NATIONAL SCIENCE FOUNDATION PART II: FUTURE OPPORTUNITIES AND CHALLENGES FOR SCIENCE

HEARING

BEFORE THE

SUBCOMMITTEE ON RESEARCH AND TECHNOLOGY

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

HOUSE OF REPRESENTATIVES

ONE HUNDRED FIFTEENTH CONGRESS

FIRST SESSION

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CONTENTS

March 21, 2017

NATIONAL SCIENCE FOUNDATION PART II: FUTURE OPPORTUNITIES AND CHALLENGES FOR SCIENCE

TUESDAY, MARCH 21, 2017

HOUSE OF REPRESENTATIVES,
SUBCOMMITTEE ON RESEARCH AND TECHNOLOGY,
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY,
Washington, D.C.

The Subcommittee met, pursuant to call, at 10:04 a.m., in Room 2318 of the Rayburn House Office Building, Hon. Barbara Comstock [Chairwoman of the Subcommittee] presiding.

LAMAR S. SMITH, Texas
CHAIRMAN

EDDIE BERNICE JOHNSON, Texas
RANKING MEMBER

Congress of the United States
House of Representatives
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
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National Science Foundation Part II: Future Opportunities and Challenges for Science

Tuesday, March 21, 2017
10:00 a.m.
2318 Rayburn House Office Building

Witnesses

Dr. Joan Ferrini-Mundy, Acting Chief Operating Officer, National Science Foundation (NSF)

Dr. Maria Zuber, Chair, National Science Board

Dr. Jeffrey Spies, Co-Founder and Chief Technology Officer, Center for Open Science and Assistant Professor, University of Virginia

Dr. Keith Yamamoto, Vice Chancellor for Science Policy and Strategy, University of California, San Francisco

U.S. HOUSE OF REPRESENTATIVES
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

HEARING CHARTER

Tuesday, March 21, 2017

TO: Members, Committee on Science, Space, and Technology

FROM: Majority Staff, Committee on Science, Space, and Technology

SUBJECT: Research and Technology Subcommittee hearing
"National Science Foundation Part II: Future Opportunities and Challenges for Science"

The Subcommittee on Research and Technology of the Committee on Science, Space, and Technology will hold a hearing titled *National Science Foundation Part II: Future Opportunities and Challenges for Science* on Tuesday, March 21, 2017 at 10:00 a.m. in Room 2318 of the Rayburn House Office Building.

Hearing Purpose:

The purpose of the hearing will be discussion and perspectives on future National Science Foundation priorities and reauthorization issues. The hearing will examine challenges such as setting priorities to meet societal and economic needs, reproducibility and research integrity, and opportunities for open science and data sharing, increasing transdisciplinary research, and developing a new generation of STEM workers.

Witness List

- **Dr. Joan Ferrini-Mundy**, Acting Chief Operating Officer, National Science Foundation (NSF)
- **Dr. Maria Zuber**, Chair, National Science Board
- **Dr. Jeffrey Spies**, Co-Founder and Chief Technology Officer, Center for Open Science and Assistant Professor, University of Virginia
- **Dr. Keith Yamamoto**, Vice Chancellor for Science Policy and Strategy, University of California, San Francisco

Staff Contact

For questions related to the hearing, please contact Jenn Wickre of the Majority Staff at 202-225-6371.

Chairwoman COMSTOCK. The Committee on Science, Space, and Technology will come to order. Without objection, the Chair is authorized to declare recesses of the Committee at any time. Good morning and welcome to today's hearing entitled National Science Foundation Part II: Future Opportunities and Challenges for Science. I now recognize myself for five minutes for an opening statement.

For nearly 70 years, the National Science Foundation has served a mission that made the United States a world leader in science and innovation. The key question before us today: How can NSF keep us and continue to keep us at the forefront of science and innovation for the next 70 Years?

Today we will hear perspectives on how NSF can meet the challenges and opportunities of the future and ideas for ways that NSF can improve.

We will examine particular challenges such as setting priorities during a time of budgetary constraints, and ensuring that all taxpayer-funded research is high quality, reproducible, and conducted with integrity.

We will also look at the vast opportunities created by technology, which allows science to be more accessible and has created more data than ever before. I look forward to hearing how we can make science more open and harness that data to solve real-world problems.

There are also great opportunities for innovation where science disciplines intersect. How can we encourage more transdisciplinary approaches to solving some of our toughest challenges, from cybersecurity to traumatic brain injuries or Alzheimer's, diabetes, and so many more issues that we know you're addressing and that we've addressed here in the Committee and elsewhere throughout Congress. But the best breakthroughs come when we break down those silos.

Finally, we have a great opportunity and challenge to develop a new generation of STEM workers. A study by Georgetown projects 2.4 million job openings in STEM through 2018, where Virginia will lead the nation with 8.2 percent of its jobs being STEM related.

By 2018, there are projections that Virginia will need to fill 404,000 STEM jobs. These are good paying jobs, and we need to prepare students to fill them. And I'm happy to say that we have a Dominion student here from Virginia today at our hearing who is shadowing us here today to hear from our great witnesses.

So this is the second of two hearings the Research and Technology Subcommittee is holding on the National Science Foundation, NSF, this month, to provide input into a reauthorization of NSF later this year. The first hearing held on March 9 with Director France Córdova covered issues addressed in the American Innovation and Competitiveness Act, including accountability and transparency, large facility construction management reform, research misconduct, and STEM education coordination. I should actually emphasize it with preventing the research misconduct there where we're addressing that.

The AICA, signed into law in January, demonstrates that there is a strong bipartisan commitment on both sides of the aisle to the mission of NSF and to supporting basic and fundamental research.

I hope this Committee can continue to work together on making sure we maintain our nation's leadership in science. Innovation is about seeking new methods, new ideas, and new breakthroughs. We want to make sure that the way we fund, support, and conduct science is as innovative as the research it produces.

And with that, I look forward to hearing the testimony of our guests.

[The prepared statement of Chairwoman Comstock follows:]

COMMITTEE ON
SCIENCE, SPACE, & TECHNOLOGY
Lamar Smith, Chairman

For Immediate Release
March 21, 2017

Media Contact: Kristina Baum
(202) 225-6371

Statement of Chairwoman Barbara Comstock (R-Va.)
National Science Foundation Part II: Future Opportunities and Challenges for Science

Chairwoman Comstock: For nearly 70 years, the National Science Foundation (NSF) has served a mission that made the United States a world leader in science and innovation. The key question before us today: how can NSF keep us at the forefront of science and innovation for the next 70 Years?

Today we will hear perspectives on how NSF can meet the challenges and opportunities of the future, and ideas for ways that NSF can improve.

We will examine particular challenges such as setting priorities during a time of budgetary constraints, and ensuring that all taxpayer-funded research is high quality, reproducible and conducted with integrity.

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And with that, I look forward to hearing the testimonies of our guests.

###

Chairwoman COMSTOCK. And I now recognize the Ranking Member, the gentleman from Illinois, Mr. Lipinski, for his opening statement.

Mr. LIPINSKI. Good morning. Thank you, Chairwoman Comstock, for holding this hearing on the future opportunities and challenges for science. I also want to thank our panel for being here this morning to inform our discussion on the important issues facing the U.S. scientific community.

As a scientist, I chose to be on the Science Committee, and this Subcommittee in particular, because of the key role I would be able to play with my colleagues in promoting and overseeing the National Science Foundation, the world's foremost facilitator of top-quality scientific research. As Chair and now Ranking Member of this Subcommittee for more than eight years, I am proud to—proud of what I have been able to help the Foundation—how I've been able to help the Foundation fulfill its critical mission.

All of us in this room want to maximize the benefits that we can reap from federal investments in science, but we sometimes differ on the best way to do this. Some believe that federal investments in particular fields of research are a frivolous use of taxpayer dollars and that funding for these projects would be better utilized in other areas of research. I believe that there is unambiguous evidence to the contrary and that NSF investments across all fields of science and engineering have yielded tremendous societal benefits over the past 70 years.

I want to say a few words about a primary target for some criticism: research funded through the NSF's Social, Behavioral, and Economic Sciences, or SBE Directorate. I have heard the argument that, in the wake of proposed cuts to the SBE directorate, if social and behavioral science research adds value to an interdisciplinary initiative—cybersecurity, for example—the other NSF directorates participating in the initiative could fund the SBE element of the project. There are a number of problems with this approach.

First, program officers face strong competition for research funding within their own directorates and are thus very reluctant to divert funding from their own field to researchers in another field.

Second, NSF currently only supports the highest quality SBE research, guided by the expertise of the scientists in the SBE directorate, many of them supported directly by the SBE budget. If SBE research were to be supported only as an add-on to other projects, the quality of the research would inevitably suffer. And an engineering program officer, no matter how good they are in their field, cannot be expected to have the expertise to assess the social science component of a proposal.

I also want to point out that SBE funding accounts for only 4.5 percent of the total NSF research budget, or $272 million out of over $6 billion.

When I was a political scientist, I was one of the strongest proponents of interdisciplinary research. I believed that fields of study were oftentimes too siloed. But I also understood that groundbreaking interdisciplinary research required that those involved in that research needed to bring the best expertise in their own fields to the table. If SBE funding is gutted, progress in the social sciences will slow and its community of experts will shrink

along with its capacity to add value to other research initiatives. As a result, in the long term, America's capabilities in cybersecurity, medicine, military planning, disaster preparedness and aid, and countless other fields will suffer. For interdisciplinary research to be transformative, the core research it draws from must be strong.

The evidence bears out that unfettered research driven by key questions and approaches within a discipline that is carried out across all fields of science and engineering serves as the best foundation for discoveries and technological innovations. This is the philosophy the NSF has followed, and it has produced outstanding benefits for our economic and national security.

Perhaps more important, it is that unfettered ability to pursue the best and most compelling ideas that attracts and nurtures our nation's and the world's greatest scientific talent and keeps them here on our own shores, contributing to our nation and developing the next generation of American STEM talent. If we start to suffer the brain drain that other countries such as the UK and Germany suffered in decades past, we may never fully recover.

We can all agree that we want to maximize the return on federal investment in science, and there are ways of doing this that we can agree on. It is important to ensure that research is reproducible and conducted with integrity. We can make certain that data obtained from federally funded research is made available to other scientists and to the public. And we can encourage interdisciplinary collaboration while maintaining support for core research. WhileCongress should set priorities for our investments in science, it does not have to be at the expense of scientific inquiry or the viability of entire research disciplines.

Madam Chairwoman, before I yield back, I want to ask unanimous consent to put in the record a document that majority and minority staff received yesterday from the NSF Inspector General, Allison Lerner, in regard to the number of incidents of research misconduct over the past 12 years.

Chairwoman COMSTOCK. So directed.

Mr. LIPINSKI. And if the Chairwoman——

Chairwoman COMSTOCK. Without objection.

[The information appears in Appendix II]

Mr. LIPINSKI. Thank you. And if—allow me to go on another minute?

Chairwoman COMSTOCK. Sure.

Mr. LIPINSKI. I just want to talk a little bit about this, what I just inserted for the record. In her testimony before the Committee two weeks ago, Ms. Lerner stated that there were 175 cases of research misconduct reported in the OIG semi-annual reports over the last four years. Immediately after the hearing, she notified the staff that she had erred in her testimony and there were only 75. At the same hearing, she testified that there had been a significant increase in the number of substantial allegations of research misconduct in recent years. Committee staff followed up the same day by asking her for the data, and yesterday she shared a 12-year history of allegations, investigations, and findings of research misconduct at NSF.

When you look at the data, you will notice two striking things. First, it would be very hard to discern any clear trend over the last decade, let alone a significant increase. Second, looking just at fabrication and falsification, which are arguably much worse than plagiarism, and what the IG claims to have been referring to her in testimony, you will see an average of 12 OIG investigations per year for the past 12 years, 15 cases per year if you look just in the last five years. When it comes to actual agency findings of misconduct, the average is 2.6 per year over 12 years and 3.2 over the last five years. It is important to point out that these numbers apply to all NSF proposals, not just funded grants. NSF receives 50,000 grant proposals per year. Fifteen cases of substantive allegations of research misconduct represents 0.03 percent of all of those proposals; 3.2 findings of research misconduct per year represents .0064 percent of all proposals. Research misconduct is a very serious issue, but I think it is important to keep these numbers in mind.

I look forward to discussing all of these issues. I thank all of the witnesses for being here today, and I yield back. Thank you.

[The prepared statement of Mr. Lipinski follows:]

OPENING STATEMENT
Ranking Member Daniel Lipinski (D-IL)
of the Subcommittee on Research and Technology

House Committee on Science, Space, and Technology
Subcommittee on Research and Technology
"National Science Foundation Part II: Future Opportunities and Challenges for Science"
March 21, 2017

Good morning. Thank you Chairwoman Comstock for holding this hearing on the future opportunities and challenges for science. I also want to thank our panel for being here this morning to inform our discussion on the important issues facing the U.S. scientific community.

As a scientist, I chose to be on the Science Committee, and this Subcommittee in particular, because of the key role I would be able to play with my colleagues in promoting and overseeing the National Science Foundation, the world's foremost facilitator of top-quality scientific research. As chair and now ranking member of this subcommittee for more than eight years, I am proud of what I have been able to do to help the foundation fulfill its critical mission.

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I want to say a few words about a primary target for some of criticism – research funded through the NSF's Social, Behavioral, and Economic Sciences, or SBE, Directorate. I have heard the argument that, in the wake of proposed cuts to the SBE directorate, if social and behavioral science research adds value to an interdisciplinary initiative – cybersecurity, for example – the other NSF directorates participating in the initiative could fund the SBE element of the project. There are a number of problems with this approach.

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American STEM talent. If we start to suffer the brain drain that other countries such as the UK and Germany suffered in decades past, we may never fully recover.

We can all agree that we want to maximize the return on federal investment in science and there are ways of doing this that we can agree on. It is important to ensure that research is reproducible and conducted with integrity. We can make certain that data obtained from federally funded research is made available to other scientists and to the public. And we can encourage interdisciplinary collaboration while maintaining support for core research. While Congress should set priorities for our investments in science, it does not have to be at the expense of scientific inquiry or the viability of entire research disciplines.

