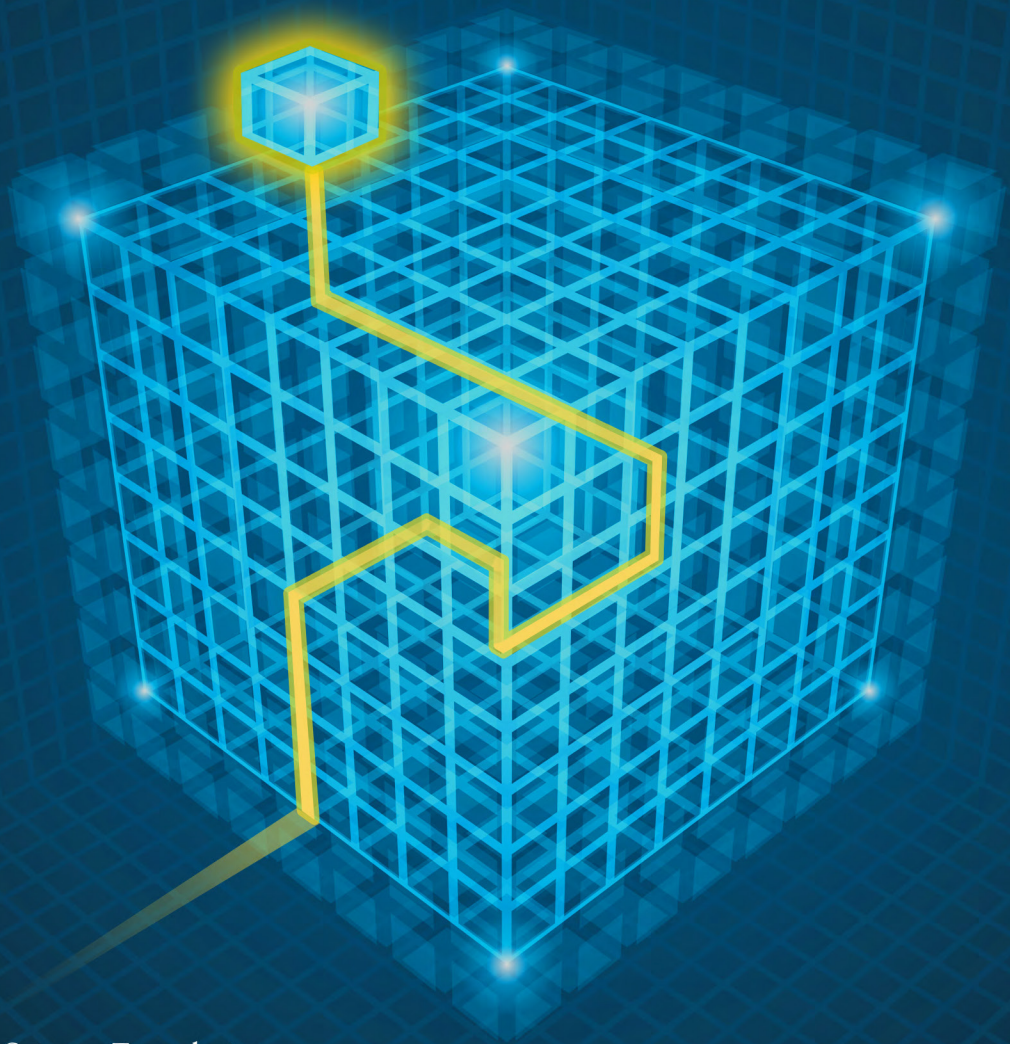
Roadmap for Workforce Development for the U.S. National Science Foundation Directorate for Technology, Innovation and Partnerships:

Building Pathways and Innovations for the Critical and Emerging Technology Workforce.



