Testimony of
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"Losing Ground: U.S. Competitiveness in Critical Technologies"

Since World War II, advancements in science and technology have driven much of our economic growth, underpinned our national security, and transformed nearly every aspect of Americans' daily lives. New technologies built on federally funded discovery research have led to new businesses, revolutionized health care, and created the mobile, digital world.

Our preeminence has not happened by chance. Sustained, bipartisan commitment to investing in basic research has played a key role in establishing and maintaining our knowledge ecosystem and the innovation-driving partnership among academia, government, and the private sector. As we think about what our country needs to compete in the 21st century global economy, we must renew our commitment to strengthen this key component of our national infrastructure and ensure that we are not technologically surprised in critical technologies like quantum computing and artificial intelligence. Collectively, we must do this because the world has changed, and our country has changed – and while science is the endless frontier, we are **not** the only explorers.

The data in *Science & Engineering Indicators 2020*, released two weeks ago by the National Science Board (NSB), illustrate this new global context.[1] Science and engineering (S&E) is now a truly worldwide enterprise, more connected and complex, with more players, more opportunities everywhere, and humanity's collective knowledge growing exponentially. This dynamic multipolar landscape is characterized by interdependence as well as competition. While future American preeminence is not assured, we should react with excitement, not fear to this new world. We are well positioned to compete, collaborate, and thrive.

Freewheeling creativity, an entrepreneurial ethos, and the exchange of talent and ideas across sectors are hallmarks of America's S&E enterprise. A wonderful example can be found in the story of last year's Nobel Prize in Chemistry. After arriving in the U.S. to take up a postdoctoral fellowship at Stanford University, Dr. Stanley Whittingham's research in basic chemistry focused on the phenomenon of intercalation in solid materials. His work led him to propose that these materials could be used as electrodes in powerful batteries.

[1] *Science & Engineering Indicators* is prepared under the guidance of the NSB by the National Center for Science and Engineering Statistics, a federal statistical agency within the National Science Foundation.

Using superconducting materials and lithium, he invented the rechargeable lithium battery while working as a research scientist at Exxon, which was interested in developing alternatives to gasoline-powered vehicles during the oil crisis of the 1970s. Dr. Whittingham was granted the original patent on the concept for this type of battery, and his foundational research, developed further by his co-laureates, ultimately led to the invention of rechargeable lithium-ion batteries – which now power everything from cars to the mobile phones we hold in our hands.

This story encapsulates many of the strengths of our S&E ecosystem – support for basic science from both the federal government and the private sector, welcoming of talent from around the globe, and giving the best minds the freedom to explore new frontiers and see where discovery leads them. This freedom of inquiry enabled by federal support for basic research through NSF and other government agencies has led to surprising new knowledge that has 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." Over the past seventy years, NSF has supported 242 Nobel Prize winners, including Dr. Whittingham, who has received thirty NSF awards in his illustrious career. History has shown that the risks taken by the federal government to fund such creative researchers and bold ideas has paid off time and time again, with all sectors of our knowledge ecosystem partnering to drive innovation.

U.S. Research and Development in the Global Context

Since 2000, global research and development (R&D) investments have tripled, reflecting increased competition in knowledge-intensive industries and recognition of the crucial role R&D plays in addressing global health, security, and environmental challenges. *Indicators 2020* confirms a trend that NSB has observed for several years: while the U.S. remains a leading player, other countries have seen the benefits of investing in research and education and are following our example.[2] The world of R&D performance, historically centered around the U.S., Western Europe, and Japan, has been shifting toward East and Southeast Asia.

U.S. spending on R&D grew modestly between 2000 and 2017, averaging 4.3% growth annually, driven mainly by the business sector. Business has been the largest funder of total R&D in the U.S. since the 1980s (currently 70% of the total). Even with this growth, since the beginning of this century our global share of R&D has declined from 37% to 25%. This is a pattern that we see repeatedly in *Indicators 2020* – that while the U.S. S&E enterprise is growing in absolute terms, the global S&E enterprise is growing faster and consequently the U.S. share of discovery is dropping.

