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"An Overview of the National Science Foundation Budget Proposal for Fiscal Year 2019"

Introduction

Science has long been at the heart of the American experiment. "An investment in knowledge always pays the best interest," noted Benjamin Franklin, and the revolutionaries who founded our Nation and enshrined the promotion of "the progress of science and useful arts" in the Constitution. Since World War II, the United States has led the world in basic and applied research. The resulting advances have transformed nearly every aspect of Americans' daily lives, driven our economic growth, and underpinned our national security. New technologies built on federally-funded discovery research have led to new businesses, revolutionized health care, and created the digital world. Sustained, bipartisan commitment to investing in fundamental research has played a key role in establishing and maintaining American global leadership in science and technology (S&T). Our innovation enterprise is a national asset, and as we make the investments our Country needs to compete in the 21st century global economy, we should renew our commitment to strengthening this key component of our national infrastructure. Collectively, we must do this because the world is changing, other nations are upping their game, and we cannot take our leadership for granted.

The U.S. Science & Technology Enterprise in a Changing Global Landscape

The global S&T landscape is dynamic and fast-changing, and is becoming increasingly multipolar as developing economies, particularly China and other nations in the Asia/Pacific region, are emerging as major players (in addition to historic leaders like the U.S., Western Europe, and Japan). According to the National Science Board's (Board; NSB) 2018 *Science and Engineering Indicators* (*Indicators*) report, the United States is still the global leader in S&T. Our 2018 report shows the U.S. invests the most of any nation in research and development (R&D), attracts the most venture capital, awards the most advanced degrees, provides the most business, financial, and information services, and is the largest producer in high-technology manufacturing sectors. However, the U.S. global share of S&T activities is declining as other nations continue to rise. For the first time in over a half century, U.S. S&T leadership is threatened.

R&D expenditures reflect a nation's commitment to expanding capabilities in S&T, which in turn drive innovation. While the business sector is the largest performer of R&D in the United States, accounting for 72% of the $495 billion total in 2015, the bulk of those funds are spent on applied research and experimental development. The Federal government remains the largest funder of *basic* research ($36.9 billion, 44% of the U.S. basic research total). This Federal government investment is the primary driver of both innovative discovery research and the training of a science, technology, engineering, and mathematics (STEM)-capable U.S. workforce. *Total* federal R&D funding has been on a declining trend since 2011 – from $127 billion in 2011 to $120 billion in 2015.

Other countries have recognized the importance of R&D in fueling innovation and economic growth and are emulating the United States. China has grown its R&D spending rapidly since 2000, at an average of 18% annually, and is now a decisive second with 21% of the global total ($408 billion). During the same time frame, U.S. R&D spending grew by 4%. Although emerging economies start at a lower base and therefore tend to grow much more rapidly, China's growth rate is remarkable.

To produce results, R&D investments must be coupled with building a highly skilled workforce and, on this dimension, we are also seeing increased competition. Students in India and China earned nearly half of the more than 7.5 million science and engineering (S&E) bachelor's level degrees awarded in 2014; the United States earned one tenth. At the doctoral level, the U.S. awarded the largest number of degrees (40,000) of any country, followed by China (34,000). While for many decades the U.S. has benefitted from and counted on an influx of the best and brightest from around the globe, international student numbers in the U.S. dropped between the fall of 2016 and the fall of 2017, with the largest declines seen at the graduate level in computer science (13% decline) and engineering (8% decline). As other countries build their innovation capacity, competition for the world's best students will continue to intensify.

In addition to education and R&D funding, *Indicators* reports on increased global competition in venture capital and knowledge and technology-intensive industries. Although the overall trends described above are not new, in some cutting-edge areas of research the trajectory is more pronounced. For example, over the next five years China plans to invest 20 times more in artificial intelligence per year than the United States did in 2016. And China now claims more than 200 of the fastest 500 supercomputers, while the U.S. has less than 150.[1] These trends raise concern about impacts on our economy and workforce, and have implications for our national security.