U.S. National Science Foundation
Directorate for Technology, Innovation and Partnerships

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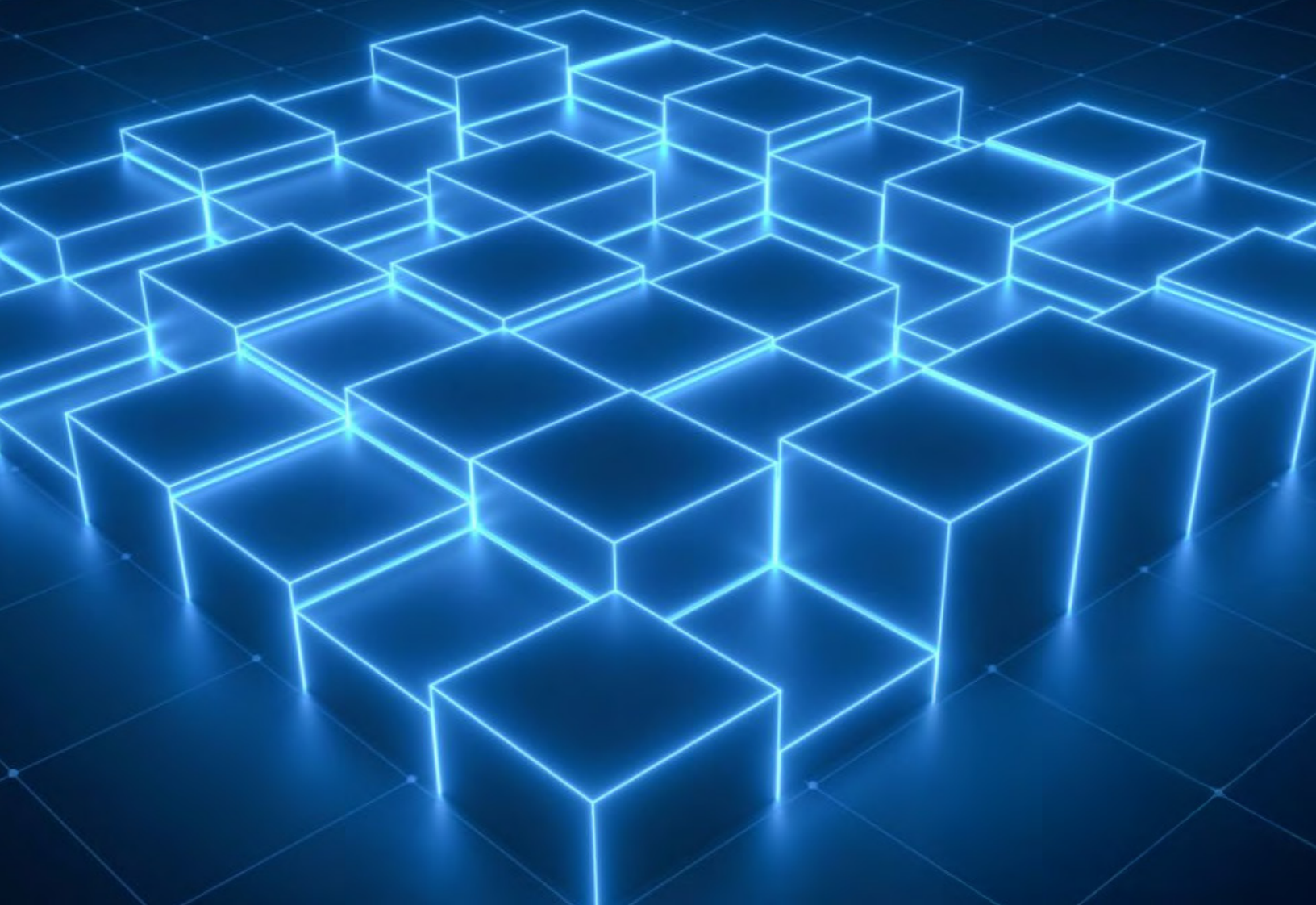

Roadmap for Workforce Development for the U.S. National Science Foundation Directorate for Technology, Innovation and Partnerships:

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Executive Summary

As global competitors race to supplant America as the leader in technological innovation, it is more important than ever to invigorate and empower the ambition of all Americans — especially in critical and emerging technologies, such as artificial intelligence, biotechnology, quantum information science and nuclear technologies. Research, development and commercialization of critical and emerging technologies is vital to America's national defense and economic competitiveness, but none of this work is possible without a skilled workforce to carry it forward. As U.S. innovations in critical and emerging technologies continue to rapidly advance and expand across industry, the demand for skilled workers is increasing across all economic sectors. The U.S. science, technology, engineering and math workforce faces several critical challenges that impact America's position as the global leader in transformative technologies, including: a shortage of workers; mismatches between industry needs and workers' knowledge, skills and abilities (KSA); limited hands-on opportunities to gain skills for STEM jobs; and retention and career transition challenges.