While China is not the only story, its dramatic annual rate of R&D investment sets the country on a path to soon becoming the world's largest R&D performer.[3] If we look at the changes in global R&D expenditures since 2000, China has accounted for almost one-third of the total global growth. It is worth noting that the majority of the rise of China's R&D expenditures have been in experimental development.

In 2018, the NSB issued a statement noting that China would likely surpass the U.S. in total R&D expenditures by the end of 2018.[4] The most recent data show that there was higher than projected growth in U.S. R&D, primarily due to increased business expenditures in experimental development. In fact, in 2017 the U.S. spent more on R&D than any other country: $548 billion. Even so, the trend lines in Figure 1 suggest that in 2019 China may have surpassed the U.S. in **total** R&D expenditures.

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[2] National Science Board (2020). "Research and Development: U.S. Trends and International Comparisons," *Science & Engineering Indicators 2020*. NSB-2020-3.
[3] Performer is defined in the OECD Frascati manual, pg. 377.
[4] National Science Board (2018). "Statement on Global R&D Investments." NSB-2018-9.

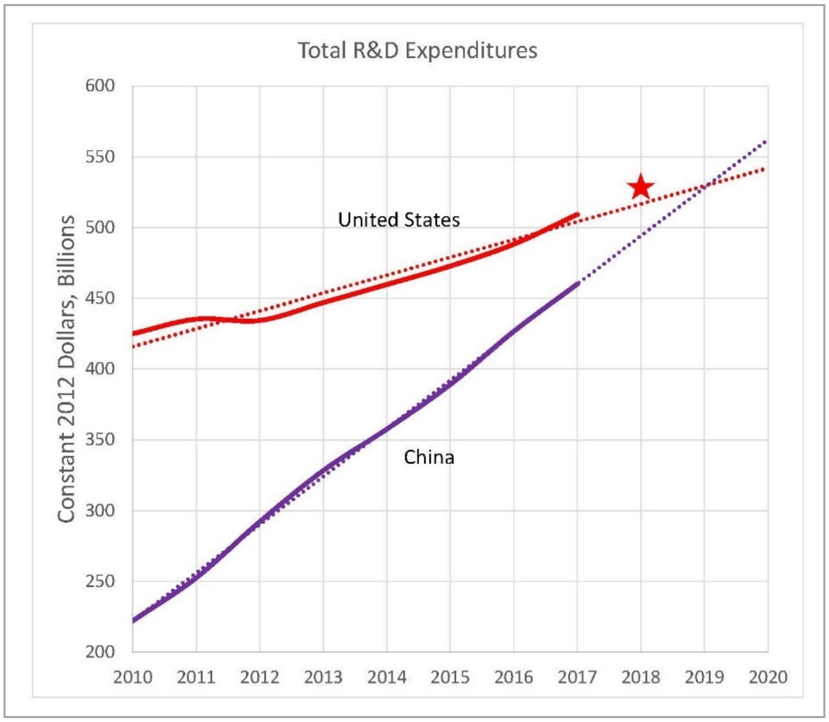

Figure 1: Gross Expenditures on R&D for the U.S. and China

Amid this dramatic growth in China's R&D investment, it is crucial to note that the U.S. maintains a significant advantage in *basic* research – the seed corn for our entire S&E enterprise. In 2017, the U.S. invested $92 billion in basic research; China came in a distant second, investing $27 billion.

