A Research Infrastructure for Maximizing Public Value of Science

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Introduction

Madam Chair, Members of the Committee, it is a privilege to testify today. Thank You. My name is Mahmud Farooque. I am the Associate Director of the Consortium for Science, Policy and Outcomes (CSPO) and a Clinical Associate Professor in the School for the Future of Innovation in Society (SFIS) at Arizona State University. I am also the Principal Coordinator of the Expert and Citizens Assessment of Science and Technology (ECAST) Network.

I come before you to express my personal views on the questions posed about the challenges and opportunities before us as a nation, the role of the National Science Foundation in meeting those challenges, and the opportunities the NSF has to integrate public values and societal outcomes while leveraging the advances it has seeded in science and engineering research, education and engagement.

I offer these views on the basis of my over thirty years of combined academic training and professional experience of working in the public, private, non-profit and academic sectors. My circuitous journey began when I left Bangladesh at age of 19 to come to the U.S. to pursue undergraduate education in engineering. I worked first as a student and then as a professional in the US energy and petrochemical industries. I became disillusioned by the lack of attention to social and environmental concerns and decided to pursue graduate education in Public Administration and Public Policy in science and technology. Yes, I was an early contributor to the leaky pipeline problem in STEM.

After my PhD, in the second phase of my professional career, I directed research collaborations at the City University of New York, led research development in physical science and engineering at Northwestern University, and directed transportation research at a Purdue University-led consortium, before coming to the ASU Washington Center eleven years ago.

I offer the evidence for my support of this bill in three segments. The first segment is informed by my education and research of the evolution in U.S. science and technology policy. I use it to express how I view our present-day innovation challenges at the national and global scales. The second segment is informed by my work at the interface of scientific research and practice at CSPO. I use it to point to some contemporary opportunities and challenges that are within NSF's purview to address through a shift from an input-output to an outcome-oriented paradigm. The third and final segment is informed by my role as a scholar practitioner in public engagement. I use it to point to the promising developments of recent years and what is needed to define, operationalize, measure and ensure the success of public engagement in science.

Introduction: NSF for Futures

In general, the NSF for the Future Act is a bold step in the right direction. It offers an opportunity to address questions that are longtime in the making: How can we make science useful for society as we simultaneously advance knowledge and discovery in real time? How might we ensure that our decisions about science and technology enhances society's pursuit of equality, justice, freedom, and overall quality of life? How might our science and technology investments, developments, and outcomes more fully reflect our public values?

As I describe in the second and third segments, NSF has already been funding and supporting research that has taken on many of these questions, some of which continue to create social benefits and impact. What the bill does is that it provides the same type of support infrastructure and affordance NSF currently provides for research oriented towards market outcomes to research oriented towards public value outcomes. It is additive and not substitutive and it is informed by the most pressing social challenges that can only be addressed through increased seeding of new and rapidly scaling of existing inter and transdisciplinary research, education and engagement.

I. Technological Change and Social Transformation

I begin with a question the famous Evolutionary Economist Richard Nelson asked almost 50-years ago:

> "Why was it that a country that recently had accomplished the truly remarkable feat of sending a man to the moon and bringing him back to earth safely, had wiped out scourges like infantile paralysis, and more generally had achieved an historically unprecedented standard of living for the middle class, for some reason seemed unable to provide an effective education for ghetto kids, halt or significantly slow down the rising cost of medical care, keep the air and water clean, or cut down on the incidence of drug addiction and drug-related crime?"

Revisiting the question about ten years ago, Nelson concluded that the dilemma behind tremendous successes in technological advancements and persistent failures in certain social realms can be found in the design, composition and orientation of our national innovation system. Indeed, the national innovation system is a powerful determinant of the variation among the technological development of different nations. A country's national innovation system comprises the networks of public and private institutions that fund and perform R&D, translate the results of R&D into commercial innovations, and influence the diffusion of new technologies.

