Date: January 15, 2026

To: Dr. Mary Crowe
Program Director, ExLENT, TIP/ITE
National Science Foundation
401 Dulany St
Alexandria, VA 22314

From: Kacy Redd, PhD
Associate Vice President, Research & STEM Education,
Association of Public and Land-grant Universities

Emily R. Miller, PhD
Vice President Research & Institutional Policy
Association of American Universities

RE: Association of Public Land-grant Universities (APLU) and Association of American Universities (AAU) Response to NSF's TIP Roadmap for Workforce Development

---

Dear Dr. Crowe:

The Association of Public and Land-grant Universities (APLU) and the Association of American Universities (AAU) appreciate the opportunity to provide feedback on NSF TIP's Roadmap for Workforce Development. APLU and AAU share NSF TIP's commitment to strengthening the U.S. workforce in critical and emerging technologies.

APLU is a membership organization that fosters a community of university leaders collectively working to advance the mission of land-grant and public research universities. The association's U.S. membership consists of more than 240 public research universities, land-grant institutions, state university systems, and affiliated organizations spanning across all 50 states, the District of Columbia, and six U.S. territories. The association and its members collectively focus on increasing student success and workforce readiness; promoting pathbreaking scientific research; and bolstering economic and community engagement. Annually, its U.S. member campuses enroll 4.5 million undergraduates and 1.4 million graduate students, award 1.3 million degrees, employ 1.2 million faculty and staff, and conduct $64 billion in university-based research.

The Association of American Universities (AAU) was founded in 1900 and is composed of America's leading research universities. AAU's member universities earn the majority of competitively awarded

federal funding for research that improves public health, seeks to address national challenges, and contributes significantly to our economic strength, while educating and training tomorrow's visionary leaders and innovators. Its members include 69 public and private research universities in the United States.

APLU and AAU offer an overview of key recommendations and address each of the six questions posed by NSF's TIP. Additionally, APLU and AAU will submit a response to the six questions via the Airtable form as specified.

Strengthen the evidentiary basis for workforce investments. The Roadmap for Workforce Development relies on aggregate STEM workforce projections that lack granular occupational data for critical and emerging technologies. APLU and AAU recommend that NSF:

- Invest in granular occupational data for STEM fields, especially critical and emerging technologies, potentially through partnerships with Bureau of Labor Statistics (BLS) and industry associations.
- Partner with other federal agencies and Congress to enact a student-level data network through the College Transparency Act that tracks outcomes from education to employment.
- Invest in evaluation infrastructure that identifies which interventions improve career outcomes.

Leverage NSF's foundational STEM education and research programs. Breakthrough innovations in emerging technologies emanate from strong foundations across all STEM disciplines. Technology boundaries are porous: AI draws on mathematics and statistics, quantum computing requires physics and materials science, biotechnology integrates biology, chemistry, and computation. Graduate students are the workforce advancing these innovations, making graduate education essential to TIP's mission. Therefore, APLU and AAU recommend that NSF:

- Continue to invest in the full spectrum of scientific disciplines alongside the critical technologies.
- Coordinate with NSF's education research programs to ensure workforce initiatives benefit from the investments made in evidence-based STEM teaching and learning.
- Continue to support graduate research fellowships across all NSF-eligible STEM fields using merit-based selection.

Land-grant and research universities stand ready to be partners with NSF TIP to realize its bold vision for building pathways and innovations for the critical and emerging technology workforce. Land-grant and research universities are essential local and national infrastructure that connects every level of the STEM ecosystem. Universities simultaneously advance the research creating emerging technologies, prepare the faculty members who teach at all higher education institution types, develop K-12 teachers, educate undergraduate and graduate students, partner with industry in research and education, and evaluate which interventions improve outcomes. Their embedded and interconnected role in the system makes them critical partners for regional workforce initiatives that span educational levels across all 50 states.

Question 1: How might NSF TIP collaborate with critical and emerging technologies industries to best prepare future workers and reskill current workers?

Invest in Faculty as a Force Multiplier for Workforce Development

As the Roadmap notes, one of the most scalable approaches to impact workforce development is to improve teacher and faculty professional development. As identified in the Roadmap, educators also need experience with integrating educational technologies into their courses.