Madam Chairwoman, before I yield back, I want to ask unanimous consent to put in the record a document that Majority and Minority staff received yesterday from the NSF Inspector General, Allison Lerner, in regard to the number of incidents of research misconduct over the past 12 years. In her testimony before the Committee 2 weeks ago, Ms. Lerner stated that there were 175 cases of research misconduct reported in the OIG semi-annual reports over the last 4 years. Immediately after the hearing, she notified the staff that she had erred in her testimony and there were only 75. At the same hearing, she testified that there had been a "significant increase" in the number of substantial allegations of research misconduct in recent years. Committee staff followed up the same day by asking her for the data, and yesterday she shared a 12-year history of allegations, investigations, and findings of research misconduct at NSF. When you look at the data, you will notice two striking things. First, it would be very hard to discern any clear trend over the last decade, let alone a significant increase. Second, looking just at fabrication and falsification, which are arguably much worse than plagiarism, and what the IG claims to have been referring to her in testimony, you will see an average of 12 OIG investigations per year for the past 12 years, 15 cases per year if you look just in the last 5 years. When it comes to actual agency findings of misconduct, the average is 2.6 per year over 12 years and 3.2 over the last 5 years. It is important to point out that these numbers apply to all NSF proposals, not just funded grants. NSF receives 50,000 grant proposals per year. Fifteen (15) cases of substantive allegations of research misconduct represents 0.03% of all of those proposals. Three point two

(3.2) findings of research misconduct represents 0.0064% of all proposals. Research misconduct is a very serious issue, but I think it is important to keep these numbers in mind.

I look forward to discussing all of these complex issues and I thank all of the witnesses for being here today. I yield back the balance of my time.

Chairwoman COMSTOCK. Thank you. And Chairman Smith has a schedule conflict this morning, so we have a statement for the record to submit on his behalf.

[The prepared statement of Chairman Smith appears in Appendix II]

Chairwoman COMSTOCK. And I now recognize the Ranking Member of the Full Committee for a statement. Ms. Johnson?

Ms. JOHNSON. Thank you very much, and good morning. I want to thank the Chairwoman and Ranking Member Lipinski for holding this hearing, and welcome to our very distinguished panel of witnesses.

I believe that the stated purpose of this hearing is something we can all support. The process for setting research priorities at the National Science Foundation has always been a combination of science-driven and policy-driven, or bottom-up and top-down. The Congress does have a role to play.

Reproducibility is a well-documented challenge across all STEM fields and one for which this Committee can help promote progress. Research misconduct is the rare exception. Nevertheless, we should remain vigilant and promote good policies, including education and training, to minimize misconduct everywhere.

I strongly support open science and data sharing. For the last two Congresses I cosponsored the Public Access to Public Science Act with Representative Sensenbrenner. To this date we have been unable to convince the Chairman to take it up in a Committee. I hope that we will continue to look forward to considering it. Along with every other Science Committee Democrat, I also cosponsored with Representative Tonko's Scientific Integrity Act that promotes open science and data sharing while protecting privacy and confidentiality. I encourage the Chairman to take that bill up as well.

However, data sharing is never as simple as it sounds, and our witnesses will help shed some light on the complexity.

While the core STEM disciplines remain essential, many scientific frontiers are at the boundaries between disciplines. We must continue to look for policies and funding incentives to promote transdisciplinary research. National Science Foundation has come a long way just in the last decade. However, unhelpful stovepipes between disciplines remain, especially at our research institutions. Finally, there are few topics that I am more passionate about than developing a new generation of STEM workers. On all of these topics, I have no doubt that the experts sitting before us today have many wise recommendations based on many decades of collective experience. Those of us sitting on this side of the dais would be most wise to heed their recommendations.

For example, I am quite confident that none of these witnesses will endorse slashing funding for the geosciences or social and behavioral sciences in order to increase funding for other fields. I also doubt that any of these witnesses confuse research reproducibility with research misconduct, yet I often hear the rare cases of misconduct being used as a sledgehammer to impugn scientists broadly.

We can set priorities and develop good science policies without stifling scientific inquiry or shutting down entire fields of research. If we truly care about developing a new generation of STEM work-

ers, if we truly care about our nation's economic and national security, and if we truly care about the well-being of our children and grandchildren, we will listen to the experts before us today and the many other scientific leaders who have so thoughtfully developed recommendations for the future of the National Science Foundation and U.S. leadership in science and technology.

I so look forward to the testimony from our panelists today, and I thank you, Madam Chair, and yield back.

[The prepared statement of Ms. Johnson follows:]

OPENING STATEMENT
Ranking Member Eddie Bernice Johnson (D-TX)

House Committee on Science, Space, and Technology
Subcommittee on Research and Technology
"National Science Foundation Part II: Future Opportunities and Challenges for Science"
March 21, 2017

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truly care about the wellbeing of our children and grandchildren, we will listen to the experts before us today and the many other scientific leaders who have so thoughtfully developed recommendations for the future of the National Science Foundation and U.S. leadership in science and technology.

I look forward to today's testimony and discussion, and I yield back.

Chairwoman COMSTOCK. Thank you. I'll now introduce our witnesses. Our first witness today is Dr. Joan Ferrini-Mundy, Acting Chief Operating Officer of the National Science Foundation.

Prior to this role she served as Assistant Director of the NSF for Education and Human Resources since February 2011 and has been at NSF in various capacities since 2007. From 1999 to 2011 she held an appointment at Michigan State University where she was a University Distinguished Professor of Mathematics Education. She was elected a fellow of the American Association for the Advancement of Science in 2011. Dr. Ferrini-Mundy holds a Ph.D. in Mathematics Education from the University of New Hampshire, and she is a resident of the 10th District in Chantilly. We welcome you here today.

Dr. Maria Zuber, our second witness, is Chair of the National Science Board. In 2013, Dr. Zuber was appointed Vice President for Research at the Massachusetts Institute of Technology where she oversees more than a dozen interdisciplinary research laboratories and centers. Dr. Zuber was awarded the NASA Distinguished Public Service Medal in 2004, and in 2008 she was named to the U.S. News list of America's Best Leaders. She received a Bachelor of Arts in Astronomy from the University of Pennsylvania as well as a Master of Science and Ph.D., both in Geophysics from Brown University.

Dr. Jeffrey Spies is our third witness, and he is the Co-Founder and Chief Technology Officer for the Center for Open Science and Assistant Professor at the University of Virginia. Dr. Spies was recently named the Association for Psychological Science Rising Star for early career scientists whose work has already advanced the field and signals great potential for continued contributions. He completed his undergraduate work at the University of Notre Dame where he also earned his Master's Degree in Psychology and Computer Science. He also holds a Ph.D. in Quantitative Psychology from the University of Virginia.

Dr. Keith Yamamoto is our fourth witness, and he is the Vice Chancellor for Science Policy and Strategy at the University of California, San Francisco, where he joined the faculty in 1976. He chairs the Coalition for the Life Sciences and sits on the National Academy of Medicine's Executive Committee, the National Academy of Sciences, Division of Earth and Life Studies' Advisory Committee, and the Executive Committee of Research America. He is also an elected member of the American Academy of Arts and Sciences and a Fellow of the American Association for the Advancement of Science. He received a Bachelor of Science from Iowa State University and a Ph.D. from Princeton University.

I now recognize Dr. Ferrini-Mundy for five minutes to present her testimony.

TESTIMONY OF DR. JOAN FERRINI–MUNDY,
ACTING CHIEF OPERATING OFFICER,
NATIONAL SCIENCE FOUNDATION (NSF)

Dr. FERRINI-MUNDY. Thank you. Good morning Ranking Member Johnson, Chairwoman Comstock, Ranking Member Lipinski, and distinguished Members of the Subcommittee. My name is Joan Ferrini-Mundy, and I am the National Science Foundation's Acting

Chief Operating Officer. Previously I served as the NSF Assistant Director for Education and Human Resources. Before coming to the National Science Foundation, I was a Professor of Mathematics and Education and an Administrator at Michigan State University.

I appreciate the opportunity to testify as the Foundation celebrates nearly seven decades of funding scientific discoveries. The mission of NSF is to promote the progress of science; to advance the national health, prosperity and welfare; and to secure the national defense. I will highlight four features of NSF's approach to enacting the mission that have served science and the nation well since our beginnings: fundamental research, flexibility, partnerships, and people.

For nearly 70 years, NSF has focused on investing in fundamental research across all fields of science and engineering. When grants for fundamental research are made, it is often impossible to immediately see what the direct impact on society will be. Yet, NSF investments have benefitted the lives and livelihoods of generations of Americans. NSF investments drive U.S. economic growth, strengthen our nation's security, and give the country the competitive edge we need to exert our global leadership.

A second hallmark of NSF's approach is maintaining the flexibility to fund the very best scientific ideas from wherever they may come. This means having evolving mechanisms for investing in ideas and solutions that span existing and established scientific fields and lead to new ones that cross disciplinary boundaries and that are high risk for potential for high reward. Our gold standard merit review process ensures a fair and expert hearing for each of those ideas. Flexible collaborations across our disciplinary directorates ensure that we are able to make awards for the very most promising ideas.

Third, I wish to highlight the centrality of partnerships in NSF's effectiveness. We partner across government with the U.S. and international scientific community and with the private sector.

Through the NSF Organic Act of 1950, the Foundation is established as a partnership between the National Science Board and the National Science Foundation Director. Our nation's most distinguished and respected researchers prepare decadal surveys and synthesis reports for the National Academies of Science. The pool of nearly 50,000 NSF proposals received annually and the reviews that we obtain for them from partners in the scientific community provide a rich snapshot of the directions and trends of U.S. science and engineering. The private sector relies on the steady stream of basic science that fuels their efforts at innovation and enhances their efficiency and productivity.

NSF promotes the growing emphasis on open science through its policies for sharing publications and managing data. Finally, and I know of great importance to this Subcommittee, are people. Government, universities, colleges, business, and industries all depend upon a steady supply of well-prepared people in science and engineering, drawing on talent from across the diversity of our nation. All should have the opportunity to be inspired by the wonders of science, technology, engineering, and mathematics through learning opportunities in K through 12 schools, community colleges, uni-

versities, as well as in informal, self-directed, and lifelong learning environments.

NSF has a unique role to play to nurture the next generation of STEM talent. That generation will carry the mantle of discovery and innovation into the future.

NSF looks forward to its continuing responsibility for advancing the frontiers of discovery, innovation, and learning. I thank the Subcommittee for your support of the Foundation. This concludes my oral testimony. More detail on the four points I have briefly highlighted today can be found in my written statement. I will be pleased to answer any questions that you have.

[The prepared statement of Dr. Ferrini-Mundy follows:]

Testimony of

Joan Ferrini-Mundy, Ph.D.
Chief Operating Officer (Acting)
National Science Foundation

Before the
Subcommittee on Research and Technology

for the
Committee on Science, Space, and Technology
U.S. House of Representatives

March 21, 2017

"National Science Foundation Part II: Future Opportunities and Challenges for Science"

Chairwoman Comstock, Ranking Member Lipinski, and other distinguished members of the Subcommittee. My name is Joan Ferrini-Mundy and I am the National Science Foundation's (NSF) Acting Chief Operating Officer. Prior to assuming my current role, I served as the NSF Assistant Director for Education and Human Resources since 2011. Thank you for the opportunity to testify before you today as NSF examines the societal challenges and opportunities for the nation's future, and NSF celebrates nearly 70 years of scientific accomplishment.

Since its establishment in 1950, the mission of NSF has been "to promote the progress of science; to advance the national health, prosperity and welfare; [and] to secure the national defense…" To do so, NSF has provided funding with an eye toward the frontier – in order to identify the most innovative and promising new research and education projects. NSF specifically targets its investments in discovery research at the edge of science and engineering. Here, advances push the boundaries of innovation and lead to progress and productivity. We prioritize such frontiers by maintaining our proven, "bottom-up" philosophy: the best ideas for research will come directly from the science and engineering community.

The cornerstone of NSF is the merit-based, competitive process that fosters the highest standards of excellence and accountability – standards that have been emulated at funding agencies around the world. To evaluate which proposals have the greatest potential to promote the progress of science, reviewers seek to identify two key factors in every proposal: intellectual merit and broader impacts. Evaluating proposals on the basis of these factors assures that the Foundations' activities are in the national interest.

NSF is vital to our nation because we invest in the fundamental research and the talented people who make the discoveries that transform our future. Those discoveries are a primary driver of the U.S. economy, enhance our nation's security, and give the country the competitive edge to remain a global leader.

NSF: Where Discoveries and Discoverers Begin

Federal support for research and education has fueled innovation and provided benefits to the American public for decades, and NSF has played a significant role in this success. For nearly 70 years, NSF has been a catalyst for the development of new ideas in science and engineering and supported the people who generate them.

In 1952, using one of NSF's first grants, Caltech professor Max Delbrück invented molecular biology techniques that enabled one of his students, James Watson, along with colleagues Rosalind Franklin, and Francis Crick, to determine the molecular structure of DNA. Since then, an entire biotechnology industry has bloomed and prospered and understanding of DNA has led to fundamental discoveries about genetics and disease. When considered as an industry in itself, biotech and its economic impact rival the mining, utilities, chemical, computing and electronics industries. In the 1960s and 1970s, NSF provided funding that resulted in seminal fundamental mathematical and process innovations for manufacturing that industry considered too risky to fund. These led directly to rapid prototyping, and revolutionized how products are designed and manufactured.

In the 1980s, NSF supported the very first computer science departments in U.S. universities, growing out of mathematics departments, establishing computer science as a mainstream area of scientific and engineering research, and providing a training ground for the first and subsequent generations of computer scientists and entrepreneurs. Today, NSF provides 82 percent of total federal support for research in computer science conducted in the nation's universities and colleges. Jobs related to computer and information technologies are among the most rapidly growing in the nation according to Bureau of Labor Statistics projections. In the 1990s, NSF supported pioneering research in the emerging field of nanotechnology, an early example of convergent research spanning multiple fields of science and engineering. Between 2001 and 2010, 175 start-ups and collaborations with over 1,200 companies came about as a direct result of NSF-supported centers and networks.

And just last year, NSF-funded infrastructure and research provided for the first direct detection of gravitational waves by NSF's Laser Interferometer Gravitational-Wave Observatory (LIGO). This historic discovery is the result of funding by NSF in the 1970s of the infrastructure needed to prove one of the predictions of Einstein's theory of General Relativity. This detection will continue to push the boundaries of science and discovery for decades to come.

Such investments in basic research often yield unexpected benefits. NSF's support of game theory, auction theory, and experimental economics through the Directorate for Social, Behavioral, and Economic Sciences provided the Federal Communications Commission (FCC) with its current system for apportioning the airwaves. Since 1994, FCC "spectrum auctions" have netted over $45 billion in revenue for the federal government and more than $200 billion in worldwide revenue. Although the payoff was unexpected at the time NSF started supporting game-theory research, the payoff is many times greater than the total investment NSF has made in social and behavioral sciences over our Agency's history.