While the lion's share of business investment continues to be on the development side, the business sector is also now the largest funder of basic and applied research at 43% (compared to the 38% share from the federal government). Industry's commitment to basic and applied research is a strength for our S&E ecosystem, which is built on partnerships across sectors. It is worth noting that business basic and applied research is concentrated in a few areas, with much of their investment occurring in pharmaceuticals, transportation, and computing. Federal basic and applied research investments complement and underpin these private sector investments. Furthermore, only the federal government can make a strategic, long-term commitment to creating new knowledge across *all* fields of science and engineering – including areas that cannot be anticipated to lead to new or improved technologies, goods, or services – and support risks that are difficult for the private sector to undertake.

We Must Adapt

American preeminence in S&E has shaped our way of life for seven decades. As we look to the future, one thing we can be sure of is that scientific discoveries and inventions will continue to open new, unexpected frontiers. The U.S. is no longer the uncontested world leader in S&E, and so we cannot be complacent in the face of these changes. **We must adapt.**

Why is U.S. leadership in S&E so important? From quantum computing to artificial intelligence (AI) to the data revolution, scientific advancements come with both opportunities and risks. To mitigate those risks in a competitive world, it is essential that we stay at the forefront of science and cutting-edge research. The U.S. will not regain its share dominance, so we must be proactive, and ask - what do we need to do *now* to *continue* to be a global S&E leader in the coming decades?

Continue robust federal funding for basic research

> *"There is…the risk a society runs when it falls into the habit of responding to long-term risks with short-term solutions…. It is the ceding of technical and scientific leadership to China. It is the innovation that never occurs, and the knowledge that is never created, because you have ceased to lay the groundwork for it. It is what you have never learned that might have saved you."*
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> *– Michael Lewis*

We know that China and other nations are actively working to lead in critical technologies that hold enormous promise for revolutionizing our world. The White House and Congress are stepping up to meet this challenge, with increased focus and investment in key areas of S&E research and development. With sustained federal investments, the Administration is advancing U.S. leadership in Industries of the Future: AI, quantum information sciences, 5G/advanced communications, biotechnology, and advanced manufacturing R&D. The NSB applauds these efforts – it is wonderful to see the influx of national attention and both public and private sector investment in these areas – and believes that NSF will continue to play an essential role in addressing fundamental questions in these fields as we go forward.

Many of these research areas are now ripe for an explosion of public and private investment in part *because* NSF supported early-stage research in these fields years ago. Public funding of basic research is a sustained commitment over a long time horizon, and a competitive advantage for the U.S. 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. So, in addition to furthering the development of cutting-edge fields that are widely recognized as important to our nation's competitiveness, at its core, a central mission of NSF is to ask: what is the *next* big thing? NSF is the only federal agency that supports basic research in and among *all* areas of science and engineering. Identifying the most promising, creative ideas of America's research community, through rigorous peer review, is what will lead to the transformative discoveries that will shape our world decades from now.

In anticipating what's next for our nation's S&E ecosystem, it is also important to recognize the interdependent roles in our current one. A basic research agency like NSF has significant differences in scope and time horizons from private business and mission agencies. Partnerships among and between the federal government and universities, between universities and the private sector, and those with non-profits have led to a system in which the federal government supports 42% of basic research, including the high risk, long-term basic research that the private sector is not positioned to undertake. Universities perform nearly half of U.S. basic research, with industry funding and performing a majority of applied and developmental work. These investments set the table for directed research of the mission agencies and the private sector. For example, it is worth noting that the percentage of U.S. patents *derived from government-funded research* is near an all-time high.[5]

We need to formulate a strategy for federal investment in basic research that considers current national needs and competitive opportunities *and* lays the groundwork for future discoveries. An effective plan, built on a holistic evaluation of our national research portfolio – including the private sector – and a recognition that the best ideas come from researchers, would help us match our strategic priorities with our investments. Our vision of the future cannot be limited to competing with other countries in current areas of global importance. To pursue the next "big thing," our brightest minds will need the time, space, and resources to scout the path to new frontiers.