However, national innovation systems are not static. Historical accounts of industrial development reveal two important relationships between technological advancement and economic development of nations. First, it shows that technological advancement by itself was not enough for sustained technological leadership; complementary innovation in the realm of institutional and social systems was required to sustain the advantages brought about by advances in science and technology. Second, the nature and characteristics of technological innovation vary not only over time but also across industries, cultures and regions.

Through World War II, the federal government became the chief benefactor of science in ways not known before. The success of the Manhattan project, whose research budget in some years exceeded that of the Department of Defense, demonstrated the power of organized science for a cause that now appeared to be intricately tied to national welfare. In the blueprint for post war science, *Science, the Endless Frontier* (Bush, 1990/1945), the basic features of this scientist-driven model were not only retained but given a permanent institutional cushion that placed unquestioned faith in the power of curiosity-oriented basic science and did everything to shield it from market forces by arguing that the benefits of science are not predictable. This model treated science as the sole driver of technological innovation with the implicit argument that curiosity-oriented research would ultimately lead to new technologies, which would yield handsome financial returns and critical national security benefits.

Between 1945 and 1965, a wide-spread consensus emerged surrounding this governing model. The rise of productivity at a faster rate than any other industrialized country, coincided with a rapid increase in R&D spending with the result that in 1969, the total expenditures in the United States was more than twice of the combined total of France, West Germany, Britain and Japan. As Historian Bruce Smith noted, this left very little room to challenge the belief that there was no need for a self-conscious strategy to promote innovation. There was some tinkering at the edges with various patent laws and tax incentives, but nothing strategic.

Smith notes that beginning from the mid 1960s, the post-war consensus began to show signs of cracks. Rachel Carson's *Silent Spring* ushered in a new era of environmental consciousness while Ralph Nader's *Unsafe at any Speed* stimulated long drawn out crusades against corrupt corporate interests. Social impacts of science and technology, not previously considered a part of basic research driven science policy, began to enter the political discourse. Productivity gains began to erode along with the unquestioned domination of U.S. firms in the global markets. The cushion of financial security enjoyed by scientists began to fade as pressures for early payoffs began to intensify. The reduction in public support, in turn, prompted the merit-based award system to cause increasing rivalries and frictions among funded and unfunded institutions. The diffused nature of the problems magnified the cracks in the system, producing wide public skepticism and doubt about science's ability to lay the basic foundation of a better life for all citizens.

Many of these domestic challenges coming to a head during the 1980s reached mission critical status when deep seated concerns began to sweep across many U.S. industries from automobiles to semiconductors about our ability to compete with Japan. For example, although transistors and integrated circuits were both invented in the U.S., manufacturing quality in Japan far exceeded that found here. This quality lag had a serious consequence as U.S. manufacturers steadily lost market share to their Japanese competitors.

Faced with social and economic anxieties and perhaps the most significant challenge to its post-war innovation system, the U.S. mounted a very complex and multi-pronged response. During President Reagan's time in office bi-partisan faith in basic science led to substantial increases in research funding at NSF and the Department of Defense (DOD). On the civilian R&D side (including for NSF) funding increases were accompanied by an emphasis on actively advancing the technological frontiers. Congress enacted the Bayh-Dole Act to incentivize universities to accelerate technology transfer. Industry helped lead government-industry-university consortia like the Semiconductor Research Corporation and SEMATECH. For its part, the NSF created Engineering Research Centers and added relevance and effect criteria in the peer review process for awarding research grants.

Efforts to link research with national goals continued in the 90s with the addition of the Critical Technologies Institute at RAND by DOD, the Advance Technology Program at National Institute of Standards and Technology (NIST), and the IGERT program by NSF. By the late 1990s the governing paradigm of the US innovation system made an appreciable shift towards use inspired science. With other federal agencies following suit, universities rushed to set up technology transfer offices, start-up incubators and research parks.

Through this period, the U.S. successfully responded to the challenge to its innovation system by setting a different climate for research and development, surveying critical technologies, coordinating linkages between university, industry and government and filling gaps by creating bridging programs and institutions. And it did all that without altering the characters of its foundational research and development institutions.