The U.S. National Science Foundation Directorate for Technology, Innovation and Partnerships (NSF TIP) recognizes that our nation needs a robust STEM workforce with varied extensive technical and entrepreneurial skills in addition to traditional STEM competencies. To fulfill this charge and strengthen the American workforce to secure the national defense and grow the economic industries of the future, NSF TIP will expand its efforts to build a resilient workforce ecosystem that will fuel America's competitive edge in the years to come. Central to our approach is an ethos that by meeting individuals where they are and by fostering collaboration within local and regional transformative technology ecosystems, we can best unleash American ambition, innovation, and discovery. As outlined in this roadmap, NSF TIP will make investments in the following areas: crosssector networks to address emerging technology workforce needs; industry-informed workforce development that increases entry into, retention in, and advancement in critical and emerging technology careers; and accelerated translation of education technology innovations from research to practice for workers across all ages and educational pathways.

NSF TIP's Workforce Development Roadmap is an actionable agenda to address these challenges by fostering cross-sector collaborations and partnerships, creating innovative community-specific solutions, and leveraging existing capacities to expand access to experiential learning and training pathways. NSF TIP will help build strengthen the nation's science and technology talent base. Harnessing the full power of American innovation will strengthen national security and enhance the United States' competitive edge across key technology areas.

Introduction

As global competitors race to supplant America as the leader in technological innovation, it is more important than ever to invigorate and empower the ambition of all Americans — especially in critical and emerging technology sectors, including AI, advanced communications, cybersecurity, semiconductors and biotechnology. Research and development, workforce development and commercialization of critical and emerging technologies in these sectors are vital to the United States' national defense and economic competitiveness, but none of this work is possible without a skilled workforce to carry it forward. As traditional industries adopt new technologies that bolster efficiencies, increase capacities and drive innovation and economic development, there is an increasing demand for skilled workers across all industrial and economic sectors. Thus, the nation finds itself with a significant labor shortage projected across many technology-based industries, including those integral to national security[1]. Addressing this gap requires bold strategic investments in industry-informed workforce development and government-private sector partnerships that prepare individuals for higher-skilled, higher-paying jobs and increase their prospects for economic and social mobility.

The U.S. National Science Foundation Directorate for Technology, Innovation and Partnerships (NSF TIP) makes strategic investments that aim to engage all Americans in accelerating critical and emerging technologies to advance U.S. competitiveness and bolster national security[2]. For example, the directorate partners across sectors to advance three primary focus areas: accelerating technology, fostering regional innovation and economic growth, and preparing the American workforce for better-quality, higher-wage jobs. TIP recognizes that the nation needs a robust science, technology, engineering and math workforce that has varied, extensive technical and entrepreneurial skills that drive greater productivity and innovation in critical and emerging technologies. To accomplish this undertaking and strengthen the U.S. workforce for national defense and for the industries of the future, TIP has constructed a roadmap focused on building a resilient workforce ecosystem that will fuel America's competitive edge in the years to come. As outlined in this roadmap, TIP will:

- Build cross-sector collaborations among industry, employers, educational institutions, government agencies and nongovernmental organizations to better align workforce development with critical and emerging technology workforce needs.
- Invest in a future-ready workforce development that increases entry, retention and advancement in critical and emerging technological pathways; and
- Accelerate the translation of educational technology innovations from research to practice for workers across all ages and educational pathways.

Together, these efforts will open new career opportunities for individuals and empower the American worker to succeed in transformative technology fields, unleashing the full potential of the U.S. workforce to secure the nation's competitive edge in critical and emerging technologies.

Background

The U.S. STEM workforce landscape faces several critical challenges that impact America's position as the global leader in transformative technologies.

Workforce demand and shortage. The U.S. Bureau of Labor Statistics projects a 10.4% increase in STEM occupations from 2022 to 2032, compared to only 3.6% growth in non-STEM jobs[3]. This growth is driven by the demand for STEM professionals in increasingly critical technology fields like advanced communications, biotechnology, data science and quantum. However, supply trails demand, with a shortage of up to 3.5 million STEM professionals expected by 2025[4]. Although high-skilled STEM jobs offer significant economic mobility, we need to ensure that all Americans have access to these jobs[5].