These transformational discoveries often span many disciplinary fields. The breadth and flexibility of NSF's functions as specified in the NSF Organic Act[1] – "to initiate and support basic scientific research and programs to strengthen scientific research potential and science education programs at all levels, in the mathematical, physical, medical, biological, social, and other sciences, and to initiate and support research fundamental to the engineering process and programs to strengthen engineering research potential and engineering education programs at all levels in the various fields of engineering...." – enables the unexpected interdisciplinary connections that are so often critical to scientific advances.

[1] 42 U.S. Code § 1862

NSF is unique among science agencies in that education is fully integrated with the investment in science and engineering research, and has been since NSF's founding in 1950. By engaging the nation's experts in science and engineering in shaping the education of tomorrow's scientists and engineers, NSF's investments are critical in ensuring that the most talented and innovative people are well prepared to do science and engineering. In addition, having a science, technology, engineering, and mathematics (STEM) literate society is also critical to promoting the progress of science. As Vannevar Bush wrote in *Science – The Endless Frontier*, "Basic scientific research is scientific capital...How do we increase this scientific capital? First, we must have plenty of men and women trained in science, for upon them depends both the creation of new knowledge and its application to practical purposes." In the 1950s NSF began its Graduate Research Fellowship Program, providing support for graduate education for our nation's best and brightest. Over the years NSF has supported over 50,000 fellows, 43 of whom have received Nobel Prizes. NSF-funded evidence-based innovations in K-12, undergraduate, and informal education have led to major shifts in the depth and quality of science and mathematics instruction, opportunities for research and direct collaboration with scientists that prepares undergraduates to pursue science and engineering careers, and inspirational out-of-school learning opportunities that draw young people into science.

Responsiveness to National Needs

NSF may not be the largest agency that funds science and engineering research, but our size serves to keep us nimble. The NSF portfolio of funded projects is continually evolving as the science and engineering communities identify and pursue new research at the frontiers of knowledge. An essential part of our mission is to constantly allow for the rethinking of established categories and traditional perspectives as needed to promote the progress of science. This ability is more important than ever, as conventional boundaries constantly shift and disappear – boundaries between disciplines, between science and engineering, and between what is fundamental and what is applied. NSF, with its mandate to support all fields of science and engineering, is uniquely positioned to meet the needs of researchers exploring human knowledge at these interfaces, and those who are establishing new interfaces, whether we are supporting interdisciplinary conferences, enabling cyber-sharing of data and information, or encouraging new collaborations and partnerships across disciplines.

NSF's comprehensive and flexible support of meritorious projects with broad societal impacts enables the Foundation to identify and foster both fundamental and transformative discoveries within and among fields of inquiry. NSF is able to support emerging fields, high-risk ideas, interdisciplinary collaborations, and research that pushes, and even transforms, the very frontiers of knowledge. In these ways, NSF's discoveries inspire the American public—and the world.

NSF's organization mirrors the ways that science and engineering are organized and conducted in universities. Our portfolio spans the biological sciences, computer and information science and engineering, engineering, geosciences, mathematical and physical sciences, and social, behavioral, and economic sciences – encompassing both research and education in these areas. NSF also carries out specific national responsibilities for polar programs and US operations in Antarctica; provides cyberinfrastructure, including high performance computing, used by colleagues funded by multiple federal agencies; fosters international science and engineering; operates scientific instruments and facilities used by researchers worldwide; and successfully engages in a range of responsibilities related to the nation's overall capabilities in science and engineering. Key among those is providing statistical resources on the overall U.S. and international research and development enterprise through our statistical agency, the National Center for Science and Engineering Statistics.

The 25-member National Science Board and the NSF Director jointly pursue the goals and function of the NSF, including the duty to "recommend and encourage the pursuit of national policies for the promotion of research and education in science and engineering."

Priority Setting and Strategic Planning

NSF constantly strives for a portfolio of investments that best meets the needs of the Nation. The planning and development of that portfolio is an ongoing, multifaceted process for the agency. It engages the National Science Board, incorporates Administration guidance, and addresses requirements established in Congressional legislation. It reflects discussions of emerging areas of science and engineering with NSF's Advisory Committees. And, it draws on a wide array of inputs such as studies by the National Academies and decadal surveys that set priorities for our disciplines. And finally, it incorporates the inputs and analyses of NSF scientific staff from the nearly 50,000 proposals received annually at NSF from the research community, which reflect interests and potential new frontier opportunities.

NSF's periodic strategic plans[2], developed in partnership with the National Science Board, are also an important component of setting priorities. The strategic plan is based on NSF's uniqueness as a federal agency, with attention to the wide range of fields within the scope of its mission and its ability to support the broad interdisciplinary collaborations needed to advance discovery. Our plan will encompass investments in projects, people, and infrastructure with a goal of supporting significant discoveries that will help to: stimulate economic growth; improve the quality of life for Americans; and deepen our understanding of the universe around us. In preparation for developing the new plan (2018 – 2022), since August 2016, NSF has been seeking wide input[3]. We anticipate that the final version of NSF's updated strategic plan will be submitted to Congress with the President's FY 2019 budget request.

Discussions among leadership within NSF are structured so that the directorates work together to identify and pursue the most important priorities and greatest challenges -- regardless of discipline. The cooperation among the directorates, especially at the leadership level, is the defining characteristic of the process. This cooperation allows the NSF Director to present a budget on the frontier of science and engineering. It often results in significant interdisciplinary efforts that span several directorates and are possible because of the flexibility afforded to NSF through its funding structure. For instance, such NSF-wide efforts as Innovations at the Nexus of Food, Energy, and Water Systems, which is seeking to "catalyze well-integrated interdisciplinary and convergent research to transform scientific understanding of the FEW nexus (integrating all three components rather than addressing them separately), in order to improve system function and management, address system stress, increase resilience, and ensure sustainability" indicate NSF's ability to prioritize key areas of societal need.

NSF's current process fosters cooperation across disciplines, provides flexibility to pursue emerging interdisciplinary opportunities, and draws fully upon input from the community, best responds to and anticipates the nation's needs and enables the agency to fulfill its responsibilities for strengthening U.S. science and engineering overall, in keeping with the NSF mission.

The Science of Tomorrow

At NSF, we constantly look toward the frontier in order to identify the most innovative and promising directions for research and education. In *Science – The Endless Frontier*, Vannevar Bush wrote:

> *Basic research leads to new knowledge. It provides scientific capital. It creates the fund from which the practical applications of knowledge must be drawn. New products and new processes do not appear full-grown. They are founded on new principles and new conceptions, which in turn are painstakingly developed by research in the purest realms of science. Today it is truer than ever that basic research is the pacemaker of technological progress. In the nineteenth century, Yankee*

[2] https://www.nsf.gov/about/performance/strategic_plan.jsp
[3] https://www.nsf.gov/od/oia/strategicplan/feedback.jsp

mechanical ingenuity, building largely upon the basic discoveries of European scientists, could greatly advance the technical arts. Now the situation is different. A nation which depends upon others for its new basic scientific knowledge will be slow in its industrial progress and weak in its competitive position in world trade, regardless of its mechanical skill.

As we look ahead to the coming decades, we must envision bold questions that will drive NSF's long-term agenda for research and education investment -- questions that will ensure future U.S. generations continue to reap the benefits of fundamental research in science and engineering. This is the reason NSF developed the "Ten Big Ideas."[4] These ideas capitalize on what NSF does best: catalyze interest and investment in fundamental research, which is the basis for discovery, invention and innovation. They are meant to suggest a set of cutting-edge research agendas and processes that are uniquely suited for NSF's broad portfolio of investments, and will require collaborations with industry, private foundations, other federal agencies, scientific societies, and education partners ranging from K-12 systems, to community colleges, to universities. Funding the research that will advance these ideas, and efforts to develop the talented people who can pursue them, will push forward the frontiers of U.S.-based science and engineering, contribute innovative approaches to solving some of the most pressing problems the world faces, and lead to unimagined discoveries that can change lives.

The work of today's NSF-funded researchers provides previews of the science and engineering of tomorrow. The need for the research to be robust and reliable so that science has the confidence of the public and of policy makers is paramount. And, to enable collaboration, replication, and wider access to science, concepts of open science are developing, being enacted, and advancing rapidly in all fields. Because the complex problems being addressed by scientists and engineers frequently require expertise from multiple disciplines, the science of tomorrow is increasingly interdisciplinary and convergent across multiple fields of science. And finally, tomorrow's science and engineering advances will be accomplished by people who are being educated today – both in our nation's formal education systems ranging from K-12 schools through graduate school, as well as in informal and self-directed learning environments that range from educational television, to museums, to Massive Open Online Courses (MOOCs), to certificate and badging programs. Thus the preparation of the STEM and STEM-capable workforces is essential.

Interdisciplinarity and Convergence in Science and Engineering

The National Academies of Sciences defines interdisciplinary, or convergent, research as "a mode of research by teams or individuals that integrates information, data, techniques, tools, perspectives, concepts, and/or theories from two or more disciplines or bodies of specialized knowledge to advance fundamental understanding or to solve problems whose solutions are beyond the scope of a single discipline or area of research practice."[5]

NSF has long recognized the value of interdisciplinary research in pushing fields forward and accelerating scientific discovery. Important research ideas often transcend the scope of a single discipline or program. NSF also understands that the integration of research and education through interdisciplinary training prepares a workforce that undertakes scientific challenges in innovative ways. Thus, NSF gives high priority to promoting interdisciplinary research and supports it through a number of specific solicitations. NSF also allows unsolicited interdisciplinary proposals for ideas that are in novel or emerging areas extending beyond any particular current NSF program.

Numerous NSF programs are designed explicitly to be interdisciplinary, often involving several NSF directorates. The NSF *Understanding the Brain* Initiative, for instance, involves multiple NSF directorates:

[4] https://www.nsf.gov/about/congress/reports/nsf_big_ideas.pdf
[5] Convergence: Facilitating Transdisciplinary Integration of Life Sciences, Physical Sciences, Engineering, and Beyond (2014)

the Biological Sciences; the Mathematical and Physical Sciences; the Social, Behavioral, and Economic Sciences; and Computer and Information Science and Engineering. NSF also develops activity portfolios focusing on areas of national interest, often in collaboration with other federal agencies. For example, NSF has considerable investment in *Safe and Trustworthy Computing*, another initiative that spans several directorates including: Computer and Information Science and Engineering; Engineering, Mathematical and Physical Sciences; Social, Behavioral, and Economic Sciences: and Education and Human Resources. In addition other agencies, including the Department of Homeland Security and the Office of Personnel Management are involved, because of the need for workforce development.

Because the challenges that we face as a society are often complex and require an integrative, collaborative approach, these areas are often interdisciplinary and NSF is poised, as a nimble agency with flexibility, to arrange for funding opportunities that address them as they emerge. NSF's Centers and programs are designed to bring together interdisciplinary research teams, and NSF promotes interdisciplinary research through programs that support development of the next generation of researchers, such as the NSF Research Traineeship Program.

Robust and Reliable Science

In order for advances in science and engineering to proceed and have impact it is critical that the public and policymakers have confidence in the robustness and reliability of science. It is also critical that scientists be able to rely on the results of others and build on them. Producing and disseminating scientific knowledge are at the heart of the research enterprise and are central to the mission of NSF. To succeed in our mission, the Foundation is constructing and implementing a framework for fostering scientific "reliability" – the term used within NSF to encompass characteristics of published results in which others have confidence and on which they can build. Because different research practices are appropriate and effective in different scientific and engineering domains, any such framework must accommodate the substantial variety of research that NSF funds. While there are common themes such as clear presentation of methods, appropriate and rigorous statistical analyses, and long-term availability of data that contribute to the reliability of all research, constructing a useful framework requires a broad view of research results as more than observations and conclusions but also as data, calculations, analytic methods, and simulations along with the models and software on which they rest.

A number of factors can contribute to lack of reproducibility of scientific results. Several of those factors have to do with the ways in which research is reported. For instance, details about workflows, methodological steps, and statistical analyses employed need to be clearly specified. NSF is directly addressing the problem of irreproducibility with a multi-pronged approach. We have entered an agreement with the National Academy of Sciences, as specified in the American Innovation and Competitiveness Act, where an Academy committee will assess research and data reproducibility and replicability issues in interdisciplinary research, and make recommendations for improving rigor and transparency in scientific research. Each NSF directorate also has taken up deeper looks into the particular issues of robust and reliable science for their own disciplinary domains, where the nature of scientific inquiry varies considerably. For instance, issues of replicability for mathematicians proving theorems are quite different from those of engineers designing tools and devices, or for social scientists conducting ethnographic inquiries. The education of the next generation of researchers is important and will vary by field. Also, standards and expectations in scientific journals, the research community, and professional societies have an important part to play in emphasizing the critical nature of replication and reproducibility in science.

To further inform continued development and implementation of our framework for fostering scientific reliability, the Foundation is engaged in a wide-ranging examination of issues related to scientific reliability both internally and in consultation with our scientific communities. All of the NSF directorates are examining the nuances of reliability relevant to their scientific disciplines, and all have had specific agenda

items on the topic during their respective Advisory Committee meetings in recent years. Several directorates have funded pilot reproducibility studies, and sponsored workshops on the topic to hear from a broad range of stakeholders in the research enterprise, including investigators, other federal agencies, business and industry, private foundations, journal editors, and professional societies.

These activities are ongoing and are expected to inform an agenda that deepens our knowledge about factors that compromise scientific reliability and guides our efforts to improve it in NSF-funded work. An internal working group has been tasked with proposing NSF policy and practice changes to improve scientific reliability in NSF-funded work. Possibilities include strengthening the agency's guidelines for data management plans and the reporting requirements for the research we fund. Ensuring reliability of scientific findings rests on efforts from all corners of the research enterprise and therefore NSF will continue to operate in a transparent fashion, inviting input on its activities from staff across the Foundation and the external scientific communities that we serve.

Opportunities for Open Science and Data Sharing

Openness and data sharing in science are already leading to acceleration of discovery, efficiency in analyses, more rapid efforts to conduct replication studies, and innovation in approaches to analysis and methodologies. In addition, when open science principles are applied to government-funded science, new levels of access and transparency are available to the public as well as the private sector, generating the potential of wider and more effective use of funded work. NSF has an agency priority goal aimed at public participation in scientific research which builds on the idea of "citizen science", encouraging the public to participate in data collection, as in the bird observations collected through the Cornell Laboratory of Ornithology, and also in finding patterns and events, as is possible with various public data sets from astronomy.

