Expanding the Graduate Research Fellowship Program to Preserve American Innovation in the Industries of the Future

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Summary

The U.S. government has identified artificial intelligence (AI), quantum information science, 5G networks, advanced manufacturing, and biotechnology as the five "Industries of the Future (ITF)":[1] key technological domains projected to have the greatest impact on advancing national competitiveness in the coming years. Sustained investment in the ITF is crucial to preserving national security, improving American healthcare, advancing towards a green economy, and achieving other societal priorities. Continued progress in the ITF is also necessary for the United States to stay ahead of global economic competitors such as China and the European Union.

However, the United States currently lacks the robust science, technology, engineering, and math (STEM) workforce needed to maintain ITF leadership. Systemic inequities in the U.S. STEM talent pipeline hinder development of the deep scientific and technological expertise needed for U.S. workers to realize the full potential of the ITF. To address these inequities, the federal government must leverage and invest in its strongest vehicle of American scientific talent: the National Science Foundation (NSF).

By expanding its Graduate Research Fellowship Program (GRFP), the NSF can help build a scientific and technical workforce that fully reflects American diversity and captures the full value that such diversity offers. The result will be a nation in which more students—including the socioeconomically disadvantaged, minorities, women, and those far-removed from academia—have the skills and opportunities to contribute to the Industries of the Future.

Challenge and Opportunity

A Turning Point in Scientific and Technological Development

Technologies that fall under the ITF umbrella are often referred to by an array of terms, including Deep Tech, high tech, foundational tech, and frontier tech.[2–6] Regardless of nomenclature, the technological domains that comprise the ITF are likely to have transformational impacts around the world in the coming years. At a time when both authoritarian regimes and international economic rivals are making robust investments in emerging technologies, U.S. leadership in the ITF is essential.[7,8] The ITF has already emerged as a battleground for global economic competition. For example, China has announced aggressive strategic investments aimed at leapfrogging the United States in numerous ITF domains.[9,10]

At home, progress in the ITF can change American livelihoods for the better. Just as the advent of the Internet kickstarted the e-commerce industry, the ITF will spur the creation of new industries and revitalize others.[11] This in turn will create new economic opportunities for Americans across diverse

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[1] The National Institute of Standards and Technology (NIST) worked with stakeholders across government, industry, and academia to identify the "Industries of the Future": five key technological domains—artificial intelligence, quantum information science, 5G, advanced manufacturing, and biotechnology—that have transformational potential and will be critical to national competitiveness in the coming years. See the "Frequently Asked Questions" section for more details on the ITF.
[2] Rae, K.; et al. (2020). A Foundational Technology Development and Deployment Office to Create Jobs. Day One Project, October.
[3] Jump, L.; et al. (2021). Creating a National DeepTech Capital Fund. Day One Project, January.
[4] Kurose, J.; et al. (2020). Advancing American AI through National Public-Private Partnerships for AI Research. Day One Project, November.
[5] BCG. (2019). The Dawn of the Deep Tech Ecosystem. March.
[6] Titus, A. (2020). A National Bioeconomy Manufacturing and Innovation Initiative. Day One Project, December 2020.
[7] New America. (2020). Xi Jinping's Sept. 2020 Speech on Science and Technology Development (Translation). September.
[8] European Commission. (2018). Member States and Commission to work together to boost artificial intelligence "made in Europe". December.
[9] Metz, C. (2018). As China Marches Forward on A.I, The White House Is Silent. The New York Times, February 12.
[10] New America. (2020). Xi Jinping's Sept. 2020 Speech.
[11] The Engine. (2020). Building a 21st-century American Economy: The Role of Tough Tech in Ensuring Shared, Sustainable Prosperity. November.

geographies in the United States. The ITF also has critical implications for national security. Advances in AI and quantum computing[12] can support strong cyber infrastructure.[13] Advanced manufacturing will revolutionize commercial and military supply chains.[14] Biotechnology innovations will improve the capacity of the United States to anticipate and defend against biological hazards, as well as foster economic prosperity.[15]

Overall, our nation's achievements in the ITF directly affect our nation's ability to defend against threats abroad and at home. Federal policymakers have taken notice of the ITF's importance and responded by increasing investment in federal research and development (R&D), placing emerging technologies under intense scrutiny, and establishing public-private partnerships to scale ITF projects.[16]

Industries of The Future and the STEM Talent Pipeline

Maximizing potential in the ITF requires a workforce with significant training in core science, technology, engineering, and mathematics (STEM) disciplines as well as interdisciplinary expertise. But investment in the U.S. STEM talent pipeline falls far short of the levels needed to build such a workforce. Systemic barriers throughout the STEM talent pipeline discourage participation by many Americans, meaning that the United States is leveraging only a small fraction of the skills and ideas its populace has to offer.