KSA mismatches. Employers in transformative technologies and employers whose industries are being changed by transformative technologies require employees with specialized skills. Critical and emerging technology industry leaders report persistent misalignments among the KSA of the workers in their workforce[6,7,8]. Addressing these mismatches and scaling effective programs are essential for developing robust talent pathways that meet the evolving demands of transformative technology industries. Skilled STEM professionals are critical in helping transformative technology start-ups and small companies navigate the proverbial entrepreneurial "valley of death"; our investments in **NSF Innovation Corps (NSF I-Corps™)**, America's Seed Fund powered by NSF [Small Business Innovation Research/Small Business Technology Transfer (SBIR/STTR)], and NSF Regional innovation Engines play an important role in filling the gap in the expertise needed to move an idea from lab to market.

Limited hands-on opportunities to gain skills for STEM jobs. Ensuring that all Americans — including those affected by the economy in recent years — are given the opportunity to acquire the essential STEM skills needed to meet the workforce demands in high-growth STEM fields, and the opportunity to pursue and succeed in these careers is a priority. The demand is particularly high in middle-skilled STEM occupations, which typically require less than a bachelor's degree but involve specialized technical skills with roles like robotics service technicians and semiconductor validation engineers, fields that are expected to grow rapidly[9]. Additionally, many Americans are not aware of the career pathways available in technology industries; therefore, efforts are needed to attract people to pursue these careers. Paid apprenticeships and internships and other direct engagement and experiential experiences that help connect individuals to mentors and provide opportunities to hone skills must become more widely accessible and applicable to attract a larger domestic talent pool to address the critical shortage found in our skilled STEM workforce.

Retention and career transition challenges. STEM jobs have a faster skills treadmill than non-STEM jobs. Workers who are "burned out" leave[10] and the talented STEM workers who stay on the job are promoted into management, taking them out of the pool of STEM workers. These two mechanisms further drive the need for employers to recruit new talent. Opportunities to re-skill and upskill non-STEM workers in critical and emerging technology fields (e.g., designers,

operations logistics) could play a vital role for ensuring that skilled workers remain engaged and adaptable in a rapidly evolving job market[11,12].

The TIP Roadmap for Workforce Development includes an actionable agenda to address these challenges by fostering cross-sector collaborations and partnerships, creating innovative community-specific solutions and leveraging existing capacities to expand access to experiential learning and training pathways. Through its implementation, TIP will launch scalable initiatives that will help build and strengthen the nation's science and technology talent base so that the nation may better harness its full power of American innovation, national defense and global competitive edge in critical technology fields.

Vision

A collaborative, cross-sector ecosystem to build a strong American talent base that bolsters national security and enhances the nation's global competitiveness in today's and tomorrow's critical and emerging technology sectors.

Mission

To grow a continually ready and adaptable American workforce in transformative technology fields that has the expertise and necessary technical skills to drive research, innovation, entrepreneurship and technology translation that results in commercialization and economic growth.

Core Values

Central to NSF's approach is meeting individuals where they are and by fostering collaboration within local and regional transformative technology ecosystems, we can best unleash American ambition, innovation and discovery. The following values are integral to TIP's mission of growing a strong domestic workforce for critical and emerging technology fields.

Promote growth: TIP is committed to creating pathways to high-paying critical and emerging technology careers for all Americans and ensuring that TIP investments capture the power of American innovation and the pioneering spirit of the nation's talent base. The pathways that begin in K-12 institutions must extend beyond our traditional higher education systems to unleash the potential of every American.

Partnerships and collaboration: TIP is committed to bringing together the brightest minds from K-12 and higher education, industry, nonprofit organizations and government to foster innovations that will build resilient workforce ecosystems that can quickly adapt to a rapidly changing technology landscape. Of note, it is increasingly important for collaborations and initiatives to be industry-informed and relevant so that workers have the KSA for the jobs that they may pursue.

Flexibility and lifelong learning: TIP is committed to building flexible workforce pathways that adapt to new workforce training and technologies, such as AI and the use of augmented

and virtual reality, ensuring that Americans have access to reskilling or upskilling opportunities that reinvigorate their spirits for exploration and discovery so that they remain competitive throughout their careers.