Yet the fundamental problem articulated by Richard Nelson remains unaddressed. With a few substitutions, we can ask a very similar question today:

> "Why is it that a country that recently landed a second Rover on Mars, sent a new crew to the space station and brought the old crew back to earth safely, developed not one, but three effective vaccines for a runaway global pandemic in record time, and more generally has led the world in research and development funding for 70 years, seems unable to avert the untimely death of a half a million of its citizens in just one year, unable to provide equity, justice and basic standards of living for millions of its citizens living in poverty and facing discrimination, powerless to halt or significantly slow down the rising cost of medical care, unable to keep the air and water clean and our neighborhoods safe, and struggling to protect our democracy from falling victim to misinformation and manipulation?"

It is my observation that this is in part because the innovation system, despite strengthening its linkages towards use, has remained fixated on market outcomes. We have continued to rely on the linear model of innovation through our default assumption that more money invested in R&D will create more patents and journal articles and more scientists and engineers, which would in turn power economic growth and provide benefits to our fellow citizens. But as my colleague Dan Sarewitz testified to this committee in 2010, the basic "problem with an input-output oriented model is that it can't tell us very much about what actually matters." The problem is particularly consequential when we are dealing with post-normal science challenges characterized by uncertain facts, disputed values, high stakes and urgent decisions. We face such decisions in emerging science and technology issues such as geoengineering, gene editing, and managing a global pandemic. How can we make science useful for society as we simultaneously advance knowledge and discovery in real time? How might we ensure that our decisions about science and technology enhances society's pursuit of equality, justice, freedom, and overall quality of life? How might our science and technology investments, developments, and outcomes more fully reflect our public values?

These are the questions I found myself asking and pursuing after I joined CSPO.

II. Science for Society

The Consortium for Science, Policy and Outcomes (CSPO) was formerly launched in 1999 as a center of Columbia University and relocated to Arizona State University in 2004. When I arrived in 2009, CSPO was involved in different phases of three consequential NSF funded projects.

1. **Usable Science:** Science Policy Assessment and Research on Climate (SPARC) was a five-year joint project funded by the National Science Foundation (NSF) under its Decision-Making Under Uncertainty program to assess the effect of climate research on decision-making and how this process can enhance societal values. The project helped operationalize the concept of reconciling the supply of and demand for (RSD) scientific information. It led to the publication of a handbook on usable science, documenting best

practices across a broad spectrum of federal agencies, and produced a series of reviewed articles and case studies. Among its tangible impacts were a robust network of practitioners and scholars advancing the connections between science and decision making outcomes.

2. **Social Implications**: The Center for Nanotechnology and Society (CNS) was a Nanoscale Science and Engineering Center that received two rounds of funding from NSF. CNS was a test bed for "real time technology assessment (RTTA)", which aimed to build capacity to understand the linkages between new knowledge, emerging innovations, and societal outcomes as they were unfolding. It trained a community of scholars with new insights into the societal dimensions of nanoscale science and engineering (NSE), engaged the public, policy makers, business leaders, and NSE researchers in dialogues about the goals and implications of NSE, and partnered with NSE laboratories to introduce greater reflexiveness in the R&D process. The center contributed to concepts important for managing emerging technologies for societal benefit now in use in NIH-funded research on human genome editing. The center also helped develop Participatory Technology Assessment (pTA), an engagement model that seeks to improve the outcomes of science and technology decision-making through dialog with informed citizens, that's been used by several federal agencies and philanthropic organizations.
3. **Public Value Mapping**: The program, supported by NSF's Science of Science and Innovation Policy program with supplemental support from the V. K. Rasmussen Foundation and the Rockefeller Foundation, was designed to develop a non-economic model for assessing the social value of science and innovation policy. The model used a method called Public Value Mapping (PVM) in detailed case studies to evaluate several S&T policy issues such as technology transfer, natural hazard research, nanotechnology for cancer treatment, environmental chemistry, and climate research. The studies indicated instances where scientists, agency staff, legislative mandates, and various stakeholders expressed public values that were in strong coherence with each other (as was the case with natural hazard research at the US Geological Survey) or where they were in conflict with each other (as was the case with US Global Change Research Program). In the latter case the finding of public value failure led to programmatic changes and course corrections.