With technological advances that allow for more ubiquitous data collection through sensors and other instrumenting of our environment, the potential for science to advance through open science and data sharing increases. Indeed, one of NSF's "Ten Big Ideas" is Harnessing Data for 21st Century Science and Engineering. And, with this emphasis on open science comes the development of new fields of scientific practice and inquiry, such as data science. NSF is already funding efforts to determine how to best educate the next generation of scientists who can be leaders in data-enabled science and engineering.

NSF is part of the movement toward open science through a variety of approaches. In 2015, NSF developed a plan outlining a framework for activities to increase public access to scientific publications and digital scientific data resulting from research the foundation funds. The plan, entitled "Today's Data, Tomorrow's Discoveries"[6], sets forth the requirement that NSF funded investigators are expected to share with other researchers, at no more than incremental cost and within a reasonable time, the primary data, samples, physical collections and other supporting materials created or gathered in the course of work under NSF grants. Grantees are expected to encourage and facilitate such sharing. NSF also requires that articles derived from NSF-funded research that appear in peer-reviewed scholarly journals and papers in juried conference proceedings or transactions be deposited in a public access-compliant repository and be available for download, reading and analysis within one year of publication. And, since 2011, NSF has required all proposals to provide information about plans for data management and sharing of the products of research. Prospective principal investigators must outline in detail such things as the standards to be used for data and metadata format and content, and policies for access and sharing with attention to issues of privacy, confidentiality, and intellectual property, and plans for archiving.

[6] https://www.nsf.gov/pubs/2015/nsf15052/nsf15052.pdf

Preparing the STEM Workforce and a STEM-Literate Society

In our efforts to advance the frontiers of knowledge and spur innovation, and in ensuring the success of the progress of tomorrow's science and engineering, NSF also aims to develop the nation's talent pool and support the creation of a highly skilled workforce that can be engaged in STEM in a variety of ways, at a variety of levels. This has a profound, and lasting, impact. NSF's education and STEM workforce investments, centered in the Directorate for Education and Human Resources (EHR) and spanning the entire agency, fund activities that support students, teachers, researchers, and the public. The EHR investment in fundamental STEM education research helps build the nation's knowledge base for strategically and efficiently improving STEM learning.

NSF-funded research is characterized by its breadth across all fields of science, and by the assumption that we cannot predict which field of science, or which interdisciplinary mix, will give rise to the next most important discovery that could reshape our lives or society. NSF, with its commitment to investing in fundamental research, has long recognized that any science being applied to practical problems, whether it be developing strong encryption for cybersecurity, to training soldiers in visual recognition as they encounter unfamiliar enemies, rests on fundamental results, theory, and principles. Thus our investment in the training of PhD level scientists and engineers, who become expert in the fundamentals of the NSF-supported disciplinary areas as part of their training, are essential in advancing that work to the new levels that can ultimately offer solutions to problems in the national interest.

For America to continue to lead the world in science and technology innovation, it must have the most knowledgeable and skilled STEM workers in the world. NSF prioritizes the integration of its education and science investments. Our programs support learners at all ages, inside and outside of school, with the goals of inspiring them in STEM and helping them gain access to the complex and powerful concepts and tools of the STEM fields. This is not just the smart thing to do – it is the right thing to do for our country. By drawing on the spectrum of talents and backgrounds of America's diverse populace, we can bring new approaches to scientific discovery, new vantage points to engineering design, and new insights to ensure innovation. And, by helping a public have access to the inspiration and wonder of science and engineering, we build the future. This is essential as we strive to remain competitive in the diverse international marketplace.

A long-standing focus of NSF's workforce development portfolio is on broadening the context of what it means to prepare the *entire* STEM workforce. With STEM playing an increasingly important role in the nation's technological innovation and economic growth, it is important that we provide the technical skills and infrastructure required for all workers to contribute to and take full advantage of today's economy. NSF has supported both two-year institutions and students enrolled in associate's degree programs and undergraduate research.

Conclusion

In today's high-tech economy, the supply of new jobs is inextricably linked to the health of the nation's innovation endeavor. NSF support drives all aspects of innovation; NSF not only funds the discoveries that directly become the innovations of tomorrow, we fund the development of the discoverers.

Industry continues to rely upon government support for the high-risk, high-reward fundamental research that powers their successes. It is no accident that our country's most productive and competitive industries – including computers and communications, semiconductors, biotechnology, advanced manufacturing, health fields, and aerospace – are those that benefited the most from sustained federal investments in research and development.

I believe that America can continue to be on the leading edge of ideas and research. Through strong federal leadership, we can maintain the standing of our businesses and universities. We must not only maintain our position, we must actively seek to increase our strengths: leadership in fundamental discovery, including high-risk, high-reward transformational research; state-of-the-art facilities and scientific research infrastructure; and a world-class science and engineering workforce. With a firm commitment to these fundamental building blocks of our high-tech economy, we can solidify America's role as the world leader in innovation.

I've touched on just a handful of examples from NSF's diverse and vibrant portfolio. NSF's research and education activities support the nation's innovation enterprise. America's present and future strength, prosperity and global preeminence depend directly on fundamental research.

Madam Chairwoman and members of the Subcommittee, I hope my testimony explains NSF's transformative role in building our nation's future prosperity and continued leadership at the frontiers of discovery, innovation and learning. NSF investments in fundamental science and engineering have paid enormous dividends, improving the lives and livelihoods of generations of Americans.

This concludes my testimony. I thank you for your leadership. I will be pleased to answer any questions the Members may have.

Joan Ferrini-Mundy, Ph.D.
Chief Operating Officer (Acting)
National Science Foundation

Dr. Joan Ferrini-Mundy is the acting chief operating officer of the National Science Foundation (NSF). Since 2011, she served as the NSF assistant director for Education and Human Resources (EHR). Additionally at NSF, Ferrini-Mundy was the inaugural division director of the Division of Research on Learning in Formal and Informal Settings in EHR.

Ferrini-Mundy served as an ex officio member of the U.S. Presidents's National Mathematics Advisory Panel and co-chaired its Instructional Practices Task Group (2007-2008). She was also a member of the Mathematics Expert Group of the Programme for International Student Assessment (2009-2012).

Ferrini-Mundy has co-chaired the White House National Science and Technology Council's Federal Coordination in Science, Technology, Engineering and Mathematics Education Task Force. Prior to coming to NSF, she was a University Distinguished Professor of Mathematics Education at Michigan State University.

Ferrini-Mundy holds a Ph.D. in mathematics education from the Department of Mathematics of The University of New Hampshire. She was elected a fellow of the American Association for the Advancement of Science (2011) and a member of the Executive Committee of the Association of Women in Mathematics (2013-2016). She began her career as a high school mathematics teacher. Her research interests are in calculus learning, mathematics teacher knowledge and K-12 science, technology, engineering and mathematics (STEM) education policy.

Chairwoman COMSTOCK. Thank you. I now recognize Dr. Zuber.

TESTIMONY DR. MARIA ZUBER, CHAIR,
NATIONAL SCIENCE BOARD

Dr. ZUBER. Good morning. Thank you very much. Chairman Comstock, Ranking Member Lipinski, and Members of the Subcommittee, I appreciate the chance to speak with you on challenges and future opportunities for science. I would also like to acknowledge Chairman Smith in absentia and Ranking Member Johnson.

In 1945, after radar and the atomic bomb changed the course of World War II, Vannevar Bush outlined a vision for the future. In Science, the Endless Frontier, he wrote, scientific progress is one essential key to our security as a nation, to our better health, to more jobs, to a higher standard of living, and to our cultural progress. Bush's vision resulted in the National Science Foundation.

For nearly 70 years, NSF has trained scientists and catalyzed discoveries in all fields of science and engineering. Our unwavering commitment to promoting the progress of science has opened new windows on the universe, made possible new industries, and improved the lives of all Americans.

NSF investments have given us the internet, touchscreen technologies, and better natural disaster warning systems. These discoveries have put millions of Americans to work and improved our nation's prosperity and security.

The question before us is will the world's richest, most-powerful nation continue to invest in our future? Do we still want to be the first to know, to understand, to discover, to invent? The Board is fully aware of these challenges: budget constraints, questions about priorities in the role of government, and of course, growing competition. Our government plays a unique role as a supporter of basic research. The private sector will not, cannot, invest large sums in open questions for 20-plus years as we did for the LIGO gravitational wave detector, for example.

The discoveries of the past 70 years were made possible by Congress, presidential administrations, and the research community working together with a common purpose. We cannot allow today's challenges to unravel the partnerships that have supported NSF's core mission and benefitted our country.

I offer three suggestions for how to move ahead. First, maintain the Federal Government's unique investment in discovery research across all fields of science and engineering. Second, prepare a STEM-capable workforce so that all Americans can participate in and benefit from scientific progress. And third, for the research community, maintain the trust and confidence of the American public.

One of the Board's key responsibilities is to help NSF realize its vision. The Foundation must continue to push the frontiers of science investing wisely without fear of failure. This means in part identifying and setting priorities that will serve our long-term national interest. NSF has not picked winners and losers or determined in advance what discoveries will emerge in a project or even a field of science. Instead, NSF must continue to take advantage

of the creativity and ingenuity of the best minds in America to drive science progress and let discovery be our guide.

While the education and training of scientists and engineers remains at the heart of NSF's mission, to secure our future, we need a STEM-capable U.S. workforce at all educational levels. On the farm, the factory floor, the laboratory, and everywhere in between, workers are using STEM capabilities to innovate, adapt, install, and debug. This workforce must include women, underrepresented minorities, and blue-collar workers who have been hard-hit by automation and globalization.

NSF is realizing this future through its unique integration of basic research and education and through its investments in fundamental research into STEM. Investing in people not only ensures that all Americans have the tools to thrive but it also guarantees that U.S. businesses will have the talent necessary to compete in a global economy.

Finally, the scientific community must do its part. We must be champions of transparency. Our processes, institutions, and the conduct of research itself must be unassailable. We must work together to stamp out fraud, be forthright about the limits of our knowledge, and hold ourselves to our highest ideals. We must publish our data and describe our methods clearly so our peers can critique our results. For NSF, this means ensuring the integrity of merit review, advancing the best ideas, and promoting the progress of science in a way that is transparent, accountable, and can be understood and appreciated by taxpayers.

As this Committee has recognized throughout its history, promoting the progress of science is essential to America's future. We look forward to working with you toward a reauthorization of NSF that empowers the nation's scientists to explore those endless frontiers. Thank you.

[The prepared statement of Dr. Zuber follows:]

Testimony of
Maria T. Zuber, Ph.D.
Chair
National Science Board
National Science Foundation

Before the
Subcommittee on Research and Technology
for the
Committee on Science, Space, and Technology
U.S. House of Representatives

March 21, 2017

"National Science Foundation Part II: Future Opportunities and Challenges for Science"

Introduction

In July 1945, Vannevar Bush, the head of the Office of Scientific Research and Development during World War II and one of my predecessors at MIT, sent the White House a landmark report titled, *Science - the Endless Frontier*. In that report, Bush outlined a vision for national investment in fundamental scientific research and the next generation of scientists. As Bush wrote in his letter of transmittal, "Science offers a largely unexplored hinterland for the pioneer who has the tools for his tasks. The rewards of such exploration both for the Nation and the individual are great. Scientific progress is one essential key to our security as a Nation, to our better health, to more jobs, to a higher standard of living, and to our cultural progress."

Bush's observations about the value of fundamental research to the Nation came from direct experience. He and his colleagues had witnessed how insights from fundamental physics research conducted over the previous 20 years earlier had unexpectedly found application in the atomic bomb and other tools of the U.S. victory in World War II. Bush also saw firsthand the contributions of academic scientists. He led the Radiation Laboratory on MIT's campus during the war years, driving improvements in radar that changed the course of history.

Bush also realized that had it not been for the specific circumstances of the war, other nations might have reaped the fruit of fundamental research that had been conducted largely in Europe. Peacetime federal investment in research and scientists, Bush realized, would not only allow the United States to surpass European nations as a source of basic research, but it would, if sustained, release the United States from its dependence on other nations for the basic scientific knowledge foundational to our security and prosperity.

The result of Bush's vision was the National Science Foundation (NSF). For nearly 70 years, NSF has catalyzed pioneering basic research in *all* fields of science and engineering (S&E). This research has opened new windows on our universe, made possible new industries, and given all Americans life-changing and life-saving technologies. Last year, NSF researchers—through the LIGO experiment (the Laser Interferometer Gravitational-Wave Observatory)—observed gravitational waves. These ripples in the fabric of the universe confirmed a key prediction of Einstein's theory of general relativity and opened a new approach to studying fundamental questions about the universe. LIGO is but one of NSF's many successes. NSF-funded research led to the invention of core routing protocols of the Internet, the original algorithms for the Google Search engine, and the lithium ion batteries and touch screen technologies of the iPhone. These and other developments have put hundreds of thousands if not millions of Americans to work and improved our Nation's prosperity and security.

Thanks to nearly 70 years of sustained federal investment in basic research, today's hinterlands of science differ from those of 1945. However, Bush's conviction about the importance of fundamental research to the United States' future economy, security, and prosperity remains every bit as relevant. As the second decade of this new century draws to a close, we find ourselves in an increasingly competitive global landscape with challenges that only the insights of science and technology and the ingenuity of the American workforce can help us address.

Meeting challenges and seizing the opportunities of today and tomorrow requires NSF, Congress, the Administration, and the research community to continue to work together to support U.S. S&E leadership. The past 70 years has provided us with a blueprint: sustained, predictable federal investment in curiosity-driven research across all fields of S&E, preparing a STEM-capable U.S. workforce, and maintaining the faith and confidence of the American public. Only by working together will our Nation realize the promise of the future.

Basic Research – The Bedrock

Fundamental, curiosity-driven research supported by NSF forms the basis of the U.S. science and technology ecosystem. As the largest source of federal support for non-medical, basic S&E research at U.S. colleges and universities, NSF drives the earliest stage of research. By building deep domain knowledge across all fields of S&E and laying the groundwork for commercialization through our Innovation Corps, Small Business Innovation Research, and Small Business Technology Transfer programs, NSF creates the foundation for the mission-oriented science pursued at other agencies and technological innovations that industry develops and brings to market.