APLU & AAU Recommendations

- Support research and implementation projects that help K-12 teachers and higher education faculty gain industry experience in emerging technologies. These investments will enable educators to integrate their experiences into course content and competencies, creating a multiplier effect as a single faculty member reaches hundreds or thousands of students over multiple years, including future K-12 teachers who will teach thousands more.
- Support research and implementation projects that help teachers and faculty members integrate emerging educational technologies effectively into their courses. As TIP invests in scaling AI-enabled personalized learning and immersive technologies, educators need professional development in evidence-based practices for deploying these tools to support student learning in STEM.

Support Experiential Learning at Scale

The Roadmap identifies internships, apprenticeships, and other experiential experiences as being critical. These experiential learning experiences take multiple forms that research universities regularly provide, including undergraduate research experiences, work study, industry-sponsored capstone projects, graduate research fellowships, and cooperative education programs where students learn through compensated workplace experiences while completing degrees.

APLU and AAU support the Roadmap's approach to scale Experiential Learning for Emerging and Novel Technologies (ExLENT), with work-based learning opportunities such as internships and apprenticeships in critical and emerging technologies. Additionally, APLU and AAU support the Roadmap's emphasis on entrepreneurial thinking. Many research universities offer entrepreneurship programs that help STEM students understand technology commercialization and create startups.

APLU & AAU Recommendations

- Invest in scaling proven experiential learning experiences (e.g., undergraduate research, co-ops, industry capstones) in emerging technology fields, with evaluation to identify which approaches are most effective for which technologies and student populations.
- Require workforce development in large-scale NSF-funded research programs to help build a competition-ready workforce. Large-scale research projects in emerging technologies provide opportunities for undergraduate students, graduate students, and postdocs to develop deep expertise while advancing the technology. These investments should be structured to both advance translational research in emerging technologies and prepare the workforce to develop and deploy it. The Regional Innovation Engines are an example of this dual-purpose implementation.

Question 2: How might NSF TIP leverage local, state, and tribal, including regional, efforts in workforce development to help provide all Americans with the skillset(s) required for careers in critical and emerging technologies or closely aligned fields?

Strengthen Regional Hubs and Cross-sector Networks

Land-grant and research universities serve as regional economic anchors and workforce development hubs, making them natural partners for coordinating local and state efforts. They are often among the largest employers in their regions and maintain extensive relationships with state governments, employers, community colleges, tribal colleges, K-12 systems, Cooperative Extension, and regional economic development agencies

APLU & AAU Recommendations

- Expand NSF Regional Innovation Engines to additional regions. Each Engine has created robust cross-sector collaborations between academia and local industry, building networks of up to 60 industry and academic partners. Each Engine seeds a regional consortium that trains and retains skilled labor in states across the country, further strengthening rural and urban communities.
- Continue support for the Engineering Research Centers (ERC). These centers are funded between five and ten years, and since 1985 have created over 250 spinoffs and 1,400 invention licenses across technology fields such as microelectronics, advanced manufacturing, and biotechnology. Beyond metrics, many ERCs have reported to NASEM how their work benefited from industry partners joining in the strategic leadership of their respective centers. APLU and AAU urge NSF to continue to support these centers, which demonstrate how sustained industry collaboration with university researchers generates new ventures in critical technology sectors.

Invest in Data Systems that Help Regions Meet Workforce Needs

A critical gap in regional workforce development is the lack of data systems to understand whether supply of STEM workers meets regional workforce demand. Current classification systems for educational credentials and occupations are outdated and poorly aligned, making it impossible to assess regional workforce gaps. Since students may be educated at multiple institutions across multiple states, understanding STEM workforce pathways requires national-level data. Without such systems, policymakers, funders, and educational institutions lack the data needed to make strategic investments or respond to rapid shifts in emerging technologies.