Reflecting on all that has happened in the projects above in which NSF-funded socially beneficial research and practice, there is a lot to celebrate. However, it is doubtful that the ways in which CSPO applied that funding could be easily replicated elsewhere. As I mentioned in my brief biography, prior to coming to CSPO and ASU, I had the privilege of working at other universities, mostly in the areas of physical and natural sciences. I can attest that what happened here could not have happened in any of those places. The explanation is simple. The incentives, infrastructure, training and collaboration opportunities for societal-outcome oriented research were just not there. ASU is a unique institution, where departmental silos have been broken down and use-inspired research has been written into the design principles for the university's structure and work.

If the NSF is to support scientific research that maximizes social return and public value, it must find a way to do so differently from how it does now. For example, the standard review criteria of intellectual merit and broader impact need to be revised and broadened to include public values and goals. In this spirit, research should prioritize collaborations with civic partners, government, and industry so that the knowledge, know-how, and technologies that come from research can be tested and deployed in the real world. Training programs for graduate students should include these same emphases so that science and engineering are not treated as separate of societal and ethical concerns. These suggestions are connected by a concern for public values alongside market and scientific ones.

This may appear daunting, but NSF will not be starting from scratch. The NSF has funded projects focused on generating social returns from research, as well as generating research agendas based on social needs, beyond the projects mentioned above. NSF's existing Civic Innovation Challenge requires specific civic needs to drive research and action and requires that civic partners help define research questions and approaches. NSF's Long Term Ecological Research Program (LTER) has funded urban ecological research sites that have worked alongside regional and local governments to conduct research relevant to problems on the ground, as well as fundamental knowledge about ecological systems. In the same way that NSF's I-CORPS program and others support entrepreneurship, an NSF that supports research for public value should support programs that create incentives, training, and institutional structures for linking research and public values.

We are once again at a potential moment of major transformation of our national innovation system. As I described, seventy five years ago Vannevar Bush gave us a blueprint for a post-war research enterprise primarily focused on knowledge creation. This enterprise served us well until we were faced with a challenge in the 1970s, and we responded with deliberate, strategic, sophisticated policy and investments to add a new use-inspired focus to our innovation system. This focus helped us build better linkages between knowledge production and use, transforming our public R&D institutions to generate knowledge with these dual purposes. The institutional transformation again served us well for thirty years.

Increasing the input-output of the current system will not be enough to meet this moment. There is no vaccine that is going to magically rid us of deep-seated social, environmental, economic and political challenges. The tools that we used successfully to respond to 20th century challenges are inadequate. In far too many challenges, we face uncertain facts, disputed values, high stakes and urgent decisions. As we see now, developing vaccines in warp speed was not enough to overcome the challenges of getting people vaccinated, or to overcome disparities that have been the results of years of systemic failures, historic discrimination and political disempowerment.

The U.S. already has a robust public-private and university-industry-government R&D enterprise, which with strategically directed investments, can rapidly scale scientific and technological outcomes. However, what our current moment calls for is institutional innovation that places societal outcomes on the same footing as scientific and market ones.

The good news is that thanks to the NSF's previous and ongoing sponsorship of societally relevant research, education, and outreach—some of which I have already mentioned in this section—the basic building blocks are already in place. What is required is a supporting infrastructure that can allow the required synthesis and a cross-cutting imperative that can help tie it all together – public engagement.