The U.S. STEM workforce falls especially short in three core areas: gender diversity, racial diversity, and socioeconomic diversity. In computer science, for example, women account for less than a quarter of undergraduate and doctoral degree recipients.[17] Although Black, African-American, Latinx, and Hispanic populations together comprise 30% of the American population, they accounted for only 10% of computer-science Ph.D. recipients in 2018.[18] Additionally, socioeconomic inequities that plague undergraduate studies similarly affect who applies and gets in to graduate schools, as 87% of doctoral recipients have parents who've attended college.[19]

The United States is currently making up for weaknesses in the domestic STEM talent pipeline by recruiting talent from overseas. In 2019, for instance, 60% of computer-science Ph.D. recipients were non-resident aliens.[20] This strategy relies on the attractiveness of the United States as a place to pursue education and employment, and hence presents long-term risks. If the United States begins to fall behind in the ITF, it will become less of a draw for international talent. This in turn will further erode U.S. capacity in the ITF and create a vicious cycle. The supply of foreign talent is also more vulnerable to external shocks.[21] A more sustainable strategy is to invest in cultivating domestic STEM talent, especially in priority fields such as artificial intelligence, biotechnology, computer science and quantum information science.[22]

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[12] Quantum computing is a subcategory of quantum information science. See the "Frequently Asked Questions" section for more details.
[13] Segal, E. (n.d.). The Impact of AI on Cybersecurity. IEEE Computer Society.
[14] United States Army. (2019). Secretary of the Army approves new advanced manufacturing policy. October 4.
[15] National Defense University. (2018) Roadmap for Biosecurity and Biodefense Policy in the United States. June.; Titus, A. (2020). A National Bioeconomy Manufacturing and Innovation Initiative. Day One Project, December.
[16] Kratsios, M. (2020). Remarks by Acting Under Secretary of Defense for Research and Engineering Michael Kratsios. Georgetown University Center for Security and Emerging Technology. August 13.
[17] National Science Foundation (NSF). (2020). Doctoral degrees awarded to female U.S. citizens and permanent residents, by field of degree, ethnicity, and race of recipients: 2008–18.
[18] NSF. (2020). Doctoral degrees awarded to male U.S. citizens and permanent residents, by field of degree, ethnicity, and race of recipients: 2008–18.
[19] NSF. (2018). Survey of Earned Doctorates. https://ncses.nsf.gov/pubs/nsf20301/data-tables/.
[20] Zweben, S.; Bizot, B. (2019). Total Undergrad CS Enrollment Rises Again, but with Fewer New Majors; Doctoral Degree Production Recovers from Last Year's Dip. Computing Research Association.
[21] The COVID-19 pandemic presents a case in point, as it has significantly disrupted our foreign talent pipeline already.
[22] The President's Council of Advisors on Science and Technology (PCAST). (2020). Recommendations for Strengthening American Leadership in Industries of the Future.

Driving STEM Talent Through the GRFP

The National Science Foundation (NSF)'s Graduate Research Fellowship Program (GRFP) is a logical place for the federal government to start. Expanding the GRFP offers a direct, near-term solution to increase the nation's scientific and technological capacity and funnel more Americans into the ITF workforce. Since its inception in the 1960s, the GRFP has funded graduate students to conduct unrestrained research, free from financial constraints.

The GRFP has traditionally been marketed towards senior-year undergraduates or recent graduates who are usually hyper-focused in their field of study. However, not everyone has the means to and/or interest in going to graduate school shortly after finishing their undergraduate studies. Expanding the GRFP could support the many students on track for less traditional paths in post-graduate education. For instance, a revamped GRFP could attract a mid-career software engineer interested in going back to school or a lab technician trying to find a pathway into materials research. Deliberately framing the GRFP as a GI Bill-like opportunity to participate in the innovation ecosystem could stimulate interest in STEM from all corners of America and dramatically increase the number of potential scientists and technologists equipped to participate in the ITF workforce.