Employ people locally (and regionally): TIP is committed to investing in approaches that enable individuals to make a quality living across all American communities. Thus, investments are intentionally designed to be responsive to local and regional challenges, prepare people for local and regional critical technology jobs, and have meaningful impact at the community level. Put plainly, one should be able to find a good-quality and good-paying job in their own backyard.

Strategic Goals

#1: Build cross-sector networks to address workforce needs.

Facilitate development of local and regional stakeholder networks that connect students and local workers with critical and emerging industries in their own communities, grow America's talent, and build nimble and resilient education programs that retrain workers and adapt to changing technology workforce needs.

#2: Invest in industry-informed workforce development that increases entry into, retention in and advancement in critical and emerging technology careers.

Create a portfolio of funding initiatives that support varied, effective pathways across, within and beyond traditional educational systems, thereby enabling individuals to chart their path forward from low- to mid- to high-skilled jobs and transition across technology sectors.

#3: Accelerate the translation of education technology innovation from research to practice for workers across all ages and educational pathways.

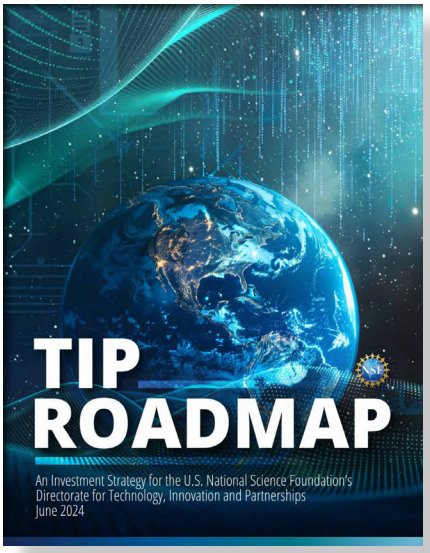
Scale up evidenced-based initiatives while building an interdisciplinary network focused on integrating critical and emerging technologies in workforce development so that more Americans gain entryways into high-paying jobs in transformative technology areas.

Approach

Data demonstrates that talent is distributed equally but opportunity is not[14]. TIP seeks to overcome this challenge by meeting individuals where they are, providing opportunities that serve as a springboard to new career pathways. Thus, it prioritizes workforce development investments that are innovative, ambitious and have the potential to reshape the access all workers have to these opportunities. Investments should be rooted in agility, partnerships and evidence-based innovation. The following are the key components of TIP's approach.

Target investments in critical and emerging technologies: Workforce development initiatives will align with the critical and transformative technologies such as those areas identified in the

TIP Roadmap. Investments will be designed to build capacity in these fields through workforce programs (including students as well as teachers and faculty), apprenticeships, reskilling initiatives and the facilities and equipment that support these efforts designed for the evolving needs of the critical and emerging technology workforce.



Solutions-oriented investments: TIP's investments bring together the brightest minds to develop evidencedbased, scalable solutions that address the specific needs of transformative industries and American workers. In partnerships with industry and other cross-sector partners, TIP will prioritize the expansion of experiential learning opportunities, including apprenticeships, fellowships and internships, that allow workers to gain practical experience while mastering new skills.

Support the full range of jobs needed: TIP recognizes that individuals of all ages, levels of education and with varied skills have ambition and a pioneering spirit that can contribute to a flourishing innovative economy. Reskilling and upskilling play a crucial role in career longevity and enabling workers to transition within and between transformative technology fields[13]. TIP will invest in strategies that will meet individuals where they are and provide support to propel them into new roles spanning the full range of jobs needed to support critical and emerging technology areas, from researchers and entrepreneurs to educators, technicians, and practitioners.

Leverage a broad array of funding mechanisms: TIP will use the full scope of funding mechanisms (e.g., grants, prize challenges, other transactions, memoranda of agreements) to support workforce development efforts.

Leverage partnerships: As one of TIP's core values, partnerships are central to all workforce development initiatives. TIP will prioritize collaborating with other NSF directorates, federal agencies, industry and other external partners when designing, scaling and evaluating initiatives. Funding opportunities will also incentivize sustainable cross-sector partnerships to address challenges in critical and emerging technologies.