Yet although NSF's funding has grown in real terms, NSF's funding rate for research grants has fallen from 33% (total submitted proposals: 29,508) in 2000 to 21% (total submitted proposals: 40,678) in 2017, leaving

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[5] Fleming et al. (2019). "Government-funded research increasingly fuels innovation," *Science*, 364(6446) 1139-1141.

$1.6 billion in great proposals unfunded.[6] When that happens, a researcher may leave the country to pursue his/her work, submit the proposal elsewhere, perhaps to one of our international competitors, or the idea may die in the intellectual dustbin of unfulfilled promise, as the researcher drops the line of inquiry, or – worse – leaves S&E for another career.

To attract, develop, and retain S&E talent, and to be competitive in developing critical technologies of today while also searching for the breakthroughs of tomorrow, the nation needs **robust, sustained** federal funding for basic research. Overall, the federal government's share of R&D funding has declined since 2000; government spending on R&D now is 0.7% of GDP, as compared to 1.69% in 1960. We thank you for the strong, bipartisan support shown for NSF in FY 2019 and FY 2020. But this upward turn is not enough to keep up with the accelerating pace of global research and the new global bidding war for the world's best S&E talent.

Be a magnet for talent

> *"We've arranged a civilization in which most crucial elements – transportation, communications, and all other industries; agriculture, medicine, education, entertainment and protecting the environment; and even the key democratic institution of voting – profoundly depend on science and technology. We have also arranged things so that almost no one understands science and technology."*
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> *– Carl Sagan, "With Science on Our Side," The Washington Post, January 9, 1994*

To produce results, R&D investments must be coupled with building a highly skilled, STEM-capable workforce, including everyone from skilled technical workers to PhDs. Demand for people with S&E skills keeps growing, driven by international opportunities and competition, and by disproportionate growth in the number of jobs at all levels that require STEM skills, including lines of work that historically did not require S&E knowledge. As of 2017, nearly 21 million U.S. workers with at least a four-year degree say that their job requires a "bachelor's level" of STEM expertise. The majority of these workers (71%) are employed by the business sector, the cornerstone of our nation's global economic competitiveness. Industry and the Federal government report that they are unable to find enough workers at all levels with enough STEM knowledge and skills. This situation will only become more urgent: by 2026, S&E jobs are predicted to grow by 13% compared with 7% growth in the overall workforce.

The U.S. has long relied on foreign-born talent to help meet its S&E job needs at the bachelor's and advanced degree levels, and this dependence has increased significantly over the last 25 years. As of 2017, over 40% of our doctoral-level S&E workforce was foreign-born, and in most S&E occupations, the higher the degree level, the greater the proportion of the workforce that is foreign-born.[7] In computer sciences, mathematics, and engineering – fields that are crucial to many of the Industries of the Future – nearly 60% of PhD holders in the U.S. workforce are foreign-born (Figure 2), and over 50% of the U.S. doctoral degrees awarded in these fields since 2010 were earned by foreign-born students.

At the same time, the U.S. share of internationally mobile students has declined slightly, even as the number of these students has risen dramatically worldwide. Between 2015 and 2017, the number of foreign students enrolled in graduate study in natural science or engineering programs in the U.S. decreased by 7%.[8] Since 2003, there have also been notable declines in the "stay rates" for the two largest source countries for

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[6] Report to the National Science Board on NSF's Merit Review Process, Fiscal Year 2017, NSB-2019-15.
[7] National Science Board (2019). "Science & Engineering Labor Force," *Science & Engineering Indicators 2020*. NSB-2019-8.
[8] National Science Board (2019). "Higher Education in Science & Engineering," *Science & Engineering Indicators 2020*. NSB-2019-7.

international students – China and India – as more of those students leave the U.S. within five years of earning their degree.