APLU & AAU Recommendations

- Partner with federal agencies to update Classification of Instructional Programs (CIP) and Standard Occupational Classification (SOC) codes through an interagency working group. CIP codes, last updated in 2020, do not reflect emerging STEM fields or map to industry-required knowledge, skills, and abilities. SOC codes, last updated in 2018, may not capture current STEM occupations. The working group should crosswalk these systems to each other and ensure they reflect emerging technology workforce needs.
- Partner with the Census Bureau to expand the Postsecondary Employment Outcomes (PSEO) initiative to more states. The PSEO initiative enables tracking of earnings and employment outcomes

across state lines and industries through voluntary data sharing, but participation could be expanded to provide comprehensive national coverage.

- Partner with the Department of Education to support state longitudinal data systems that link education and workforce data, allowing policymakers to identify which programs lead to employment in emerging technology fields, where students exit pathways, and earnings trajectories for different credentials. In developing these systems, NSF and ED should consult with the education community on appropriate data elements for a student-level data network.

Question 3: Beyond questions 1 and 2 above, are there specific sectors, organizations, or groups that NSF TIP must especially engage to fully address the goals articulated in the workforce roadmap and this RFI? If so, which ones, why, and how?

APLU & AAU Recommendations

- Engage Council of Graduate Schools (CGS) and Graduate Programs. Master's and doctoral programs produce the researchers, innovators, and faculty essential for emerging technologies, yet the Roadmap gives this pathway limited attention. According to NSF's *Science and Engineering Indicators 2024*, doctorate holders in science and engineering are increasingly employed in business and industry.[1] Many of the fastest-growing occupations relevant to emerging technologies (data scientists, information security analysts, AI researchers) typically require graduate degrees. Graduate education is workforce development, and graduate students themselves constitute a significant portion of the research workforce in emerging technologies. Those graduate students who become future faculty members also educate the next generation of the STEM workforce. It is a multiplying investment. APLU & AAU recommend engaging with NSF's Division of Graduate Education, NSF's Directorate for Social, Behavioral, and Economic Sciences (SBE), CGS, and national programs and consortiums focused on catalyzing systemic change in STEM doctoral programs in discussions about interdisciplinary training and pathways from graduate education to emerging technology careers.
- Engage Cooperative Extension Professionals. TIP can achieve immediate national scale by engaging with the USDA Cooperative Extension System, which other agencies have done through Economy Act arrangements with the USDA National Institute of Food and Agriculture. One of Cooperative Extension's signature programs is the nation's largest youth organization, 4-H. Cooperative Extension provides a unique mechanism to translate emerging technology training into local economic contexts. Several APLU and AAU member institutions are adapting extension approaches to bring AI training to small and medium enterprises and rural communities.[2]
- Engage Education and Workforce Data Analytics Professionals. Achieving TIP's workforce goals requires robust data infrastructure to track outcomes and guide investments. APLU and AAU recommend engaging with professionals with expertise in education and workforce data systems and analysis who can inform the design of a national student-level data network. These experts include institutional research professionals, state longitudinal data system administrators,

[1] National Science Board, National Science Foundation. (2024). *Science and engineering indicators 2024* (NSB-2024-1). https://ncses.nsf.gov/indicators

[2] Extension Foundation. (2025). *2025 National AI report*. https://extension.org/national-ai-report-2025/

organizations like the Association for Institutional Research (AIR) and State Higher Education Executive Officers Association (SHEEO), federal agency data stewards, and labor economists. Partnerships with universities, industry, state, and federal agencies will be essential to ensure data systems capture education and workforce transitions.

Question 4: As technology impacts nearly all economic sectors, a full range of technology-enabled roles will require a wide range of skills. Where should NSF TIP emphasize its investments in workforce development in the near and long-term?

Invest in K-12 STEM Education and Teacher Preparation

K-12 pre-service and in-service teachers need updated content knowledge and pedagogical approaches for emerging technologies.

APLU & AAU Recommendations

- Coordinate with NSF's Directorate for STEM Education, particularly DRK-12 and IUSE, to ensure K-12 teacher preparation programs include professional development in topics like computational thinking, data science, and AI literacy, and that these concepts are integrated in the undergraduate STEM education curriculum.
- Continue to invest in foundational education research to understand how students learn and on how to best prepare teachers and faculty members to teach the content and competencies needed in emerging technology fields.