Reforming the GRFP can directly increase the diversity of the domestic STEM talent pipeline. NSF's own internal survey determined that in 2014, GRFP recipients are overwhelmingly White.[23] Currently the GRFP favors well-off applicants—who tend to be White—from resource-rich schools that gives them significantly more access to mentoring and research opportunities. By placing more emphasis on funding more students from underrepresented groups in science, NSF can cultivate a STEM workforce that truly looks like America.

A substantial investment into the GRFP would also mitigate the disruption caused by the COVID-19 pandemic, which has already made pursuing academia financially arduous for many potential scientists into the private sector and has exacerbated existing socioeconomic and racial inequities within the R&D enterprise. Providing more funding for post-graduate education and research in STEM will help more Americans, regardless of socioeconomic status, pursue opportunities in the ITF.

Finally, the GRFP can be reformed to better align the U.S. STEM talent pipeline with national priorities. Since 2017, NSF's 10 Big Ideas[24] have served as a lodestar for scientific progress in the United States. But the GRFP continues to be underutilized as a tool for the realization of those ideas. The Trump Administration's President's Council of Advisors on Science and Technology (PCAST) has already proposed expanding the GRFP to accelerate the STEM talent pipeline. This action fits with the Biden Administration's stated intention to break down the systemic barriers that hinder the United States from realizing prosperous innovation.[25]

A proposal to expand the GRFP would likely meet with bipartisan support. In the past few years, Congress has passed bills—such as the Quantum Initiative Act[26] and the Endless Frontiers Act[27]—targeted at

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[23] In 2014 the study concluded that from 1994–2011, GRFP recipients were 80% White. In 2018, the most recent year for which data are available, only 23% of GRFP awards went to underrepresented minorities—not much of an improvement. Source: NSF. (2014). Evaluation of the National Science Foundation's Graduate Research Fellowship Program. NSF.; Muller Parker, Giselle (2020) Cancel Cuts to Graduate Research Fellowships. Science. January 2020: 519

[24] See NSF's Big Ideas. https://www.nsf.gov/news/special_reports/big_ideas/.

[25] Subbaraman, N.; Witze, A. (2021). Biden Names Top Geneticist Eric Lander as Science Adviser. Scientific American, January 16.

[26] (2018). H.R.6227 - National Quantum Initiative Act.

[27] Office of Senator Todd Young. (2020). Young, Schumer Unveil Endless Frontier Act to Bolster U.S. Tech Leadership and Combat China. May 27.

fostering the ITF workforce. Moreover, both the Trump Administration[28] and the Biden Administration[29] have explicitly stated their support for investment in the ITF. Presidential Memorandum Expanding the GRFP would build on this and related legislation. By investing in its domestic STEM talent pipeline through a bigger and better GRFP, the United States can catalyze American scientific research and train a new cadre of workers prepared to help the United States lead in the ITF.

Plan of Action

NSF's Division of Graduate Education (DGE), part of the Directorate of Education and Human Resources (EHR), is primarily responsible for managing the GRFP. Through EHR and DGE, NSF can take four main actions to better invest in our scientists and technologists, building a stronger and more diverse STEM workforce equipped to participate fully in the ITF.

<u>Action 1.</u> **Expand the GRFP with an additional $276 million per year over the next five years to augment the talent pipeline of the Industries of the Futures with 2,000 additional fellows per year.** The DGE should establish an "ITF Frontiers" fellowship under the GRFP aimed at recruiting prospective American graduate students from underrepresented groups (including women, geographic minorities, Blacks and African-Americans, Native Americans/Indigenous Americans, and Latinxs and Hispanic-Americans) to ITF-relevant disciplines. These disciplines include, but are not limited to, artificial intelligence (AI), quantum information science (QIS), computationally intensive research (CIR), nanotechnology, and biotechnology.[30] The ITF Frontiers fellowship should be funded at $276 million per year over the next five years to support an additional 2,000 diverse scientists and technologists per year—representing a 225% increase of the GRFP's current awardee base—to contribute to the ITF.

The NSF should include the expanded GRFP program in its funding request to Congress. This request would likely be granted given the aforementioned bipartisan support for ITF investment. Resources to support GRFP expansion could also be pooled from recently approved legislation related to the ITF, including the National Quantum Initiative Act, the National AI Initiative Act, and the National Defense Authorization Act.