Building the foundation for the science and technology enterprise is a critical task, not the least because science and technology have been responsible for over half of the growth in the U.S. economy since World War II. For its part, NSF fuels this enterprise by supporting a robust portfolio that includes a mix of core and directed research in all fields of S&E. Priorities for this portfolio are set using a mixed bottom-up and top-down approach that incorporates extensive input from the research community, NSF senior leadership, National Science Board (NSB; Board), the Administration, Congress, and industry. To ensure that every proposal NSF funds represents the best science in the national interest we use NSF's internationally-acclaimed merit review system.

Unsolicited core research allows researchers to follow the science and deepen fundamental knowledge in all fields. Rather than picking winners and losers *a priori*, this core research takes advantage of the creativity and ingenuity of the best minds America has to offer to drive science progress—often in unanticipated, groundbreaking directions. This crowd-sourced, grass-roots approach to finding ideas and research opportunities is the bedrock of NSF's success. It has created a stock of knowledge, tools, and methodologies that can be drawn on by industry, inventors and entrepreneurs, other scientists and engineers, and even the public for generations. Core research also lays the foundation of knowledge critical for pathbreaking work at the intersection of fields—what is often called interdisciplinary or convergent research.

NSF couples unsolicited core research with initiatives that encourage research germane to timely concerns and/or opportunities for U.S. scientific leadership. Directed initiatives help to break down disciplinary silos, accelerate progress on particularly challenging matters, and move science in directions that provide opportunities for strengthening U.S. global leadership. At the Board's urging, this year NSF identified 10 Big Ideas to help drive NSF's long-term research agenda. These ideas, which NSF has generated in concert with us and the community, provide a blueprint for today's scientific hinterlands that are ripe for exploration. The Big Ideas, which range from data science and the quantum leap to the human/technology frontier and the new Arctic, would enable NSF and the United States to push the boundaries of science, seize new opportunities, and ensure U.S. leadership on topics that are of national interest and global competition.

Scientific discoveries advance in concert with tools and technology, as the recent LIGO detection underscores. NSF's major facilities, including research vessels, supercomputers, telescopes, laboratories, and more, span the United States and the globe. These assets are vital to new discoveries and to sustaining the Nation's S&E enterprise. As we evaluate our facilities portfolio, NSF must balance continued operations and maintenance of our existing highly productive research infrastructure with the development of new, cutting-edge facilities. In addition, funding for facilities must be balanced against funding for research.

Workforce of the Future

Ensuring the long-term strength of the Nation's scientific workforce has always been a core component of NSF's mission. Our workforce has been—and continues to be—the essence of American innovation, economic competitiveness, and national security. In 1950, Vannevar Bush wrote that "the responsibility for the creation of new scientific knowledge - and for most of its application - rests on that small body of men and women who understand the fundamental laws of nature and are skilled in the techniques of scientific research." At that time, and for the next several decades, this meant scientists and engineers engaged in research and development (R&D) in government, academic, or industry laboratories.

How we think about this workforce has evolved—and expanded—since NSF's founding. While the education and training of scientists and engineers who perform fundamental research—our Nation's "Discoverers"—remains at the heart of NSF's mission, we now recognize that STEM capabilities are important to the *entire* U.S. workforce. As we look towards the next 70 years, the NSB believes that for our Nation to continue to thrive and lead in a globally competitive knowledge- and technology-intensive economy we must do more than create a "STEM workforce"; Congress, the Administration, business leaders, educators, and other decision-makers must work together to create a STEM-capable **U.S. workforce**.

Why is this so important to our Nation's future? Scientific and technological advances have transformed the workplace, especially in traditionally middle-class, blue-collar jobs such as manufacturing. These and many other jobs now demand higher levels of STEM knowledge and skill. In 2013, about 13.3 million U.S. workers were employed in a STEM job. Yet in a survey of individuals with at least a four-year degree, including many working in sales, marketing, and management, an estimated 17.7 million reported that their job required at least a bachelor's degree level of STEM expertise. And the number of non-STEM jobs requiring these skills is growing. Fostering a STEM-capable U.S. workforce ensures that all Americans are prepared to meet evolving workplace demands. Likewise, it ensures that existing and new American businesses have the talent necessary to compete and win in a global economy.

Creating a STEM-capable U.S. workforce requires a more expansive vision for STEM. This vision includes students and workers at all education levels, working on the farm, the factory floor, the laboratory, and everywhere in between using STEM capabilities to learn, adapt, install, debug, train, and maintain new processes or technologies. This vision includes women, traditionally underrepresented groups, and blue-collar workers who were hard hit by transformations in the domestic and global economy. This vision of a STEM-capable U.S. workforce does not replace what Vannevar Bush originally envisioned. It builds on that foundation to more fully mobilize what he called the vigorous "pioneer spirit" within our Nation and all of its people.

Turning this vision into a reality requires the public, private, and nonprofit sectors working together to ensure that all Americans have access to high-quality, affordable education and training. NSF is at the forefront of training the next generation of scientists and engineers, weaving education and training throughout our research grants in addition to dedicated Education and Human Resources (EHR) programs. I will focus on a few specific examples of how NSF contributes to achieving this vision.

NSF's **Graduate Research Fellowship Program** is the country's oldest fellowship program that directly supports graduate students in all STEM fields. Since 1952, NSF has funded over 50,000 Graduate Research Fellowships. NSF Fellows represent our future leaders and experts who can contribute significantly to research, teaching, and innovations in STEM. Currently, 42 Fellows have gone on to become Nobel laureates, and more than 450 have become members of the National Academy of Sciences.

Individuals with advanced degrees in STEM not only generate new knowledge through R&D activities that fuel innovation, but they also add value throughout our economy in STEM and non-STEM jobs alike. The **NSF Research Traineeship** (NRT) program ensures that graduate students develop the skills, knowledge, and competencies to pursue a range of STEM careers, especially in areas of national need, such as cybersecurity and data science, brain research, and the food-energy-water nexus. NRT emphasizes institutional capacity building and encourages partnerships with the private sector, non-governmental organizations, government agencies, national labs, and other relevant groups.

In addition to the fellowships and traineeships aimed at graduate students, NSF contributes to the education and training of the next generation of STEM-capable workers in other critical ways. The **Research Experiences for Undergraduates** (REU) program supports active research participation by undergraduate students in the areas of research funded by NSF. **EHR Core Research** (ECR) supports fundamental research into STEM learning and learning contexts, both formal and informal, from childhood through adulthood, for all groups, and from the earliest developmental stages of life through

participation in the workforce. ECR provides a coherent foundation of research evidence to guide and improve STEM learning, STEM workforce development, and Federal STEM investment strategies.

Deeply embedded in the vision of a STEM-capable U.S. workforce is the imperative that all Americans be afforded the opportunity to participate in and reap the benefits of our Nation's great scientific endeavor. NSF supports this goal through its numerous investments aimed at tapping into populations historically underrepresented in STEM. For example, **NSF INCLUDES** ("Inclusion across the Nation of Communities of Learners of Underrepresented Discoverers in Engineering and Science") is a national initiative designed to ensure that all Americans have access to educational and career opportunities enabled by STEM. Multiple NSF programs focus on elucidating how students can better understand and employ skills in computer science and computational thinking. The **Advanced Technological Education** (ATE) program is focused on two-year colleges and supports the education of technical workers who form the backbone of our S&E enterprise.

This vision for the future workforce can be realized only through the bipartisan efforts of Congress and the Administration. Recently, the President signed into law two bipartisan bills that exemplify this. The *Promoting Women in Entrepreneurship Act* mandates that NSF should "encourage its entrepreneurial programs to recruit and support women to extend their focus beyond the laboratory and into the commercial world." The *Inspiring the Next Space Pioneers, Innovators, Researchers, and Explorers (INSPIRE) Women Act* directs NASA to "encourage women and girls to study science, technology, engineering, and mathematics, pursue careers in aerospace, and further advance the Nation's space science and exploration efforts."

The bipartisan *American Innovation and Competitive Act* recognizes NSF's critical contributions to the development of a skilled, diverse, and globally competitive STEM-capable U.S. workforce. The NSB believes that NSF is poised to lead this development through its unique integration of basic research in all scientific fields with the education and training of a STEM-capable workforce. If we do not take advantage of this opportunity, U.S. businesses could look elsewhere to find the STEM-capable workers they need to compete. With the support of Congress, NSF will continue to make investments that ensure our Nation takes full advantage of the creativity, ingenuity, and hard work of all Americans.

Reproducibility, Transparency, and Confidence in Science

As scientists and engineers, we must be champions of transparency. It's not enough for the scientific community to point to our many accomplishments and expect public support. Our process, our institutions, and the conduct of research itself need to be unassailable. For the Foundation and Board this means ensuring the integrity of merit review and making sure that our grants and priorities fund the best ideas from the community and serve the national interest. It also means doing all of this in a way that can be understood and appreciated by taxpayers. NSF also needs to continue to work in partnership with research institutions to make sure that they comply with fiduciary requirements with the lowest possible administrative burden.

Scientists must work together to stamp out fraud, be honest about the limits of our knowledge, and generally hold ourselves to our highest ideals. Indeed, the reason we publish is to present our data and describe our methods openly to our colleagues and to the world. We want to help others to independently verify our conclusions, by reproducing our experiments where possible, and by designing and executing complementary experiments to test our conclusions. This openness is critical to maintaining credibility

among our scientific peers and with the public. This requires not just the traditional sharing of experimental techniques and measurements, but also openness into underlying data, algorithms, and software.

Public support for civilian science has served our Nation well over the past 70 years. This support has been made possible in large part due to the trust and confidence of the American people. In 2014, 90% of Americans expressed "a great deal" or "some" confidence in the leaders of the scientific community—second only to the military.[1] But we must not be complacent, and reports over the last few years of irreproducible results should concern all scientists. They certainly concern the Board.

Science is an ongoing process of hypothesizing, observation, experimentation, and testing. The scientific theories that are derived from this process are the product of many repetitions of this cycle. By its very nature, reproducibility and repeatability are essential to science. However, the process of science is not simply one of direct duplication of results—repeating the same experiment using the same data and identical protocols. Not every study is exactly repeatable—for example, studies that use data from one-time events such as natural disasters or observations of astronomical phenomena. Instead, the process involves doing multiple experiments or making multiple observations of the same or similar objects or phenomena (often by independent investigators), perhaps with different data sets, perhaps with a variety of techniques, that together lead to a recognition and verification of the underlying processes that can explain the observed results. These constitute the built-in mechanisms for reproducibility and self-correction—mechanisms that depend on transparency.

Of course, science is a human endeavor, and, as such, is replete with frailties and imperfections. Scientists need to recognize that and vigorously embrace our self-correcting norm, addressing the reported rise in irreproducible findings and retractions with sunlight and experiments designed to cross-check published results. As the sociologist of science Robert Merton put it more than half a century ago "the activities of scientists are subject to rigorous policing, to a degree perhaps unparalleled in any other field of activity." Instances when scientists detect and address flaws in work constitute evidence of success, not failure, because they demonstrate the underlying protective mechanisms of science at work. In fact, it is not always the case that the inability to reproduce a result indicates unreliable data, protocols, or analysis. Sometimes, the lack of reproducibility is the sign of a fundamental discovery.

We also recognize that scientists currently have few incentives to reproduce the work of others. In academia, researchers encounter institutional pressure to focus on work that will lead to publications, in order to land a job in an extremely competitive academic market, to progress in their careers, and to obtain grants to continue to pursue their research. It is challenging to publish studies focused on reproducibility in high-impact, high prestige scientific journals where emphasis is placed on novel, positive results. The incentives and outlets for publishing negative findings or null results are limited. Recognizing this issue, there are now a few journals devoted to publishing reproducibility studies. However, these journals are still new and relatively low-impact. This presents both a challenge and an opportunity. As we strive to raise our standards of scientific excellence ever higher, we must evolve the incentive structure in academia to reward quality over quantity, and to value the vital work of enhancing scientific credibility through independent corroboration of published results.

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[1] National Science Board (2016). *Science and Engineering Indicators 2016*. Chapter 7: "Science and Technology: Public Attitudes and Understanding."

Open access to data also presents a major opportunity and a challenge for science. We live in a data-rich age. "Big data" is already revolutionizing every area of science, allowing researchers to tackle previously elusive problems, including questions in the social, behavioral, and economic sciences that are among the hardest to crack. To harness the vast potential of these data streams, and to use the built-in mechanisms of science to ensure the integrity of published results, requires that the community have access to the underlying data. In addition, it is important that the protocols, experimental design, and techniques used to analyze the data be made available to the scientific community.

NSF's commitment to data sharing, and to clear and open communication of research findings, is long-standing. However, the issues surrounding open data are complex. For example, much biomedical research relies on medical and clinical data for which there are strong legal and institutional protections to preserve privacy. These protections often prohibit data-sharing with other researchers or with the public. Likewise, industrial data may be proprietary. Another factor to be considered is the sheer volume of data—terabytes or even petabytes per day—that are generated by many modern experiments such as LIGO, particle physics experiments, and major astronomical surveys. The infrastructure required to make all data output from these facilities fully open access may have significant budgetary and personnel impacts for academic institutions and scientific laboratories. These factors, which will only grow in prominence in the future, should all be considered when developing "open access" policies, keeping in mind that a "one-size-fits-all" approach may prove problematic.

To increase public access to scientific publications and the data resulting from research funded by the Foundation, NSF has already implemented a plan consistent with the objectives set forth by the Office of Science and Technology Policy in February 2013. For all awards resulting from proposals submitted since January 25, 2016, NSF requires that either the version of record or the final accepted manuscript be deposited in a public access compliant repository; be available for download, reading, and analysis free of charge no later than 12 months after initial publication; have a minimum of two machine-readable metadata elements available free of charge upon initial publication; and be managed to ensure long-term preservation.

Protecting the integrity of science is the responsibility of everyone in our community. All researchers need to recognize that the best science is produced when they persistently search for flaws in their arguments. Industry as well as academia should publish its failed efforts to reproduce scientific findings. Grant funding agencies and professional scientific societies should continue to educate their communities about ways to communicate key scientific findings more effectively to the public. Journals should continue to ask for higher standards of transparency and reproducibility.

To protect the hard-earned confidence society has in the scientific enterprise, to preserve the role of science and innovation as drivers of our economy, and to sustain the dynamic progress that has brought such benefits to our society and our world, we scientists must hold ourselves to the highest standards. Just as preserving a system of government requires unceasing dedication and vigilance, so too does preserving the integrity of science.

As this Committee has recognized throughout its history, science and technology are essential elements to America's future. We look forward to working with you toward a reauthorization of NSF that empowers scientists to ask fearless questions about ourselves, our world, and our universe and which supports exploration of those endless frontiers and hinterlands that represent the next steps in humanity's collective search for truth and understanding.