Why is U.S. leadership in S&T so important? From quantum computing to artificial intelligence to the data revolution, scientific advancements come with both opportunities and risks. To mitigate those risks in an increasingly competitive world, it is essential that we stay at the forefront of science and cutting-edge research. The past has shown that investment in basic research now will give us the keys to meeting the security, health, and economic challenges of the future – challenges we know will arise but whose nature we cannot predict. Recognizing the importance of our research enterprise to American prosperity, in the U.S. National Security Strategy President Trump has prioritized nurturing a "healthy innovation economy that collaborates with allies and partners, improves STEM (science, technology, engineering, and math) education, draws on an advanced technical workforce, and invests in early stage research and development."

[1] According to https://www.top500.org; this is based on the LINPACK Benchmark, and does not include the NSF-funded Blue Waters supercomputer.

The Board is encouraged that under the new spending cap levels passed by Congress, the Administration prioritized NSF's mission to pursue discovery research in the national interest. With the requested level of funding, NSF will be able support basic research across all fields of science and engineering that create knowledge while allowing us to invest in priority areas. This support could not come at a more pivotal time. As this year's *Indicators* report shows, our lead on many critical S&T measures is shrinking. The Board felt strongly enough about these trends to release a statement highlighting that if current trends continue, China will surpass the United States in total R&D expenditures sometime *this year*. America's dominance in S&E research has long been a key national asset – one which now requires a renewed strategic commitment, because the world is changing fast and our global leadership hangs in the balance.

NSF: The Innovation Agency

Innovations in Research: Big Ideas and the Convergence Accelerators

In the face of rising global competition, the Board recognizes that we also face fiscal challenges here at home. In difficult times, there can be a tendency to "play it safe." But in the United States, we have shown time and time again that we can rise to meet any challenge. We can lay out a vision for where we want to lead in the S&T landscape in this century, and then implement policies that will put us on that path. As America's innovation agency, NSF is not playing it safe. Rather, we are embracing our nation's entrepreneurial spirit and trying something new: NSF proposes in this request to break out of academic silos by adding new elements to our funding structure to invest in cutting-edge interdisciplinary research at the frontiers of S&T.

A few years ago, after several consecutive years of mostly flat budgets, the Board and Director decided that the Foundation must redouble its commitment to prioritizing potentially *transformative* research in all fields of S&E. In testimony before the Committee two years ago, we called for a fearless commitment to seize the enormous opportunities before us at an unprecedented time in human history, when we have the tools, know-how, and understanding to tackle daunting challenges and solve problems that have long defied solution. With the full support of the NSB, the Director challenged her leadership team to call out areas that are particularly promising to transform the discovery science that NSF makes happen. This challenge helped spark the Big Ideas that are a centerpiece of the President's FY 2019 budget for NSF.

NSF proposes to begin work on the Big Ideas, and in addition, implement two Convergence Accelerators, alongside the funding for NSF's disciplinary directorates. These two approaches are complementary: the fundamental research performed in individual research fields provides the seeds for interdisciplinary innovation at the cutting edge of S&T. The time-limited Convergence Accelerators will allow NSF to be more nimble and flexible, facilitating convergent and translational activities in areas of national importance while giving us greater ability to respond to a rapidly changing global S&T environment. We believe this innovative approach is vital; much transformative research happens at the intersection of scientific fields. Indeed, at our Board retreat in September 2017, we discussed convergence at length and concurred that it is essential if NSF is to succeed in its mission and stay at the cutting edge of science.

NSF's Big Ideas for fiscal year 2019 play a significant role in advancing our country's economic competitiveness and national security, and in addressing the challenges posed by the rising investments of other nations in S&E. The Quantum Leap has already begun with an investment in quantum technologies for secure communication, an area of importance for both the private sector and national security.