While expanding the GRFP, the NSF should consider implementing key programmatic reforms.
- o First, DGE should seek to fund more research-based master's degrees. Though the GRFP does fund students in research-oriented master's programs—and allows those students to transition to Ph.D. programs—GRFP awards overwhelmingly go to those starting on a Ph.D. track. Funding more research-oriented master's degrees would give grantees more flexibility in pursuing research positions and other STEM jobs outside of the academic ecosystem, where financial support and fellowships can be notoriously sparse.
- o Second, the NSF should collect longitudinal data on awardees to better track short- and long-term impacts of receiving a GRFP fellowship. This information will be useful for identifying the strengths and weaknesses of the GRFP and for determining how to further improve the program.
- o Third, the NSF should explicitly message that this new iteration of the GRFP *adds* 2,000 annual fellowships for students in ITF fields: it does not reallocate existing fellowship slots. To avoid any

[28] Vought, R.T.; Droegemeier, K.K. (2020). Memorandum for the Heads of Executive Departments and Agencies. Executive Office of the President: Fiscal Year (FY) 2022 Administration Research and Development Budget Priorities and Cross-cutting Actions. August 14.
[29] Biden for President. (2020). The Biden-Harris Plan to Fight for Workers by Delivering on Buy America and Make it in America.
[30] NSF listed a number of these fields in its most recent GRFP solicitation. This list is not exhaustive, as ITF-related fields fall under many different names. But a start is better than none.

misunderstandings, the NSF could even consider marketing the ITF Frontiers Fellowship as an entirely separate program from the GRFP.[31]

Action 2. Permit GRFP awardees to delay their funding timeline by a year. Currently, the GRFP requires that students accept their first year of awarded funding before being eligible to defer two of the remaining four years. Relaxing this first-year funding requirement would give awardees the flexibility to gain industry experience before entering graduate school and offset the financial burden of attending graduate school. In the near-term, relaxing the first-year funding requirement would also mitigate disruptions caused by COVID-19 in onboarding new graduate students.

Action 3. Promote recruitment and retention in the STEM talent pipeline by establishing more undergraduate internships in ITF-relevant fields. NSF can further bolster the ITF workforce by helping prepare undergraduates to participate in programs like the GRFP and other post-graduate opportunities in STEM. NSF's current plan to establish a national network of emerging technology research centers presents an opportunity to establish ITF-targeted internships for undergraduates.[32] EHR should make a concerted effort to establish new REU (Research Experiences for Undergraduates) sites at universities with programs focused on ITF-relevant basic and applied research. The NSF could easily establish REUs sites at its new centers for artificial intelligence, advanced manufacturing, quantum computing, and biotechnology. Since 2003, NSF's REU partnership with the Department of Defense has served as a successful example of interagency collaboration to engage undergraduates in STEM fields.[33] NSF should build on this precedent by forming additional partnerships with the Department of Energy, the National Oceanic and Atmospheric Administration, and other federal science agencies to create new ITF-relevant internship opportunities. To recruit and retain diverse talent, EHR should prioritize REU sites at historically Black colleges and universities (HBCUs), Native American-serving Institutions (NASNTIs), Hispanic-serving institutions (HSIs), and rural colleges.

Action 4. Reform the GRFP with an institution-blind GRFP review process to ensure a fair and merit-based selection process. Fantastic minds are found everywhere across America. The GRFP selection process should reflect that fact. Institution-blind reviews remove reviewer bias that disproportionately hurts the chances of applicants from non-elite schools. The student demographics of elite schools are overwhelmingly white and rich, and favoring grantees from this pool reinforces exclusivity. A case in point: only 0.3% of GRFP grants in 2017 went to students from HBCUs, HSIs, and NASNTIs, while students from high-prestige, research-rich institutions were awarded 25% of grants.[34] The NSF should also publish data on application success rates across fields and demographic groups to increase the transparency and accountability of the GRFP's mission to "ensure the quality, vitality and diversity of the science and engineering workforce."[35]

Conclusion

Developments in the Industries of the Future are proceeding rapidly, with significant implications for national security, economic competitiveness, societal well-being, and innovation. The United States needs a robust STEM workforce to keep up. Expanding and reforming the GRFP is a direct, near-term strategy

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[31] See FAQ for more on this.
[32] NSF. (2020). NSF Launches Artificial Intelligence Research Institutes. 2020.
[33] NSF. (n.d.) REU Sites: Department of Defense.
[34] Hu, J.C. (2019). NSF graduate fellowships disproportionately go to students at a few top schools. Science, August 26.
[35] NSF. (2021). NSF Graduate Research Fellowship Program (GRFP).

for rebuilding our nation's eroding STEM talent pipeline and enabling every American to contribute to the future of innovation.