III. Science with the Public

Public engagement refers to many different types of activities that can usually be grouped into three categories on the basis of flow of information between the sponsor and the public. Public consultation is when the information flow is from the public to the sponsor. Public communication is when the flow is reversed. Public participation occurs when there is a mutual exchange. In general, public engagement in science refers to this third category, including activities, events, or interactions characterized by mutual learning—not one-way transmission from "experts" to publics—among people of varied backgrounds, scientific expertise, and life experiences who articulate and discuss their perspectives, ideas, knowledge, and values. It may have different goals: avoiding controversy, educating the public, building democratic capacity through deliberation, widening representation of voices, soliciting inputs on value debates, enabling responsible innovation and shaping policy.

I turn to describe a public engagement effort that I have been coordinating during my tenure at CSPO while tracing its NSF roots.

About the same time as its funding of the Nanoscale Science and Engineering Center and Center for Nanotechnology and Society at ASU, NSF also funded a Nanoscale Informal Science Education Network (NISE Net) to create a national community of researchers and informal science educators dedicated to fostering public awareness, engagement, and understanding of nanoscale science, engineering, and technology. By 2009 the network, led by 14 museums, universities, and professional organizations across the nation that included the Museum of Science (MOS) Boston and Science Museum of Minnesota (SMM) along with the Association of Science and Technology Centers (ASTC), grew to about 300 members strong, reaching tens of millions of visitors annually. The network successfully built and disseminated activities and programming that touched upon many of the phenomenological, technical and societal aspects of nanoscience. The network has also affected culture and practices within the museum community through a variety of interventions.

In 2009, the Museum of Science (MOS), one of the NISE Net leaders, which had already been collaborating with the university researchers affiliated with the Center for Nanotechnology and Society (CNS) and ASU, found themselves hosting two of the five public forums on global warming in the U.S.—part of Danish Board of Technology's World Wide Views on Global Warming project. Joining them were the Colorado School of Mines, Georgia Tech and Pomona College. The research component was funded by NSF. Building on that experience, the CNS and MOS leaders teamed up with the leadership of citizen science platform Scistarter and non-partisan science and technology think tanks, the Loka Institute and the Science and Technology program at the Woodrow Wilson Center. Together, they launched the Expert and Citizen Assessment of Science and Technology (ECAST) network to build a participatory engagement capacity in the United States.

After a demonstration project providing citizen input to the United Nations Convention on Biological Diversity in collaboration with the Danish Board of Technology, ECAST piloted its first independent project with the National Aeronautics and Space Administration (NASA) on its Asteroid Initiative. This paved the way for pTA projects with the Department of Energy on nuclear waste disposal and with the National Oceanic and Atmospheric Administration (NOAA) on community resilience. ECAST's portfolio now includes projects on climate intervention research, automated vehicle futures, and gene editing, supported by more than three million dollars of public and philanthropic funding over the past five years.

Interestingly however, this funding portfolio does not include NSF and that is not because of lack of trying. With NSF's focus on knowledge generation, projects with a primary focus on decision-making outcomes, has not been a good fit for any of NSF's existing funding programs. What has however received NSF funding are the informal education components led by the

Museum of Science Boston on Multi Site Public Engagement with Science (MS-PES) and Co Created Public Engagement with Science (CC-PES).

Interestingly, other science-based agencies picked up where NSF left off. In addition to NASA, DOE and NOAA, DARPA and EPA have also supported engagement projects, though at the expert and stakeholder levels. NOAA's Environmental Literacy Program (ELP) has been a major sponsor of participatory engagement capacity building efforts across the U.S. through its successive support of two projects led by MOS and CSPO that has engaged two dozen science centers to date.

It is worth mentioning that NSF funded a project being led by the researchers at Boise State University and the University of Maryland that is assessing the impact of public engagement on agency cultures. The overall impact of these differentiated funding of research, education and engagement by different agencies are having at least three unintended effects. First, it is forcing proposers to approach research, education and outreach projects in piecemeal and not in comprehensive manners. Second, it is reducing the success rate and increasing the burden of new potential entrants. Third, it is preventing the scaling, accelerating and deepening of the field.