Maria T. Zuber

Biography

Geophysics
B.A., University of Pennsylvania, 1980
Sc.M., Brown University, 1983
Ph.D., Brown University, 1986

Maria T. Zuber, the E. A. Griswold Professor of Geophysics, has been a member of the faulty at the Massachusetts Institute of Technology since 1995 and served as the Head of the Department of Earth, Atmospheric and Planetary Sciences from 2003-2011. In January 2013, she was appointed Vice President for Research with overall responsibility for research administration and policy at the Institute. She oversees more than a dozen interdisciplinary research laboratories and centers, including the Koch Institute for Integrative Cancer Research, the MIT Energy Initiative, the Plasma Science and Fusion Center, the Research Laboratory of Electronics, the Institute for Nanosoldier Technologies, the Center for Material Science and Engineering, and the Haystack Observatory. The Office of Sponsored Programs, International Scholars Office, and Division of Comparative Medicine, among others report to the Vice President for Research. The VPR is responsible for research integrity and compliance and plays a central role in research relationships with the federal government.

Zuber's research bridges planetary geophysics and the technology of space-based laser and radio systems, and she has published over 300 papers. Since 1990, she has held leadership roles associated with scientific experiments or instrumentation on nine NASA missions; at present, she remains involved with six of these missions. Zuber is principal investigator for NASA's Gravity Recovery and Interior Laboratory (GRAIL) mission, an effort to map the Moon's gravitational field, begun in 2008.

Dr. Zuber has won numerous awards including the MIT James R. Killian Jr. Faculty Achievement Award, NASA's Outstanding Scientific Achievement Medal, Distinguished Public Service Medal and Outstanding Public Leadership Medal, as well as the American Geophysical Union Harry H. Hess Medal, the Geological Society of America G. K. Gilbert Award and the American Astronautical Society/Planetary Society Carl Sagan Memorial Award. She is a member of the National Academy of Sciences and American Philosophical Society, and is a fellow for the American Academy of Arts and Sciences, the American Association for the Advancement of Science, the Geological Society and the American Geophysical Union.

In 2004, Zuber served on the Presidential Commission on the Implementation of United States Space Exploration Policy. In 2002, Discover magazine named her one of the 50 most important women in science and, in 2008, she was named to the USNews/Harvard Kennedy School List of America's Best Leaders.

Chairwoman COMSTOCK. Thank you, Dr. Zuber. Now we'll hear from Dr. Spies.

TESTIMONY OF DR. JEFFREY SPIES,
CO-FOUNDER AND CHIEF TECHNOLOGY OFFICER,
CENTER FOR OPEN SCIENCE AND
ASSISTANT PROFESSOR, UNIVERSITY OF VIRGINIA

Dr. SPIES. Chairwoman Comstock, Ranking Member Lipinski, Ranking Member Johnson, other Members of the Subcommittee, thank you for inviting me to speak with you today.

I'm the Co-Founder and Chief Technology Officer of the Center for Open Science, a non-profit technology company missioned to increase openness, integrity, and reproducibility of scholarly research.

NSF has had a tremendous record of success by trusting sound scientific process. My recommendations today are in service of making an already-efficient process work better. To be clear, the issues that I will describe are not the same as headline-grabbing cases of fraud or misconduct, which are relatively rare. Science doesn't have an honesty problem. It has a communication problem.

Scientific results gain credibility by demonstrating that evidence can be independently reproduced. This means that someone else can obtain similar evidence with the same data or with the same methodology. Reproducibility requires that the process used to obtain a result is described in sufficient detail. But science is complex. Brief descriptions of scientific papers cannot provide enough detail to capture the nuance necessary to facilitate reproducibility.

We need to fall back on two simple concepts that everyone learned in elementary school: show your work and share. Because if much of the scientific process is open as reasonably possible, the materials, methods, data, software analyses, then replication can occur more easily, more frequently, and with greater efficacy. Openness should be the default for scientific communication, but currently it is not. The reward system in science is built around publishing. Getting published, however, has very little to do with research being reproducible. It has to do with novel results and clean narratives. But science is often messy and ambiguous. And if we hide the messiness away, we hamper scientific progress. We need to show our work and we need to share.

These same solutions can also prevent and correct those rare cases of misconduct. And even when we can't show all of our work, for example when data must be kept private, there are still incremental steps that can increase credibility.

Openness has another benefit. If paired with outreach and education, individuals who would otherwise not be able to participate in science would now be able to do so. And because these individuals are likely to be from groups typically underrepresented in science, we would see greater efficiency not only from an increased number of contributors but from the benefits that diversity brings to collaboration and innovation.

NSF has already taken steps to encourage openness. In my written testimony submitted for the record I detail recommendations to expand upon that process. These fall into five categories.

First, metascience. NSF could fund investigations of reproducibility and reproducible practices.

Second, infrastructure. NSF could fund technology that could, for example, facilitate open reproducible practices or enable the analysis of data that must remain private.

Third, training. NSF could add reproducibility training to its research fellowships and trainingships.

Fourth, incentives. NSF could encourage the release of preprints for rapid dissemination of research. It could also fund pilots, like registered reports, where publication and award are based upon the importance of the research question and quality of the methodology, rather than the outcome.

And fifth, community. NSF could convene stakeholders to discuss and adopt guidelines that would increase the pace of change.

The scientific process that continuously improves our current understanding of the world is itself continuously improving. Critique and new evidence lead towards understanding. When we invest in NSF, we're investing in this process. When we invest in openness and reproducibility, we are making the path towards understanding easier to navigate. This path leads us incrementally towards the next innovation that will increase the quality of life here and abroad. I would like to see us get there as quickly as possible, and I believe that an increased focus on openness and reproducibility will do just that.

Thank you for this opportunity, and I look forward to your questions.

[The prepared statement of Dr. Spies follows:]

Testimony of

Jeffrey R. Spies, Ph.D.

Chief Technology Officer
Center for Open Science

Visiting Assistant Professor
Department of Engineering and Society
School of Engineering and Applied Science
University of Virginia

Before the

House Committee on Science, Space, and Technology
Subcommittee on Research and Technology
U.S. House of Representatives

March 21, 2017

"National Science Foundation Part II:
Future Opportunities and Challenges for Science"

Chairwoman Comstock, Ranking Member Lipinski, and Members of the Subcommittee, on behalf of myself and the Center for Open Science, thank you for the opportunity to discuss the role of the National Science Foundation in promoting openness and reproducibility in science.

The impact of science and the results of National Science Foundation (NSF) funding are readily observed in our everyday lives: in the food that nourishes us, the transportation that moves us, the buildings that shelter us, the technology that connects us, and the medicine that heals and saves us. The return on investment of NSF-funded science is immense no matter how the impact of that investment is measured, be it dollars, jobs, or lives. This makes sense. NSF has a diverse portfolio, and science is a very safe bet, for it is a process that is ever improving, self-corrects, and results in increased understanding no matter the substance outcome.

I am the co-founder of the Center for Open Science, a nonprofit technology company based in Charlottesville, Virginia. Our mission is to increase openness, integrity, and reproducibility of scholarly research. As the Chief Technology Officer, I direct the technical strategy of our free, open-source products, like the Open Science Framework--a platform for managing workflow as well

as collaborating on and sharing research.[1] I also co-lead SHARE, a partnership with the Association of Research Libraries to build a free, open data set about scholarly research across the research life cycle.[2] I very much have an interest in openness, but it is not as some grand ideal--openness is a practical means of increasing research efficiency, quality, accessibility, and diversity. Openness amplifies the features intrinsic to science--including reproducibility--that make the scientific process such an efficient way of learning about the world.

NSF has had a tremendous record of success by trusting sound scientific process. It is certainly not my intent to claim that in some way science is broken and no longer trustworthy. In fact, to discredit or ignore any body of evidence that comes from such a process would disrespect the same process that has resulted in society-altering advances. Although I will describe challenges that science currently faces, my recommendations to NSF on incentivizing openness and reproducibility through its grant programs is only in service of making an already efficient process work better.

The Challenge of Reproducibility

Scientific results gain credibility by demonstrating that evidence can be independently reproduced (a word I will use interchangeably with replication although their meaning can differ). This means that someone else can take the same data and observe the same outcomes; that someone else can repeat the essential part of the methodology, collect new data, and obtain similar evidence for the claim; and, that someone else can test the same idea with a different methodology and find similar evidence. For example, the same earthquake can never be repeated, but a scientific claim (hypothesis) can be identified for what should occur when another earthquake that shares the essential features occurs again in the future.

For the last few years, science has been characterized as being in a "reproducibility crisis", partly as a consequence of evidence gathered by the Center for Open Science. Collaborating using the Open Science Framework, 270 co-authors attempted to replicate 100 studies from three prominent psychology journals.[3] We found a rate of replication between 39 and 47% depending on the measure. Since then, more than 10 reanalyses of our data have been reported with varying conclusions. These rates are less than one would hope, but "crisis" was not a term we used. Moreover, it is something of a misnomer because this movement is actually just an illustration of the scientific method in practice. This round of self-skepticism is offering new solutions to improve our processes to thus increase the overall efficiency and quality of science.

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[1] See http://osf.io/.

[2] See http://share-research.org/.

[3] Open Science Collaboration. (2015). Estimating the reproducibility of psychological science. *Science*, 349(6251). doi: 10.1126/science.aac4716. Everything needed to reproduce the study is available at https://osf.io/ezcuj/.

A requirement for reproducibility is that the process used to obtain a result is described in sufficient detail. And for correction to occur, failed replications must be added to the body of evidence for a given result. Neither is happening frequently enough, and that is making science less efficient than it could be. To be clear, this is not the same as the fraud or misconduct that has been brought to light by failed replications. While those cases certainly make for buzzworthy headlines and exciting stories, they are relatively rare occurrences. And NSF, for example, has in place mechanisms for investigating and appropriately dealing with offenders. But, again, fraud and misconduct are rare. Science does not have a dishonesty problem; it has a communication problem. And it impacts every domain of science.

Much of the problem stems from the simple fact that science is complex. Brief textual descriptions in scientific papers often cannot provide sufficient detail to capture the nuance necessary to facilitate replication. This is the case for openness as the default standard in scientific communication. If as much of the scientific process is open as reasonably possible, then replication can occur more easily, more frequently, and with greater efficacy. If false leads are discovered, they can be discarded, and correction can occur at a faster pace.

Open-by-default is not the current norm. The present scholarly culture is closed by default--we have to justify why something should be open rather than why it should be closed. The current culture does not incentivize a level of description that makes reproducibility efficacious. More so, it does not facilitate or promote the conducting or communicating of failed replications. Much of this is driven by the currency system in science: publication.[4] Scientists are rewarded for publishing as frequently as possible in the most prestigious outlets as possible--this is how they get jobs, promotions and tenure, and funding. Getting published, however, has very little to do with research being open or reproducible; it has to do with novel, positive results and clean, confirmatory narratives. Journals have traditionally avoided publishing studies that did not work as expected or for which the results are messy and ambiguous. But that is exactly how much of science works--to ignore it is to fill the file drawers with unpublished but potentially important findings that no one has access to, reducing the efficiency by which we can make scientific progress.

In a competitive environment, researchers are forced to make choices that increase the likelihood of publication. These are often unwittingly biased decisions that humans have a very difficult time avoiding. The result is increased publications, but decreased accuracy. Transparency maximizes the ability of science to self-correct via critique and replication. And it has the exact same benefit for those rare cases of fraud.

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[4] Nosek, B. A., Spies, J. R., & Motyl, M. (2015). Scientific Utopia: II. Restructuring incentives and practices to promote truth over publishability. *Perspectives on Psychological Science. 7*(6) 615-631. doi:10.1177/1745691612459058

The Values of Openness

Reproducibility is a core value of science, and its success depends on the ability to understand how a result was obtained. There is often considerable nuance baked into components of the research process, including materials, methods, software, and analyses. Scholarly claims become credible via transparent communication of the supporting evidence and the process of acquiring that evidence. This way, independent observers can evaluate the quality of evidence for supporting the claim. If bias crept into the process or interpretation of results, it would be detectable when the process is open.

While openness can certainly benefit science with respect to amplifying its corrective features, it has another benefit: accessibility and inclusivity. If the goal of scholarly research is the public accumulation of knowledge--if knowledge is a public good--then a default of openness is the first step in removing exclusionary criteria for participation (e.g., monetary cost). If paired with an environment that facilitates and fosters participation through active invitation and education, individuals who would otherwise not be able to contribute to science would be able to participate. Because the individuals most often excluded are minorities in the sciences, science would see efficiency gains not only from the increased number of contributors but from the benefit that diversity brings to collaboration and innovation.

On both of these two dimensions--credibility and accessibility--there are varying degrees of openness that can be incrementally applied to increase the efficiency and quality of science. It is not all or nothing. There are occasions when openness is not possible or when a degree of open is good enough or better than nothing. For example, if data is protected health information and cannot be shared publically in the interest of human participants, there are a number of methods to still increase the credibility of the work. These include opening other components of the research process while excluding the data or making data available to authorized individuals for the purpose of auditing. In the former, you would still see benefits of accessibility, while in the latter, the focus would be on improving the credibility of the work.

Most of the changes that can help science operate more efficiently and maximize knowledge accumulation are related to two simple concepts that everyone learned in grade school: show your work and share.

Show your work. If scientists transparently show how they arrive at their claims, then the marketplace of ideas, critique, and self-correction can operate efficiently. If others cannot see the outcomes, the data supporting the outcomes, and the process by which those outcomes were produced, then it is harder to identify their strengths and limitations.

Share. If scientists share their materials and data openly, others can independently reproduce the findings and reuse the materials to challenge or extend the work. Without sharing, it is much more difficult to accumulate evidence and move toward certainty.

Recommendations

I would make the following recommendations to any funder in the sciences with an interest in increasing research efficiency and quality via openness and reproducibility. They fall into five categories:[5]

- **Metascience**, collecting evidence to encourage change.
- **Infrastructure**, developing technology to enable change.
- **Training**, disseminating knowledge to enact change.
- **Incentives**, promoting reasons to embrace change.
- **Community**, fostering inclusion and connection to propagate change.

NSF has already taken steps to encourage the values of openness and reproducibility, but, as one of the largest funders of the sciences, NSF has a unique platform to continue promoting and thus accelerating the adoption of open and reproducible practices. A cultural shift must take place, and NSF's continued endorsement can quicken the pace of change.