Likewise, the agency's Future of Work at the Human Technology Frontier holds high promise for the U.S. workforce and our economy.

As good scientists should, we will assess the performance of these new structures. The Board has worked closely with the Director as she and her team developed the Big Ideas. We will work with NSF to develop metrics for success in fostering new collaborations across disciplines and sectors, and in spurring innovative thinking and activities. As needed, the Board will encourage "creative destruction" and reinvention. If these innovations catalyze progress in research and leverage investment by external partners, they could be models for structural and cultural changes not only at NSF but in the U.S. scientific and academic community more broadly. We recognize that experimenting with changes in our funding model is a strategic risk; but it would be a bigger risk to our national S&E enterprise to remain hidebound in a time of external and internal challenges. We hope that Congress will support our new approach.

The STEM Workforce: Developing our Nation's Future Innovators

The success of NSF's Big Ideas – and our Nation's ability to discover, invent, and innovate – relies on our ability to leverage America's greatest competitive advantage – our people. As I noted in a recent op-ed,[2] the generation that propelled us into space is retiring. At the same time, more countries than ever are competing for the best minds. Both industry and the federal government report that they are unable to find enough workers at all levels with sufficient STEM knowledge and skills. These reports are especially concerning in the national security arena, where employees must be U.S. citizens. The National Security Agency recently reported significant levels of attrition among personnel whose jobs require substantial STEM knowledge.

We believe that for our Nation to continue to thrive and lead in a globally competitive knowledge- and technology-intensive economy we can no longer rely on a relatively small and distinct "STEM workforce." Congress, the Administration, business leaders, educators, and other decision-makers must work together to ensure that Americans have the STEM knowledge and skills to thrive, leveraging the hard work, creativity, and ingenuity of women and men of all ages, education levels, and backgrounds.[3] We need scientists searching for cures, engineers building stronger bridges, factory workers making our cars safer, technicians keeping our labs and hospitals operating, and farmers producing healthier crops using fewer resources.

Thanks to the strong bipartisan support of Congress, NSF will continue to play a leading role in building and sustaining this workforce. NSF is the innovation agency not only for the discoveries it funds, but for the people it helps educate and train at all levels who contribute to our Nation's economic prosperity and security. One of NSF's process-focused Big Ideas, **NSF INCLUDES,** is designed to ensure that all Americans have access to educational and career opportunities enabled by STEM. The vision of NSF INCLUDES is to catalyze the STEM enterprise to work collaboratively for inclusive change, which will help ensure that all Americans are able to participate in and benefit from our S&T enterprise.

[2] Zuber, M.T., "Falling Short on Science", New York Times, January 28, 2018. (https://www.nytimes.com/2018/01/26/opinion/falling-short-on-science.html)
[3] National Science Board (2018), "Our Nation's Future Competitiveness Relies on Building a STEM-Capable U.S. Workforce." (https://www.nsf.gov/nsb/sei/companion-brief/NSB-2018-7.pdf)

The NSB also bears responsibility for helping to build and sustain a STEM-capable U.S. workforce. NSF's *Indicators* report provides us with an opportunity to inform and update our Nation's understanding of the state of STEM education and the workforce. *Indicators 2018* shows that the number of U.S. jobs requiring substantial STEM expertise has grown nearly 34% over the past decade. As of 2015, nearly one in seven workers with at least a four-year degree say that their job requires a "bachelor's level" of STEM expertise.

These numbers do not include the more than 16 million jobs that require significant expertise in at least one technical field but do not require a bachelor's degree. These "skilled technical jobs" are well-paying, and are found across the United States. Skilled technical workers are also critical to our Nation's S&T infrastructure. In 2017, the NSB visited the Laser Interferometer Gravitational-Wave Observatory (LIGO) in Louisiana. We have heard of the LIGO scientists who won the Nobel Prize in Physics for the discovery of gravitational waves. What is less publicized is that LIGO is an industrial facility: miles of carefully welded high vacuum pipeline and banks of air filters as tall as a house. It is skilled technical workers – HVAC experts, electricians, and other workers without a four-year degree – who helped build LIGO and keep it running so that these fundamental scientific discoveries can be made.