Measure impact: To ensure transparency and accountability, TIP will evaluate the progress and impact of workforce initiatives so that they are continuously improved and contribute meaningfully to the transformative technology workforce needs of the nation.

Potential Investments for a Critical and Emerging Technology Workforce

Potential Investment #1

Strengthen local cross-sector partner networks

Identified need: Strengthen local cross-sector partner networks to address critical and emerging technology workforce needs.

Local industries, academic institutions and economic development offices are committed to creating high-paying jobs for their communities[15]. National education, workforce and industry organizations have developed and vetted instructional materials but face barriers in their dissemination and adoption. There is an opportunity to leverage national efforts within local networks. A lack of coordination can result in a workforce that is unprepared to meet industry demands, inefficient use of educational resources and missed opportunities for regional economic growth. By fostering stronger collaboration within local transformative technology ecosystems, these stakeholders can take a more unified approach to creating a skilled workforce that aligns with the needs of evolving industries.

Building partnerships between industry and educational providers can create pathways that equip the local workforce with the necessary skills, reducing reliance on external talent and strengthening regional economic resilience. Additionally, these networks can facilitate continuous learning and offer upskilling opportunities as technologies advance, which not only boosts individual innovation, creativity and employability but also help companies stay competitive by ensuring access to a well-trained labor pool.

Approach:

1. By leveraging existing NSF-funded centers, national networks and capacity-building investments, TIP will enable communities to strengthen cross-sector partnerships that can accelerate the creation of training aligned with national, regional, and local industry needs.
2. TIP will invest in local and regional networks to adapt, expand and distribute industryvalidated materials [e.g., Just-in-Time certificate programs] within local workforce ecosystems.

Anticipated outcomes:

TIP anticipates increased engagement of community and technical colleges, not-for-profit organizations, industry and local government offices with NSF Engines, NSF I-Corps Hubs and the National Network for Microelectronics Education (NNME) Coordination Hub. NSF's recent partnership with New America on a $3 million strategic initiative to empower community and technical colleges nationwide is an example of how TIP can leverage existing networks like the NSF Engines and direct partnerships with philanthropy to scale training at the local level.

Potential Investment #2

Invest in industry-informed workforce development

Identified need: Invest in industry-informed workforce development that increases entry into, and retention in, critical and emerging technology careers.

The U.S. Bureau of Labor Statistics projects a 10.4% growth in STEM occupations over the next decade, anticipating nearly 11.8 million STEM jobs by 2033[4]. This rise is driven by the rapid expansion of industries reliant on critical and emerging technologies, from artificial intelligence and robotics to advanced manufacturing and biotechnology. To meet this demand, Americans across all regions must be able to upskill and reskill for roles in critical and emerging technology sectors, thereby cultivating a strong domestic talent ecosystem that can support and sustain these high-growth sectors. To meet the demand for skilled professionals in these fields, it is crucial to disseminate industry-approved, evidencebased specialized curricula more widely so that all Americans have an opportunity to enter these rapidly growing sectors[16,17]. Concurrently with creating entry points and pathways for new workers, America must invest in its current workers as they are an important source of ideas for innovation, design, processes and efficiencies. Integrating entrepreneurial thinking into critical and emerging technology discipline-specific skill training can empower and broaden career advancement options for existing workers[16, 18].

Approach:

1. TIP will scale existing experiential learning workforce development initiatives, like Experiential Learning for Emerging and Novel Technologies (ExLENT), with a specific focus on upskilling and reskilling adult learners through hands-on opportunities such as work-based learning experiences, internships, apprenticeships, job shadowing and cooperative education in critical and emerging technologies. TIP will also leverage partnerships with industry, philanthropy and others to amplify the impact of these investments
2. TIP will invest in collaborative partnerships to develop systematic approaches to workforce efforts across all educational levels in transformative technology areas. By adapting instructional materials for different education levels, such as high school students, undergraduates and the existing workforce, TIP is poised to help develop a talent pool of workers equipped with the skills required for a range of positions in these fields[15]. This is illustrated by TIP's recent investment in NNME, which focuses on the U.S. semiconductor industry.
3. TIP will engage with cross-sector partners to capitalize on the ideas and suggestions of current workers to drive innovation and efficiencies. New strategies of support can empower even more STEM workers to remain engaged in their work and turn innovative ideas into impactful ventures.