Support Broader Workforce Competencies

Social, technical, and multi-disciplinary skills, perspectives, and knowledge are particularly important for workers in emerging technologies that intersect with complex human systems. Labor market analysis shows workers need critical thinking, collaboration, communication, project management, and data management and analysis skills.[3] One of the key findings from the NSF's 2023 Industry Partnership Summit[4], that convened 63 science and technology leaders from 49 companies, was the need to advance worker's soft-skills, including design-thinking, communication, and team dynamics. The Summit recommended emphasizing these soft-skills along with technical skills and experiential learning.

Research universities are well-equipped to provide this breadth. Students can combine technical training with coursework in economics, entrepreneurship, policy, history of science, ethics, or other fields that contextualize how technologies succeed or fail in practice.

APLU & AAU Recommendation

[3] Markow, W., Hughes, D., & Bundy, A. (2018). *The new foundational skills of the digital economy: Developing the professionals of the future*. Business-Higher Education Forum, Washington, DC. https://www.bhef.com/publications/new-foundational-skills-digital-economy-developing-professionals-future

[4] University Industry Demonstration Partnership. (2024, March 5). *Innovative partnerships for the future: NSF industry partnership summit*. https://uidp.org/custom-type/nsf-industry-partnership-summit/

- Ensure workforce development programs include broader competencies beyond technical skills, including communication, collaboration, and understanding of how technologies interact with markets, institutions, and society.

Invest in Graduate Education and Research Training

Graduate education is vital to TIP's workforce goals, producing the researchers, innovators, and faculty essential to advancing technological innovation.

APLU & AAU Recommendation

- Continue to support graduate research fellowships across all NSF-eligible STEM fields using merit-based selection. The CHIPS and Science Act authorized support for up to 3,000 fellows annually, but GRFP awarded approximately 1,500 fellowships in 2025, down from over 2,000 in 2024. To achieve the scale of innovation envisioned by TIP**,** APLU recommends that NSF continue to fund fellowships in line with the aspirations and intent of the CHIPS and Science Act. These fellows provide the research capacity required to advance critical technology areas and serve as the talent source for highly-skilled workers necessary for the critical technology sectors.

Question 5: Which of the critical and emerging technologies specified in Section 10387 of the CHIPS and Science Act of 2022 (Public Law 117-167) will have the greatest workforce needs in the next five years? The next decade?

Support CHIPS and Science Act Priorities

APLU and AAU support the investments and priorities outlined in the CHIPS and Science Act, including all technology focus areas (advanced manufacturing, advanced materials, AI, biotechnology, communications and wireless, cyberinfrastructure and advanced computing, cybersecurity, disaster risk and resilience, energy technology, quantum information science, and semiconductors and microelectronics).

APLU & AAU Recommendation

- Understanding limits to the federal budget, coordinate with other federal agencies to ensure complementary investments that leverage NSF's strengths in basic research and workforce development and other agencies' applied research and development missions.

Develop Granular Workforce Data in Critical Technologies

NSF could provide real leadership in understanding workforce needs, and investments should be based on a strong evidentiary foundation. The TIP Roadmap cites Bureau of Labor Statistics (BLS) projections of 10.4% growth in STEM occupations to justify investments in AI, quantum, semiconductors, and biotechnology. However, according to the underlying BLS analysis, healthcare and social assistance accounts for 45% of all projected new jobs.[5] This discrepancy highlights the lack of occupation-level data on current supply, demand, attrition rates, and transition pathways in specific emerging technology

[5] Colato, J., & Ice, L. (2023, October). Industry and occupational employment projections overview and highlights, 2022–32. Monthly Labor Review, U.S. Bureau of Labor Statistics. https://doi.org/10.21916/mlr.2023.24

fields. Without granular occupational data, the nation risks misaligning federal investments, potentially overproducing workers in certain sub-sectors while leaving critical gaps in others that are essential for national security.