NSF is making key investments to build the skilled technical workforce. The **Advanced Technological Education** (ATE) program, created by Congress in the early 1990s, is focused on two-year colleges and supports the education of technicians in high-technology fields. The program involves partnerships between academic institutions and industry to promote improvement in the education of S&E technicians at the undergraduate and secondary school levels. The ATE program particularly encourages proposals from Minority Serving Institutions, where the proportion of underrepresented students interested in advanced technology careers is growing. To date, ATE has awarded more than $950M total to 492 institutions.

In 2014, ATE projects and centers developed 2,430 education materials, such as courses, lab experiments or other types of educational activity. Of the students participating in ATE programs during 2014, 91% either continued in their program or completed a program. ATE projects and centers have 3,890 collaborations with business and industry, and 90 ATE projects and centers offered 2,190 professional development activities attended by 45,830 educators. ATE projects have also been successful in broadening participation. Women have significant leadership roles in ATE with 24 of the 42 ATE centers having female principal investigators. According to a survey of ATE grantees, underrepresented minority students comprise 44% of all students in ATE-supported programs; this is about double the percentage of minority students in other STEM programs. In short, ATE increases knowledge, catalyzes institutional change, and builds capacity.

CyberCorps – Scholarship for Service funds institutions of higher education to develop and enhance cybersecurity education programs and curricula; and to provide scholarships to undergraduate and graduate students in strong academic cybersecurity programs – an area of key strategic importance to U.S. national security. The students receiving scholarships must be U.S. citizens or lawful permanent residents and must be able to meet the eligibility and selection criteria for government employment. Students can be supported on these scholarships for up to three years, and in return, they agree to take government cybersecurity positions for the same duration as their scholarships. The program also requires a summer internship at a Federal agency. Government agencies eligible for job placement include Federal, state, local, and tribal governments.

In recognition of the importance of this segment of the U.S. workforce, the NSB began gathering information on the skilled technical workforce in early 2017. After holding several meetings at NSF throughout 2017, the NSB felt it could better understand the opportunities and challenges facing students, workers, business, and educators involved with the skilled technical workforce by engaging with them directly. Last autumn, NSB held "listening sessions" at Baton Rouge Community College and Xavier University of Louisiana, where we heard from local stakeholders about the skilled technical workforce as well as issues for underrepresented minorities in STEM. These sessions put names and faces to the myriad of challenges these students face. Their stories served as a powerful motivator, and in November 2017 the NSB formally established a Task Force on the Skilled Technical Workforce.[4] This Task Force is charged with leading the NSB's efforts to strengthen the skilled technical workforce, and we are eagerly anticipating our next listening session this April at one of NSF's ATE Centers outside Detroit, Michigan.

Innovating within the Agency: Improving Our Processes

In its oversight, policy, and strategy work, the Board takes seriously its responsibilities to provide strong governance and stewardship of this taxpayer investment. The Board continues to monitor NSF's implementation of transparency and accountability measures to ensure that the research goals of funded projects are clearly identified and expressed in plain language.

NSB is also currently taking a fresh look at the Board-mandated biennial merit review report. NSB sees merit review as NSF's lifeblood. We want to ensure not only that the merit review process is working well, but that in assessing it that we are asking the right questions, collecting the right data, and generating a report that helps NSF ensure that the merit review process is meeting our strategic goals.

Over the last year, the NSB has also worked with NSF to advance formal risk thinking in strategic planning and priority setting, overseeing the Foundation's adoption of Enterprise Risk Management (ERM). This work is paving the way for a true enterprise-wide approach to risk management that transcends ERM's traditional focus on business processes. As part of this effort, NSB has encouraged NSF to embrace strategy risks (i.e., to avoid "playing it safe") such as support for convergent research while stressing the need to eliminate preventable risks. Adoption of a formal approach and shared vocabulary around risk has improved NSB-NSF management discussions and is helping NSF as it implements OMB's ERM requirements.