4. Recognizing the need to spark interest and to prepare future generations for careers in critical and emerging technologies, TIP will devote resources to teacher and faculty professional development in critical and emerging technologies. Upskilling these professionals in educational innovations that intersect with critical and emerging technology fields will not only inform them of their approach to education workforce development but could also open pathways for these individuals into new careers in critical and emerging technologies.

Anticipated outcomes:

Enabling evidence-based instructional materials to reach all corners of the nation will empower Americans in every region to thrive in the critical and emerging innovation economy. Providing this broader access also facilitates the continuous reskilling and upskilling of the workforce, enabling workers to stay competitive as critical and emerging technology fields evolve.

These investments will reinvigorate and equip workers with industry-specified KSAs, which are essential for securing jobs in critical and emerging technology sectors, while providing tangible support to individuals as they navigate career paths and adapt to changing industry needs.

Equipping all workers with scientific and entrepreneurial skills to thrive in the jobs of the future will strengthen the U.S. workforce, enhance national security and reinforce America's position as the leader in the global technology landscape[16].

Potential Investment #3

Identified need: Accelerate the translation of technology innovations from research to practice for learners and workers across all ages and educational pathways.

Accelerate translation of tech innovations from research to practice

Rapid advances in generative AI, visualization tools for large datasets, augmented and virtual reality (AR/VR) and other learning technologies have the potential to reshape workforce development. Novel technologies may help us solve some seemingly intractable educational issues, such as literacy and language barriers, improving mathematical reasoning and scaling promising pedagogies across workplace learning environments. Technologies may offer the capability to create personalized learning pathways through adaptive content and real-time feedback. AI-driven chatbots and personal assistants can act as 24/7 tutors, helping workers solve problems and find answers to complex topics. Immersive in situ environments help bring abstract concepts to life and ensure learning is relatable, accessible and provides a more robust experience for learners. Taken together, these novel technologies also make upskilling and reskilling of all Americans possible by providing state-of-the-art experiences for applied learning, regardless of geography or prior knowledge, and across a range of modalities.

Scaling science and technology educational startups can play a crucial role in driving job creation and innovation, making them integral to maintaining the U.S.'s position as a global leader in critical and emerging technologies. Significant investments are critical for the U.S. to take full advantage of these promising new technologies and their potential to significantly strengthen America's critical and emerging technology workforce.

Approach:

1. Through new cross-sector initiatives, TIP will enable interdisciplinary networks of industry, workers, technologists and researchers to cocreate learning technology innovations that fill critical knowledge gaps not addressed in current workforce efforts to better prepare workers for future work in transformative technologies.

2. TIP will partner with other NSF directorates to leverage educational research to ensure that workforce development initiatives are creating on-ramps for all Americans into critical and emerging technology careers.

3. TIP will extend NSF-funded centers, networks and capacity building investments in artificial technology to support innovations in education technologies to create prototypes that support the upskilling and reskilling of workers in critical and emerging technology fields.

4. TIP strategies will harness NSF's extensive experience in research translation to provide the critical and emerging technology workforce education community with opportunities in entrepreneurial problem recognition as well as lab-to-market translation, including startup creation. These will build off existing programs such as NSF I-Corps, NSF Entrepreneurial Fellowships powered by Activate, and SBIR/STTR, which can empower educational researchers to transform breakthroughs into new startup companies.

Anticipated outcomes:

With continued and expanded investments fostering collaboration among researchers, entrepreneurs and education practitioners, TIP, in partnership with other NSF directorates, has the potential to scale its impact tenfold, making substantial progress toward addressing the skilled STEM workforce shortage projected by 2030[18] .

Through additional investment in NSF's entrepreneurial training, I-Corps could scale and offer opportunities for more cohorts per year. This entrepreneurial training will enable educational practitioners and workers in critical and emerging technology fields to translate innovations into the market, approach future work with an entrepreneurial viewpoint, and create new startup ventures in critical and emerging technologies.

Conclusion

Advancing U.S. competitiveness in critical and emerging technologies is a national-scale effort that starts within local communities. TIP is interested in building partnerships that will leverage resources to accelerate the expansion of opportunities for individuals in critical and emerging technologies. TIP welcomes your ideas, inquiries and feedback via email at TIPWorkForce@nsf.gov.

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