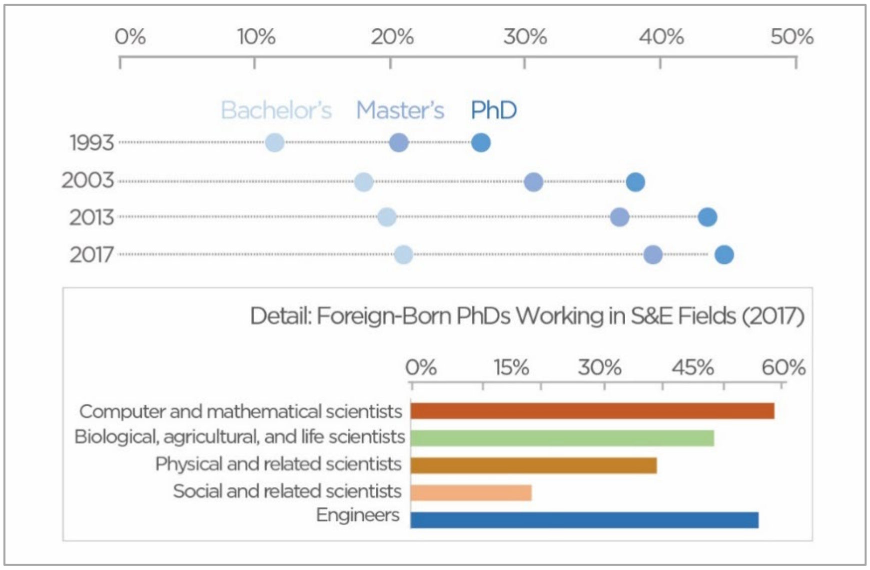

Figure 2: Percent of U.S. S&E Workers who are Foreign-Born

More countries than ever are now competing for the best minds, and these individuals have choices today that did not exist as recently as 20 years ago in selecting a place to study, perform research, and innovate. Some of our competitors have adapted their immigration policies to make it easier for highly skilled S&E workers and STEM students to work or study in their countries. Amid this global bidding war for talent, we can no longer take it for granted that the U.S. will remain the destination of choice. Even under the most optimistic scenarios for domestic talent development, in the near and medium term the U.S. will remain reliant on foreign talent. As such, we must ensure that international students and workers who choose to come here feel welcome and secure. We must also provide a research environment that is a magnet for *all* individuals who want to pursue S&E education and careers – both domestic *and* foreign.

In this new global context, relying on an ever-increasing influx of individuals from other countries is not a sustainable long-term strategy for maintaining a thriving, competitive U.S. S&E enterprise. Our ability to discover, invent, and innovate relies on our ability to develop, attract, and retain our *domestic* S&E talent while continuing to welcome researchers from around the world. We must ensure that our S&E enterprise is a magnet for curious, creative, ambitious Americans from all backgrounds who want to explore, to solve problems, and to make the world a better place. And we must recognize that STEM is no longer just for scientists and engineers, and adapt accordingly.

The NSF Act directed the agency to "strengthen research and education in the sciences and engineering… throughout the United States, and to avoid undue concentration of such research and education." The Board strongly agrees with this charge – no zip code or demographic should be unable to participate in the S&E economy, and we need *all* of our domestic talent if we want to compete in this era of globalized discovery. It is the responsibility of *all* of us to ensure that our domestic S&E talent is nurtured at every educational level, among all demographic groups, and in every region of the country. Congress, the Administration, government at all levels, business leaders, educators, and other decision-makers must work together to build a more inclusive STEM enterprise, upgrade our education system to prepare students with the skills they will need, and ensure robust pathways at all educational levels into S&E jobs. For the U.S. S&E enterprise truly to flourish, it must reflect the nation's diversity. Our message must be unified and clear: STEM is for **all**

Americans. And just as illiteracy is not considered a virtue, it can no longer be acceptable to be "bad at math."