Despite these challenges, thanks to complementary support from philanthropy like the Alfred P. Sloan Foundation, Kettering Foundation, Charles Koch Institute and New America Public Interest Technology University Network, ECAST's activities continue to expand as demand for public engagement in science picks up.

ECAST is not alone in experiencing a growing demand for public engagement in science coming from areas like climate change, gene editing, vaccination, personalized medicine, artificial intelligence, future of work, digital platform governance, automated mobility, and energy transition. ECAST network partners and collaborators in other areas of public engagement from Citizen Science, Community Science, Participatory Design and Civic Science in institutions like SciStarter, Association of Science and Technology Center, American Geophysical Union, American Association for Advancement in Science, and Public Interest Technology University Network, are also experiencing greater demand for socially relevant science and the need for community, stakeholder and public engagement.

These demands for public engagement are coming both for upstream issues having to do with "should we or should we not" questions, and midstream and downstream issues having to do with "how," "what" and "whether" questions. The 2016 National Academy Report on Gene Drives explicitly concluded that "the outcomes of engagement may be as crucial as the scientific outcomes to decisions about whether to release a gene-drive modified organism into the environment." The report declared "public engagement cannot be an afterthought." Similar sentiments can be found from industry executives. CEO of GM Cruise was quoted as saying "This [development of automated vehicles] is something we need to do with society, with the community, and not at society. And we take that very seriously. … The tech adage of 'move fast and break things' most assuredly does not apply to what we're doing here."

In a just released PNAS report Scheufele, Krause, Freiling, and Brossard cite: "CRISPR is a prime example of post normal science. Decision stakes are high, and margins of error are thin, especially once we cross the bright red line of editing the human germline and begin making edits heritable. At the same time, CRISPR raises a host of ethical, social, and regulatory conundrums that all introduce systems uncertainty that make it difficult to map the best paths forward. This makes effective public engagement more important than ever before." Finding that efforts to date have been sporadic and poorly funded they argue that at least three influences require immediate attention from the scientific and policy-making community. First, there should be a systems approach and no one size fits all situation where all goals are packed in. Second, they identify the need to build infrastructures and incentive structures related to public engagement for scientists within academia, government, and the private sector. Finally, the researchers call for public engagement to be substantive; it should not be instrumental or tick box exercise.

In conclusion, public engagement in science is fast becoming an essential component of research and development. The U.S. is seriously lacking in having a publicly supported infrastructure for incentivizing and funding substantive public engagement, the need and demand for which is continuing to grow. The good news is that NSF not only has seeded many public engagement activities that are bearing fruit, it has also supported many of the converging scientific fields: informal science education, science communication, science and technology studies, citizen science, uncertainty in decision-making, democratic theory and science policy. The task ahead then should be to take a holistic approach and support not just the engagement activity, but also its integration in research, education and decision-making.

While this offers tremendous opportunities, it also poses some risks. As recognized in the CIVICS program, starting with a societal problem requires flipping of the traditional evaluation model. Outcomes will need to be valued more than fundamental knowledge creation. In the market innovation case, there is an established trajectory with Small Business Innovation Research (SBIR) or venture funding to take a product or service to a prototyping end. In the social innovation case this require partnering with philanthropic and non-profit organizations, perhaps even local governments. Again, NSF has experience of doing that through programs such as INCLUDES. The real challenge will be to make the transitions towards solutions gradual, strategic and learning oriented. As I mentioned, there are lots of parallels between the technology transfer and usable science approach as both requires successful reconciliation of need and demand. However, there are also important differences between market and public values.

As NSF takes steps to reorient a part of its enterprise towards social outcomes, it needs to keep in mind that the current pathway towards economic outcomes wasn't developed overnight. Engineering Research Centers were launched in 1984. IGERT program started in 1995. ICROPS program started in 2011. Programs for accelerating the rate of change by building capacity and stronger linkages between knowledge production and use take time, bridge building, coordination and partnerships. The Solutions Directorate would therefore do well to start with pragmatic near term goals and take the long view.

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