- **Fund efforts to investigate reproducibility through metascience**. Studying reproducibility is not as glamorous as producing new science, but NSF could create strong incentives for this critical work by creating dedicated funding mechanisms to pursue investigations of reproducibility and create a robust science of reproducibility to determine best practices and advance our knowledge of the efficacy of reproducible practices.
- **Fund public goods infrastructure to improve openness and reproducibility across the research lifecycle**. In order to get robust participation in openness and reproducibility efforts, especially while incentives are not aligned with these practices, technology is needed to make that participation as effortless as possible for scientists. At COS we are building open-source platforms for data sharing and access to research description (i.e., metadata). NSF could dramatically expand the infrastructure available to scientists by funding the development and testing of new platforms and collaborations.
- **Fund curation activities and infrastructure to link research workflow, people, and institutions in order to aid in discovery, reuse, analytics, and metascience.** As components of the research process are made openly available (e.g., data, code, software)--likely on disparate platforms--it is important that they are related in a way that discovery of one leads to discovery of the others. This includes the use of persistent

[5] These are the same categories that we use at COS to organize the tasks necessary to meet our mission. See more in our strategic plan at https://osf.io/x2w9h/.

identifiers for content, people, and institutions. This will accelerate reproducibility and reuse and aid metascience efforts.

- **Fund the development of techniques and infrastructure that would allow for the analysis of sensitive data that cannot be made open.** There are a number of research areas and endeavors that would allow for reproducibility and reuse while data remain private. For example, secure (multi-party) computation uses cryptography to conduct analyses on data that is never exposed.
- **Fund development and dissemination of training to improve reproducibility**. Shifts in culture start with training. NSF could add reproducibility training to its research fellowship and traineeship programs, ensuring that new scientists are being mentored in these areas. NSF could also include reproducibility in training requirements like Responsible Conduct of Research training.
- **Fund projects to develop and test new models of scientific investigation and communication, including Registered Reports**.[6] NSF could fund pilots where awards and publications are based upon a review of the importance of the research question and the quality of the methods. Presently, a bias against reporting negative or null results exists because the perceived likelihood of having those results published is very low. Registered Reports include peer review before results are known to eliminate this reporting bias--the rewards are earned regardless of the outcome. Further, peer feedback occurs early enough to meaningfully impact the research rather than after the work has been completed and the manuscript has been written. Another model that could be developed is that of adversarial collaboration, where a study is conducted by two experimenters with competing hypotheses. The experimenters collaborate on the design and methods until both are satisfied that their hypotheses can be fairly tested. This model could be especially useful to make progress on contentious issues.
- **Promote and support the release of preprints for the rapid dissemination of research.** A preprint is a manuscript that precedes a peer-reviewed publication. The latter can take months to years to reach the scientific community. Peer-review is an important aspect of science, but discourse, evaluation, and feedback can occur within the community prior to publication if it is made available to them. Preprints are standard practice in some fields (e.g., physics) and mostly unknown in others (e.g., life sciences). Promotion could include encouragement for the immediate release of manuscripts as preprints as well as citation of preprints in grant applications and reporting.
- **Promote and fund the sharing and reuse of all components of the research workflow including publications and data; study the outcomes of an open approach.** Momentum is increasing around the opening of publications (open access) and data (open data), but there are other components of the scientific process useful for reproducibility and

[6] See https://cos.io/rr/.

reuse including software and analyses. Rather than waiting for momentum to build around each of these individual components, an open workflow approach could be adopted immediately--encouraging the sharing of as much of the research process as possible.

- **Convene communities to discuss and adopt recommendations and guidelines to shift incentives in order to align scientific values with scientific practices**.[7] Cultural change could be accelerated by a multi-faceted approach across stakeholders in the ecosystem, including journals, societies, and tenure committees. Alignment with other stakeholders or recommendations to other stakeholders could create the momentum needed to increase the pace of change.

Closing

The scientific process that continuously improves our current understanding of the world is itself continuously improving. The knowledge acquired by this process is only made better by critique and new evidence because the process can only lead in one direction: towards understanding. At any given time, that understanding may not be what we want to hear, or it may be more ambiguous than we would like--indicating that the problem is perhaps more complex than we thought. Either way, we may choose to go in the opposite direction, ignoring the signs that read "Wrong Way" and "Turn Back". Regardless of how stubborn we are, the process will continue working, and, when we are ready to trust it again, it will steadily lead us back towards understanding.

When we invest in NSF, we are investing in this process. And when we invest in openness and reproducibility, we are making the path towards understanding more recognizable, the terrain easier to navigate, the trek less lonely, and the warning signs more insistent.

This path leads us incrementally towards the next innovation that increases the quality of life here and abroad. I would like to see us get there as quickly as possible, and I believe that an increased focus on openness and reproducibility will do just that.

We at the Center for Open Science would be glad to continue this discussion and support the efforts of this committee and NSF in pursuit of increased openness and reproducibility.

Thank you for the opportunity to speak with you today. I will be happy to answer any questions you may have.

[7] As an example, see http://cos.io/top for the Transparency and Openness Promotion (TOP) Guidelines developed by community stakeholders and endorsed and adopted by journals, funders, and societies.

Jeffrey R. Spies, Ph.D.
Chief Technology Officer, Center for Open Science
Visiting Assistant Professor, Dept. of Engineering and Society, University of Virginia

Dr. Jeffrey Spies is the co-founder and Chief Technology Officer of the Center for Open Science (COS), a non-profit technology company missioned to increase openness, integrity, and reproducibility of scholarly research. COS was launched in 2013 with a $5.25M grant from the Laura and John Arnold Foundation and has since raised over $21M in additional funding. Spies is also the co-lead of SHARE, a partnership with the Association of Research Libraries to create a free, open data set of scholarly research activity across the research life cycle. Spies holds a Visiting Assistant Professor position in the Department of Engineering and Society at the University of Virginia's School of Engineering and Applied Science.

Spies was recently named an Association for Psychological Science Rising Star for early career scientists whose "work has already advanced the field and signals great potential for continued contributions." He is regularly invited to speak on topics of openness, reproducibility, workflow, and the role of technology in scholarship.

Spies completed his undergraduate work at the University of Notre Dame, where he also earned his Masters while in a joint program in Psychology and Computer Science. He went on to receive his Ph.D. in Quantitative Psychology from the University of Virginia. His dissertation included the development of the Open Science Framework--a free, open source workflow management system and scholarly commons that is now the flagship product of COS.

Chairwoman COMSTOCK. And now we will hear from Dr. Yamamoto.

TESTIMONY OF DR. KEITH YAMAMOTO,
VICE CHANCELLOR FOR SCIENCE POLICY AND STRATEGY,
UNIVERSITY OF CALIFORNIA, SAN FRANCISCO

Dr. YAMAMOTO. I am Keith Yamamoto, Vice Chancellor for Science Policy and Strategy and a molecular biologist researcher at the University of California, San Francisco.

Thank you for the opportunity to discuss with you today two topics important for consideration of the future of NSF. First, the opportunities, imperatives, and barriers to achieving transdisciplinary science, and second, the wisdom and perils of prioritizing research around scientific or societal needs and challenges.

First, transdisciplinary science which is virtually a merger of the physical and natural sciences, engineering, and computation as distinct from interdisciplinary or multidisciplinary interaction or cooperation between distinct endeavors.

Reports from the National Academy of Sciences and the American Academy of Arts and Sciences call for the construction of a computational knowledge network that detects the relationships between different concepts, data, and technologies, enabling assembly of transdisciplinary teams, each team member with different specialized expertise working together to tackle difficult, important problems.

Importantly, the role and need for specialization is maintained, but a general transdisciplinary literacy would fuel network approaches to solving problems that are invisible or intractable within siloed disciplines. Transdisciplinary teams would elevate the risk profile of academic research and increase the number of spectacular, unexpected advances.

Of the 25 or so federal agencies that currently support scientific research, NSF is the best situated to establish transdisciplinarity, thanks to Vannevar Bush who we heard about before who proposed creation of the NSF in his remarkable report, Science, the Endless Frontier.

He proposed the NSF as the sole federal agency to support all U.S. basic research and education programs. It is wholly possible, wholly probable, he said, that progress and the treatment of refractory diseases will be made in subjects unrelated to those diseases, perhaps in chemistry or physics.

Support of all basic research and advanced science education should be centered in one agency because separation of the sciences in more than one agency would retard scientific knowledge as a whole.

While Bush lost the battle for a single basic science agency, today's NSF is divided into seven disciplinary directorates that cover much of the scientific landscape necessary for today's and tomorrow's research and education. However, bureaucratic and fiscal silo walls establish intellectual silos as well, inhibiting effective transdisciplinarity.

To achieve transdisciplinary research and education, actions are needed both within and outside of NSF. Within NSF, I suggest cre-

ation of a new organizational layer that floats above the directorates and are sectored into big idea or big challenge research programs that cross directorate boundaries. The directorates would retain most of the funds to be awarded—let's say 90 percent—with the remainder transferred to the idea or challenge programs which would oversee the peer review process and supplement awards to transdisciplinary projects, in effect, returning funds to directorates that choose to co-host transdisciplinary teams.

Education programs would continue to emphasize specialized expertise but would additionally build transdisciplinary literacy to motivate team-based research.

Outside of NSF, the OSTP, for example, might be charged with framing a few societal grand challenges with funding to incentivize multiple federal agencies to develop joint programs to leverage their particular strengths and resources. This would begin to address current inefficiencies, fragmentation, and competition between federal agencies.

My second topic examines prioritization of NSF research around scientific or societal needs and challenges. Despite Vannevar Bush's passionate prioritization of curiosity-driven basic research, careful development of NSF grand challenges, or big ideas, is justified by the urgency to address certain societal needs and by the imperatives of social justice to correct disparities in access to social services.

Well-enunciated grand challenges will broaden the minds of those who participate and will broaden the tent to attract new participants. Imagination will still rule.

The scale and scope of the challenges will determine if they best reside within NSF or rather merit attention and support across multiple agency boundaries.

In conclusion, NSF meets its mandate to support a broad spectrum of basic research. However, the well-justified organizational boundaries that separate its directorates create barriers to achieving transdisciplinary science. Novel organizational approaches should be considered both within NSF and between agencies to lower those barriers.

Finally, NSF can stay true to its mission to support basic discovery and even improve upon it by careful framing of support programs in the context of big ideas and grand challenges.

This concludes my testimony. I would be pleased to answer any questions that you might have.

[The prepared statement of Dr. Yamamoto follows:]

National Science Foundation Part II:

Future Opportunities and Challenges for Science

Statement of Keith R. Yamamoto, PhD

Vice Chancellor, Science Policy and Strategy
Director, UCSF Precision Medicine
Professor, Cellular and Molecular Pharmacology
University of California, San Francisco

Before the

Subcommittee on Research and Technology

Committee on Science, Space, and Technology

U.S. House of Representatives

March 21, 2017

Good morning, Chairman Comstock, Ranking Member Lipinski and Members of the Subcommittee. Thank you for the invitation to present a statement before you today. I am Keith R. Yamamoto PhD, Vice Chancellor for Science Policy and Strategy, Director of Precision Medicine and Professor of Cellular and Molecular Pharmacology at the University of California, San Francisco. I received a Bachelor of Science from Iowa State University and a PhD from Princeton University before migrating to San Francisco, where I have been on the faculty for 41 years. My molecular biology lab has been studying the detailed mechanisms by which small molecules made in our bodies, hormones, control important physiological processes such as metabolism, stress responses and immunity; that research has been recognized by my election to the National Academy of Sciences, the National Academy of Medicine and the American Academy of Arts and Sciences, among other honors, and in the course of that work, I have had primary responsibility for mentoring approximately 100 PhD students and postdoctoral scholars. Our research has been funded continuously by grants from NIH, and commonly from NSF; we are currently funded by both agencies.

For over 35 years, I have also been active in matters of science and public policy, leading or serving on dozens of committees focused on a broad range of issues, challenges and opportunities, including matters of merit review, on which I testified in 2011 to this subcommittee. In particular, I chaired the Board on Life Sciences for the National Academy of Sciences, which produced two reports, "A New Biology for the 21st Century" and "Toward Precision Medicine: Building a Knowledge Network for Biomedical Research and a New Taxonomy of Disease", and co-chaired a study committee for the American Academy of Arts and Sciences that authored a report, "ARISE 2: Unleashing America's Research and Innovation Enterprise". These exercises and a range of related activities have provided me with a perspective on two topics essential for consideration of the future of NSF: [1] opportunities, imperatives and

barriers to achieving transdisciplinary science; and [2] wisdom and perils of prioritizing research around scientific or societal needs and challenges. In my testimony today, I shall address each of these matters from the context of a fundamental question: "If we were to start from scratch today, how would we organize the NSF to ensure that it motivates, identifies and supports the boldest, most innovative science with greatest intellectual and societal impact?"

Opportunities, imperatives and barriers to achieving transdisciplinary science

The New Biology, Precision Medicine and ARISE 2 reports all call for development of transdisciplinary science, virtually a merger of concepts and technologies of physical and natural (including cognitive and social) sciences, engineering and computation, as distinct from interdisciplinary or multidisciplinary interaction and cooperation between these endeavors. According to this concept, scientists would employ a computational "knowledge network" that identifies relationships or correlations between different concepts, data and technologies, enabling assembly of teams of highly trained specialists, each team member with different expertise, to form dynamic aggregations set to tackle difficult, important problems.

Thus, the role and need for specialization would be maintained, but a general "transdisciplinary literacy", coupled with computer-identified linkages of ideas and people, would open new and powerful networked approaches to address and solve problems that are intractable within any of our currently siloed disciplines. I have suggested elsewhere that if each investigator were to be involved in multiple (say, 5-10) such teams, he/she would comfortably include several very high risk problems, as other projects in his/her "portfolio" would be already succeeding or enjoy relatively high feasibility; de-stigmatizing failure, a cultural standard in Silicon Valley, could

dramatically change the risk profile of academic research, and increase the proportion of spectacular advances.

Of the ~25 federal agencies that support scientific research, NSF is best situated organizationally and philosophically, thanks to the remarkable vision and wisdom of Vannevar Bush, who proposed in his brilliant 1945 report, "Science the Endless Frontier" creation of the NSF to provide federal extramural support for *all* U.S. basic research and education programs. He could not have stated the rationale and the imperative more clearly: "new knowledge can be obtained only through basic scientific research", "no amount of achievement in other areas can insure our health, prosperity, and security as a nation", "it is wholly probable that progress in the treatment of...refractory diseases will be made...in subjects unrelated to those diseases, perhaps ... chemistry, physics", "a new agency should be established...devoted to the support of scientific research and advanced scientific education alone", "these functions should be centered in one agency", "separation of the sciences in compartments, as would occur if more than one agency were involved, would retard and not advance scientific knowledge as a whole."