Efforts to develop our domestic talent must begin at the K-12 level. Despite the emphasis on STEM education in recent years, U.S. students consistently rank below students in many other nations in science and math. Based on test scores, U.S. science and mathematics education at the elementary and secondary level is mediocre relative to other nations, and U.S. student performance has been stagnant over the last decade.[9] To improve student performance, we must redouble our efforts to ensure that all students develop STEM skills and adapt our educational system to teach the skills of today and the future, including critical thinking, problem-solving, creativity, and digital literacy. This undertaking will require coordination and renewed investment by many entities including government at all levels, public and private educational institutions, and industry, as well as a concerted effort to bring the best research-based STEM pedagogy and practices for diversity and inclusion to the classroom. For its part, the NSF invests in all levels of STEM education research, from pre-K-12 through graduate education, and has placed an emphasis on broadening participation in the sciences through programs such as its INCLUDES Big Idea.

Post-secondary STEM education and workforce development efforts must likewise welcome and serve individuals across all geographic locations and economic, racial, and ethnic backgrounds. The racial and ethnic composition of S&E degree recipients has changed over time, reflecting population changes and increasing rates of higher education attainment by members of underrepresented minority groups. Turning to the S&E workforce, the data show that the numbers of women and underrepresented minorities – blacks, Hispanics, and American Indians and Alaska Natives – have increased. Since 1993, the numbers of underrepresented minorities with their highest degree in S&E collectively increased nearly four-fold. The number of women in S&E jobs or who hold a bachelor's degree or higher in S&E has doubled since 1995. However, these increases were outpaced both by the rapid growth of S&E jobs as well as minority population growth, so that women and minorities remain underrepresented relative to their proportions in the U.S. population.

As the NSB underscored in our recent report, *The Skilled Technical Workforce: Crafting America's Science and Engineering Enterprise*, to meet the need for a STEM-capable workforce that can fuel our competitiveness, we must place emphasis on skills as well as degrees and embrace a pathways model to post-secondary STEM education and workforce development.[10] We need to remember that education is a public good, and that public universities and colleges, including community colleges, have a special role to play in providing access to high quality STEM education to students in every state. We must provide our citizens with the problem-solving skills needed for the lifelong learning that is now required to adapt and thrive in a rapidly changing job market, one often driven by advances in S&E. To achieve these outcomes, we must facilitate and deepen partnerships between educational institutions and industry to prepare individuals for the industries of the future.

While the need to improve our K-12 STEM education and to build a STEM-capable U.S. workforce are not new challenges, rising global competition, the increasing importance of S&E to our economy and security, and to individual opportunity make finding ways to move the needle on math and science competency and build a truly inclusive STEM-capable workforce more vital than ever.

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[9] National Science Board (2019). "Elementary and Secondary Mathematics and Science Education," *Science & Engineering Indicators 2020*. NSB-2019-6.

[10] National Science Board (2019). "The Skilled Technical Workforce: Crafting America's Science & Engineering Enterprise," NSB-2019-23.

Conclusion

As we see in *Indicators 2020*, there is more competition, collaboration, and knowledge production across the global S&E environment than ever before. Other countries are rapidly adopting the blueprint that has driven U.S. S&E leadership, economic prosperity, and security for the past seven decades.

It is important to remember that healthy competition in S&E benefits all of humanity. This global competition for talent and ideas is a challenge that will spur us to up our game.

Yet there is no denying that America's S&E enterprise faces headwinds, that if unaddressed, risk the S&E global leadership that we have enjoyed since 1950. As other countries invest in their S&E enterprises, ours is transitioning toward a smaller share of global discovery and innovation. Unless we take steps now, we could fall behind as other countries attract globally mobile scientists and engineers and we continue to make slow progress in fully developing our domestic talent. These factors could lead to future critical technologies being developed elsewhere, with potentially devastating impacts on our economy and national security.

To remain competitive in this new global environment, we must adapt more quickly through partnerships and collaborations, reaffirm our values, give Americans the STEM education, knowledge, and skills they need to thrive, and ensure we have the infrastructure and resources to provide a home for the world's best talent and ideas.