The restructuring of Board committees in February 2017 and NSB's risk work was done, in part, to strengthen our engagement with and oversight of major research facilities, in coordination with NSF's ongoing internal improvements. In the past year, we've worked with NSF to refine recompetition and renewal policies and improve strategic planning around divestment of facilities. We continue to push for more comprehensive lifecycle planning with all facilities awards and are very pleased with the AICA's emphasis on this and NSF's response. In a period of budget constraints and rising costs of cutting edge experiments, we are also (as directed in FY 2017 appropriations report language) taking a close look at facility operations and maintenance (O&M) and will be presenting a report on that subject to Congress in the coming months.

NSB's Budget Request

[4] Charge to the NSB Task Force on the Skilled Technical Workforce (2018). (https://nsf.gov/nsb/committees/stwcmte.jsp)

The National Science Board's FY 2019 Budget Request will facilitate the continued thoughtful enhancement of the Board's efforts to strengthen the U.S. S&E enterprise through its policy and information-related activities, as well as ongoing work reviewing and approving major NSF awards, providing guidance on new programs and budgetary priorities, and overseeing programs, merit review, and the lifecycle of facilities. The request supports the Board's ongoing efforts to communicate key data from *Indicators 2018* in accessible, policy-relevant ways through its recently released companion statement on the importance of building a STEM-capable U.S. workforce, and the production of 51 one-pagers (all 50 states and DC) on key S&E facts.

The Board will build on this companion statement through the continued the work of NSB's Skilled Technical Workforce Task Force, including through listening sessions that expand our understanding of the skilled technical workforce and other topics. One thing we have clearly learned so far is that perspective into workforce needs and challenges can only be gained by meeting with stakeholders.

In FY 2019, the Board will strive to make the next edition of *Indicators* (2020) more useful, timely, and accessible to our stakeholders by creating interactive digital products. The Request will also allow the Board to further increase its engagement with Congress, the Administration, academia, the business community, and the general public to better understand their diverse needs.

Conclusion

As we look at the world in 2018, we find ourselves at an "all hands-on deck" moment. If we do not lead the global science and technology enterprise, China will. But in challenge there is also opportunity, and the good news is that if we capitalize on the strong foundations of our research ecosystem and the talents of all our people, we are well poised to maintain our lead in S&T. Opportunities abound for creating new partnerships and strengthening those already established – among government agencies, universities, and industry; across scientific disciplines; and among scientists who span the globe.

The freewheeling creativity and competitive, entrepreneurial ethos that infuses our researchers is the "secret sauce" of America's scientific enterprise. The bedrock of our research ecosystem is the freedom we give our researchers to explore new frontiers and see where discovery leads them. Time and time again, the freedom of inquiry enabled by federal support for fundamental research through NSF and other government agencies has led to surprising new knowledge that advanced our nation in unexpected, unpredictable ways. As President Ronald Reagan noted, "The remarkable thing is that although basic research does not begin with a particular practical goal, when you look at the results over the years, it ends up being one of the most practical things government does."

Fifty-five years ago, President John F. Kennedy challenged Americans to shoot for the Moon. Our national commitment to winning that race, and our belief that we could do anything we put our minds to, spurred creative collaboration and competition that resulted in science and technology advances that have benefited every one of us, far beyond the original goal. Today, we should be inspired by the spirit to once again dream boldly and take risks in the pursuit of fundamental knowledge and innovation. Maintaining our global leadership will require increased efforts from both government and industry, working in partnership with our universities. Together, we can pursue grand visions, enable revolutionary ideas, and see what unexpected advances may emerge from asking fundamental scientific questions. To write the next chapter in the story of science and of our nation, we should continue to let discovery be our guide.