APLU & AAU Recommendations

- Invest in granular occupational data for STEM fields, especially critical and emerging technologies, potentially through partnerships with BLS and industry associations.
- Leverage the 2024 TIP Roadmap's[6] identified technology clusters to prioritize investments until more granular occupational data becomes available. The identified technologies requiring acceleration were AI, machine learning, and autonomy; advanced communications and immersive technology; biotechnology, medical technology, genomics, and synthetic biology; and data storage, data management, distributed ledger technologies, and cybersecurity.

Support the Foundational Disciplines that Enable Critical Technologies

Emerging technologies require interdisciplinarity across STEM fields. AI draws on mathematics, statistics, and computer science while biotechnology integrates biology, chemistry, engineering, and computation. Chemistry students become materials scientists essential for semiconductor innovation, and mathematicians and physicists are vital for quantum computing. Most importantly, history shows that one cannot always predict where a new technology will emerge: lithium-ion batteries from chemistry research, GPS from physics research on atomic clocks, and generative AI from machine learning research. The nation needs to invest in fundamental research, the foundation of future inventions and innovations. The nation needs a skilled technical workforce with deep expertise in their field and ability to collaborate across disciplines.

APLU & AAU Recommendation

- Continue to invest in the full spectrum of STEM disciplines alongside the critical technologies, recognizing that foundational research in physics, chemistry, biology, computer science, engineering, geosciences, social, behavioral and economic sciences, and mathematics enables breakthrough innovations across all technological areas.

Question 6: What may be the most effective strategies to address workforce gaps as critical and emerging technologies are introduced into a range of industries?

Leverage NSF's Investment in Education Research for Workforce Development

The most effective workforce development strategies leverage NSF's decades of investment in understanding how students gain competencies in STEM fields. Specifically, Discipline-Based Education Research (DBER) provides evidence on how students master complex concepts and competencies in

[6] National Science Foundation. (2024). TIP Roadmap 2024: An investment strategy for the U.S. National Science Foundation's Directorate for Technology, Innovation and Partnerships. https://nsf-gov-resources.nsf.gov/files/TIPRoadmap_WEB.pdf

fields like quantum mechanics and synthetic biology.[7] However, DBER has a lab-to-market challenge, which TIP could help address. While DBER generates evidence on effective teaching practices, these findings need translation into scalable education and workforce training programs. TIP's mission to accelerate innovation from research to practice makes it well-positioned to help bridge this gap.

APLU & AAU Recommendations

- Coordinate with the Directorate for STEM Education to support translational pilots that integrate evidence-based pedagogical practices into workforce training in the priority technology areas. These investments would provide TIP with the evidence needed to make strategic decisions about which innovations to scale. It would also help bring this research into practice.
- Continue to support research on emerging educational technologies that TIP proposes to scale. The Roadmap emphasizes AI-enabled personalized learning, immersive technologies, and other innovations. Leveraging these tools requires research on which tools may be more suited to which students and in what contexts. Critical research questions include how these tools affect learning, what competencies learners need to use them effectively, what pedagogies work in AI-augmented environments, and how institutions can integrate them successfully at scale.

Support Evaluation of Workforce Interventions

TIP has an opportunity to build rigorous evidence about what works in workforce development. The Roadmap proposes scaling promising approaches like apprenticeships, certificates, and experiential learning, but we lack evidence on their effectiveness specifically for AI, quantum, biotechnology, and other emerging fields.

APLU & AAU Recommendation

- Invest in evaluation infrastructure that benefits the entire field: require outcomes to be shared, ensure independent third-party evaluation of educational technologies and workforce development programs that NSF supports, contribute to longitudinal tracking systems following graduates into careers, and build research capacity to understand whether interventions work and why and for whom.

Conclusion

NSF TIP's Roadmap for Workforce Development addresses a critical national priority: ensuring the United States has the talent needed to lead in emerging technologies essential to national security and economic prosperity. APLU, AAU and our members look forward to partnering with NSF TIP to advance this critical national priority.

[7] National Academies of Sciences, Engineering, and Medicine. (2012). *Discipline-based education research: Understanding and improving learning in undergraduate science and engineering*. The National Academies Press. https://doi.org/10.17226/13362