As I conclude, I return to the story of Dr. Whittingham, now at the State University of New York, where his continuing work to improve battery technology has been supported by NSF for over 30 years. He discovered a fundamental chemical property of specific solid materials, and *then* saw the potential applications of his discovery – taking him down a new, unexpected path that led to an invention that changed our world. Stories like this are why we need to attract and fund the best *people*, as well as the best ideas. For the U.S. to maintain preeminence in S&E, we need to develop and attract the best minds. Then we must give them the time and space – and resources – to explore, to not be sure exactly what they might find, or why it might be useful; but being sure in the knowledge that discovery will ultimately reap huge, unexpected benefits for humanity. We know this because we have seen this story of unleashed creativity play out, over and over again. It is what has brought us the technology-driven world we live in today – and it is what will bring us the innovations that will shape our tomorrows.

So what should we do as we look to the future? We believe that our nation should **be fearless**. We should look beyond anxieties about global competition, challenges to scientific openness, or current budget limitations. Instead, we should ask how we can lead the next era of science and engineering - embracing America's identity as the land of opportunity, remembering the can-do attitude that defines our people, and racing to lead a future in which ideas are forged on a global scale. We can do this if we unleash the strength of our values – a spirit of exploration, of wonder, of discovery; coupled with a willingness to take risks and an emphasis on freedom and individual creativity – to ensure America's continued preeminence in research and innovation in the 21st century.

Because the best way to lead the future is to invent it.

Diane L. Souvaine

Biography

Computer Science and Mathematics
A.B. c.l., English & Mathematics, Harvard University
M.A.L.S., Mathematical Sciences, Dartmouth College
M.S.E., Electrical Engineering & Computer Science, Princeton University
M.A., Computer Science, Princeton University
Ph.D., Computer Science, Princeton University

Dr. Diane L. Souvaine, Professor of Computer Science and Adjunct Professor of Mathematics, has been a member of the Tufts University faculty since 1998. She served as Vice Provost for Research from 2012-2016, Senior Advisor to the Provost from 2016-2017, and Chair of the Department of Computer Science from 2002-2009.

Prior to Tufts, Dr. Souvaine was a member of the Rutgers University faculty for 12 years. During her tenure at Rutgers, she served for 2.5 years in the Directorate of NSF's Science and Technology Center for Discrete Mathematics and Theoretical Computer Science (DIMACS), a groundbreaking academic/industry collaboration of Princeton, Rutgers, Bell Labs and Bellcore. DIMACS is tasked with both the theoretical development of mathematics and computer science and their practical applications.

Dr. Souvaine's research contributions range from solving challenging problems in computational geometry to practical application across disciplines. Her work extended the results of straight-edged computational geometry into the curved world. Visibility, triangulations and geometric graphs represent another focus of Dr. Souvaine's research as does the application of computational geometry to statistics. Her research led to consulting engagements with corporations such as Exxon Chemical Research, IBM and Pfizer.

Elected Chair in 2018, Dr. Souvaine is in her second term on the National Science Board to which she was appointed in 2008 and 2014. She previously served as Vice Chair from 2016-2018, has chaired NSB's Committee on Strategy and Budget and its Committee on Programs and Plans, and served on its Committee on Audit and Oversight, all of which provide strategic direction, and oversight and guidance on NSF projects and programs.

In addition to her scientific and policy contributions, Dr. Souvaine is dedicated to increasing diversity and advancing women and underrepresented groups in mathematics, science, and engineering and works to enhance pre-college education in mathematics and computational thinking.

Dr. Souvaine is a Fellow of the American Association for the Advancement of Science (AAAS) and of the Association for Computing Machinery (ACM), and was a 2005-2006 Fellow of the Radcliffe Institute for Advanced Study. Among many other accomplishments, she was the recipient of the 2008 Lillian and Joseph Leibner Award for Outstanding Teaching and Mentoring.