Frequently Asked Questions

What are the Industries of the Future (ITF), and why prioritize ITF-relevant fields?

The National Institute of Standards and Technology (NIST) worked with stakeholders across government, industry, and academia to identify the "Industries of the Future": five key technological domains that will be critical to U.S. economic competitiveness and national security. These domains are artificial intelligence, quantum information science, 5G, advanced manufacturing, and biotechnology. Readying scientific talent in ITF-relevant fields is crucial to securing U.S. leadership in these areas of strategic importance.

The recent GRFP solicitation change to prioritize applied computational sciences spurred concern and pushback amongst the scientific community. Won't reforming the GRFP by expanding ITF-relevant fields marginalize students in other scientific disciplines?

No. This proposal recommends *expanding* the current GRFP such that the program will continues to serve all scientific disciplines at the same level as before, while making additional investments in a diverse ITF workforce. 1,600 grants will still be awarded as they have in the past, while 2,000 new grants would be established to meet the talent demand for the ITF. The expanded GRFP will hence continue to fulfill NSF's mandate to fund basic research while simultaneously emphasizing areas of national priority. The expanded GRFP will also align NSF with the ongoing national push to accelerate progress in the ITF.[36] Finally, there is precedent for prioritizing certain research areas in NSF funding programs. NSF has placed special focus on computational and data-enabled science and engineering since 2018. The agency has also focused on NSF's 10 Big Ideas in its National Research Traineeship program.

One option for avoiding misunderstanding among the S&T community would be to cast the ITF Frontiers Fellowship as a separate program from the GRFP. Such messaging would need to be accompanied by increased marketing and outreach, since a new ITF Frontiers Fellowship program would be relatively unknown at first while the GRFP is an established brand.

NSF's Computer and Information Science and Engineering (CISE) Directorate recently established a CS4GradUS, a program that awards computer-science students a GRFP-like fellowship for graduate school. Wouldn't expanding the GRFP to focus on the ITF duplicate this program?

No. The CS4GradUS program[37] is a pilot program that seeks to address some of the same systemic barriers in the U.S. STEM talent pipeline identified in this proposal. However, the CS4GradUS program has some limitations:

- First, CS4GradUS program is small, awarding only 70 fellowships per year. 70 is better than zero, but not large enough to make a substantial impact on American innovation.
- Second, CS4GradUS is limited to applicants looking to pursue a Ph.D. But doing high-caliber and impactful research at the frontiers of S&T (especially in the industry sector) does not always require a Ph.D. CS4GradUS's exclusive focus on Ph.D. students sidelines those wishing to pursue research-focused master's degrees.
- Third, eligibility for CS4GradUS is limited to people with an educational background in computer science who are interested in continuing to study the subject—a very limited pool. While there is

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acute national and industrial demand for those with expertise in computer science, similarly intense demand exists for other ITF-related fields like synthetic biology, material science, and quantum information sciences.

Expanding the GRFP as described in this proposal represents a broader and more ambitious effort to strengthen and grow the domestic STEM talent pipeline.

What can be done to increase the diversity of applicants to programs like the GRFP?

NSF should direct more resources towards casting a wide net for GRFP applicants and towards raising awareness of the GRFP in diverse communities. Options include:

- Framing the GRFP as an opportunity that is open not just to college students and recent graduates, but also to those far removed from academia.
- Tailor outreach to HBCUs, HSIs, and tribal colleges.
- Expand existing partnerships—and foster new ones—with minority-focused organizations such as the National Society of Black Engineers (NSBE), the National Society of Black Physicists (NSBP), the Society of Hispanic Professional Engineers (SHPE), and the Association for Women in Science (AWIS) to promote the GRFP.
- Prepare a comprehensive social media outreach campaign. As a start, through the GRFP Twitter and Facebook accounts, NSF can conduct more aggressive outreach with videos, talks, and Q&A sessions to tap diverse communities outside traditional academic circles.

In a 2020 report,[38] PCAST had explicitly proposed to give every computer science (CS) undergraduate student a graduate fellowship. Why not implement this solution instead?

PCAST's focus on the ITF should be applauded, but at an estimated cost of $6 billion, its proposal to give every successful computer science student a fellowship is prohibitively expensive. Furthermore, ITF-relevant fields are heavily interdisciplinary and require investments in subject areas besides computer science.

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[38] The President's Council of Advisors on Science and Technology (PCAST). 2020. Recommendations for Strengthening American Leadership in Industries of the Future.

About the Author

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