Bush proposed five divisions: medical research; physical and natural sciences; national defense; education; publications and collaboration. Medical research, of course, was largely lost to NIH. Today's NSF has seven Directorates: biological sciences; computer and information science; education; engineering; geosciences; mathematical and physical sciences; social, behavioral and economic sciences. While these are generally reasonable and necessary specialty foci (except for the absence of health research) for today's and tomorrow's research and education, even within NSF, where some admirable multidisciplinary activities are in place, it is a natural outcome that bureaucratic and fiscal silo walls harden intellectual siloes as well, inhibiting in many, likely most cases, effective transdisciplinarity.

Actions are needed both within and outside of NSF to achieve the imperative for transdisciplinary research and education. Within NSF, I suggest creation of a new organizational layer that "floats" above the directorates, sectored into broad transdisciplinary "big idea" or "big challenge" research and education programs (see next section) that cross directorate boundaries. The directorates would retain most (say, 90%) of the funds to be awarded, with the remainder transferred to the idea/challenge programs, which would oversee the peer review process, and supplement awards to transdisciplinary projects, in effect returning funds to directorates that "co-host" transdisciplinary teams. Education programs would continue to emphasize specialized expertise, but would additionally seek to build transdisciplinary literacy that would promote team-based approaches to research problems.

Outside of NSF, I propose that a chosen body secure supplements to agency funds (including philanthropy and public-private partnerships) to highlight and approach a few societal-scale grand challenges (analogous in some ways to OSTP's Presidential Initiatives in the Obama administration), that would incentivize multiple federal agencies to develop joint programs that leverage their particular strengths and resources, *e.g.*, biomedical approaches at NIH coupled with materials and device engineering, and machine learning and high performance computing at NSF and DOE national labs. This would begin to address the fragmentation of federal support for scientific research across many agencies that currently communicate and cooperate sparingly, and indeed typically compete.

Wisdom and perils of prioritizing research around scientific or societal needs and challenges

"The Usefulness of Useless Knowledge", penned nearly 80 year ago by Abraham

Flexner and just renewed in a companion essay by Robbert Dijkgraaf, is a stirring and timeless assertion that untargeted, curiosity- and imagination-driven basic research is the sole essential enabling component behind the development of every society-transforming tool and technology. Vannevar Bush's aforementioned report echoes that assertion and charges NSF to uphold the mantle for basic research: "new products and processes are not born full-grown. They are founded on new principles and new conceptions which...result from basic scientific research. Basic research in scientific capital"; "the most important ways in which the Government can promote industrial research are to increase the flow of new scientific knowledge through support of basic research, and to aid in the development of scientific talent"; "there are within Government many groups whose interests are primarily in applying fundamental knowledge to the special problems of [their] Departments"; "there should be a focal point within Government [to] furnish the funds needed to support basic research in the colleges and universities".

Is there justification, then, for NSF to embrace grand challenges or big scientific goals, and can they be framed in ways that do not inhibit, indeed that *stimulate* scientific curiosity and imagination? Interestingly, yes. Perhaps the primary justifications are *urgency* (there are societal needs and challenges that must be addressed efficiently) and *social justice* (there are disparities in access to social services, *e.g.*, health care, clean air and water, that must not stand), and the hope is that putting a bright light on these issues will hasten fundamental discoveries that will in turn produce solutions. What greater Broader Impacts could there be?

Importantly, a well-framed grand challenge or big goal neither constrains curiosity and imagination, nor narrows the range of basic discoveries that can contribute. Indeed, a well-enunciated grand challenge cannot be addressed with current concepts and technologies, and is framed in ways that captures curiosities and imaginations, and

then *involvement*, of scientists thought at first to be outside the field, unable to contribute. Such was the case with the man-to-the-moon project in the 1960's, and the human genome project in the 1990's.

Thus, the right kinds of big ideas broaden the minds of those who contribute, and broaden the tent to new contributors. The scale and scope of the challenges will determine if they best reside within NSF or rather merit attention and support from multiple government branches and agencies. Good examples include some of the recently announced "Ten Big Ideas for Future NSF Investments" such as predicting characteristics of biological organisms, and creation of technologies that "collaborate with humans to enrich their lives in the workplaces of the future", or some of the grand challenges issued in 2015 by the National Academy of Engineering, such as "Reverse Engineer the Brain" or "Provide Access to Clean Water" or "Advance Health Informatics".

Perspectives

NSF is the federal agency that is best positioned to define, defend and support the broad spectrum of basic research that must receive public funds in order for our society, its citizens and its economy to thrive. In general, it addresses that challenge admirably, although it is constrained by organizational barriers that separate its disciplinary directorates at a time where true transdisciplinary science is essential to achieve the most significant advances. There are organizational approaches within and outside of NSF with potential to reduce or eliminate those barriers, and merit consideration. Although it is essential that NSF stay true to its mission to support basic discovery, it can meet that challenge, and perhaps even improve upon it, by framing its support programs in the context of big ideas and grand challenges.

This concludes my testimony. I would be pleased to answer your questions or address your comments. Thank you again for the opportunity to discuss these important matters with you.

Dr. Keith Yamamoto is UCSF vice chancellor for science policy and strategy, director of precision medicine for UCSF, vice dean for research in the school of medicine, and professor of cellular and molecular pharmacology at UCSF. He is a leading researcher investigating transcriptional regulation by nuclear receptors, which mediate the actions of essential hormones and cellular signals; he uses mechanistic and systems approaches to pursue these problems in pure molecules, cells and whole organisms. He has led or served on numerous national committees focused on public and scientific policy, public understanding and support of biological research, and science education; he chairs the Coalition for the Life Sciences, and sits on the National Academy of Medicine Council and the National Academy of Sciences Division of Earth and Life Studies Advisory Committee. As Chair of the NAS Board on Life Sciences, he created the study committee that produced "*Toward Precision Medicine: Building a Knowledge Network for Biomedical Research and a New Taxonomy of Disease*", the report that enunciated the precision medicine concept, and he has helped to lead efforts in the White House, in Congress, in Sacramento and at UCSF to implement it. He has chaired or served on many committees that oversee training and the biomedical workforce, research funding, and the process of peer review and the policies that govern it at NIH. He is a member of the advisory board for Lawrence Berkeley National Laboratory and the board of directors of Research!America. He was elected to the National Academy of Sciences, the National Academy of Medicine, the American Academy of Arts and Sciences, and the American Academy of Microbiology, and is a fellow of the American Association for the Advancement of Science.

Chairwoman COMSTOCK. Thank you all. And I now recognize myself for five minutes.

I appreciate the three guidelines, Dr. Zuber, that you laid out, maintain the investment. And I know we're not addressing the budget at all today but I can say for myself and probably a few others here, we are very interested in maintaining that budget. And so we are seeing discussion of cuts elsewhere. I think this is a very important time and very important work that we need to maintain that type of investment. And of course, the STEM-capable workforce that you mentioned is another important area to both create that pipeline but then also make sure those kids know that we are going to maintain the investment. So this is going to be a continued priority for us. And then thirdly, maintaining the trust and confidence of the public, which you've all addressed today.

And so I wanted to focus a little bit on that transdisciplinary approach and how we are going to take advantage of this opportunity I think we have now where you have the private sector very interested in investment, you need to maintain the public investment, and how are we best going to maximize both? And I want to emphasize that anything private is not a substitute for the public because we still need that basic research, and much of the private can often be a little bit more risk taking. And I often hear that in talking to people who are interested in the private research, that they realize they are going to have opportunities that are a little riskier or a little more outside the box than by nature some of the public research.

But I wanted to follow up with Dr. Yamamoto. What has been your experience when sort of taking outside-the-box ideas to the National Science Foundation and how can we make that easier for them? And what guidelines might be the best to adjust or how do we best make that work?

Dr. YAMAMOTO. Right. So let me start by saying that I think that NSF is as an agency quite welcoming to broad-based ideas. But as I said, the barriers that are intrinsic to bureaucratic separation of directorates in this case are problematic. And my own experience in carrying some big transdisciplinary ideas and approaches to the NSF was sort of met with being handed an org chart of NSF and said go out and shop your idea around to the separate directorates. There's not a home, an intrinsic home, for these big kind of ideas.

So my idea would really be to create such a home, to be welcoming of those kinds of approaches for every grant application that's made, that currently, that when they cross those boundaries, struggle to find a natural home and may struggle in peer review as well for that reason. And so I think that that is the kind of thing that is necessary. I might say that this idea of kind of programmatic focus that floats over the boundaries that separate disciplinary approaches is basically the way that we've organized the research approaches at UCSF where we have conventional departments like every other institution that are separated by these disciplinary approaches, and then floating over those are research programs that really have a big say about how resources are deployed, how we reach into different departments and bring together investigators that can merge their skills and really go after problems

that otherwise would not be solvable or even detectible by individual researches.

So this is an idea and a way that has been tested and I think would help to address this challenge and opportunity for transdisciplinarity.

Chairwoman COMSTOCK. Thank you. And Dr. Spies, could you address when we have more openness and we get that, how that both helps the public research as well as the private and how that might help us maximize the value in both areas as well as make them more usable, data and information, and how you would see that working in an ideal situation.

Dr. SPIES. Yeah. I appreciate the question. In an open framework, we think about knowledge as a public good, and therefore its accessibility and the credibility that openness brings to it is available to anyone. Obviously we need to facilitate that sometimes, but that basic accessibility is still there.

We've heard many examples of what has come out of the NSF from a basic science standpoint. So if we can increase the quality of that and increase the efficiency of that work, the work that comes out of this basic science programs, we can see then these end users receiving those benefits. They'll see the same efficiency gains. They'll see the lower risk perhaps because the quality would have been increased.

Chairwoman COMSTOCK. And maybe in terms of the community, is there some of the fear as you were talking about that everybody makes mistakes. We were talking about how we find problems and things. But is there sort of a cultural fear of having that out there instead of sort of understand, well, let's have a whole bigger community that's finding those mistakes sooner that we all make and sharing it in a way that helps for collaboration? You know, Thomas Edison obviously had to go through a lot of experiments before things got right. If he was sharing this in a bigger community, it might have all happened faster, right? Not that you don't want to—you know, when you have your research, you want to maybe keep that to yourself, too. I understand. But do we have a culture in the scientific community that makes it sort of punishing to have that information out there and shared?

Dr. SPIES. This is certainly a cultural issue, and I don't know if it's necessarily punishing, but we don't really allow discourse around failure. Peer review happens after the work has been done. And so there's really very little influence that that can have because you already did the work.

And so it's a cultural issue. The perhaps fear I think is across any area. No one wants to make mistakes, and no one wants to be seen for these mistakes. But we need to embrace them. That's a critical role in science. It's a very important part of the scientific process.

Chairwoman COMSTOCK. Okay. I know I'm over my time, but if our other witnesses had anything to comment in that area, I just wanted to give you an opportunity, too.

Dr. ZUBER. So I would just say that, you know, in science, if you make a mistake, it's okay. But it's better if you correct the mistake yourself rather than have somebody else correct the mistake. So I

think we ought to incentivize a system where mistakes within groups are—that it's recognized in a positive way.

Chairwoman COMSTOCK. Okay.

Dr. FERRINI-MUNDY. I would just add, and perhaps we'll have more time to talk about this later, that issues of open science and the ways in which sharing can occur happen in very different ways across different scientific fields. And so learning across fields in fields like astronomy, for example, where public data has been a norm for so long, we have a lot to learn about how mistakes are determined and how we can share and accelerate findings.

So there's a lot on this topic that's of great interest to us at NSF.

Chairwoman COMSTOCK. Great. Thank you. And I now recognize Mr. Lipinski for five minutes.

Mr. LIPINSKI. Thank you. I want to start with Dr. Spies. I want to applaud your work on making data more open. We know there are issues around that that sometimes there's reasons why there have to be—some data cannot just be all put out there directly as it is. But some have proposed that government agencies should only be allowed to make regulations based on studies that have posted all their data on line. But in practice, this would make the majority of available research off-limits to government agencies.

Are there ways the government can increase the openness of the research it relies on without undermining its ability to use all the available science?

Dr. SPIES. Yeah, there are many cases where we simply can't be completely open with work with respect to data privacy, security, or even just proprietary advantage. Some people need to maintain that intellectual property. But there are many, many ways that you can still be open, you can still be transparent and really, gaining that efficiency and credibility and accessibility by taking certain steps. It's not an all-or-nothing thing.

For example, with data privacy, there's a concept called secure computing where the data can remain private, but you can still analyze it. Other people can still analyze that, but the data is never made fully available. Or you could release your methods and materials. So keep the data private but release everything else around it, and this adds to the credibility. It might not add to the accessibility of that data, but you can still have a credible experience. You can still allow people to come into that and audit that process if need be. So we can still gain that credibility that we need in science.

Mr. LIPINSKI. Thank you. I want to move on. I want to ask Dr. Yamamoto, can you just briefly say what is the difference in your mind between interdisciplinary and transdisciplinary research?

Dr. YAMAMOTO. Sure. Transdisciplinary research really attempts to merge the sciences. I think we have an opportunity to do that now. It's quite remarkable, in which the concepts, the driving concepts that are at the basis of different disciplines are applied and used to move forward, other disciplines that haven't had those concepts before or approaches. And so——

Mr. LIPINSKI. Okay. Let me come back to you. I just want to make sure that we had that out there because I had that——

Dr. YAMAMOTO. Right.

Mr. LIPINSKI. —question. I just wanted to make sure I understood that that's what it was. I want to ask Dr. Ferrini-Mundy, a few years ago there were funds that were set up to fund interdisciplinary research at NSF, and that no longer is there. What happened with that? How did that go?

Dr. FERRINI-MUNDY. I think you may be referring to our INSPIRE Program?

Mr. LIPINSKI. Yes.

Dr. FERRINI-MUNDY. And that ran as a pilot. One thing that we're finding now at NSF over time is that our work across the directorates is just as prevalent for us as our work within directorates. And so we have already initiated a number of efforts at NSF that are transdisciplinary as well as interdisciplinary, new language that is in the same family as convergence research that brings together experts from multiple fields.

And so I would put examples on the table. Our innovations at the nexus of food, energy, and water systems is one of the initiatives that we started that was meant to draw in scientists from multiple fields to solve challenging problems. Understanding the brain is another. Risk and resilience is yet another, NSF includes as another.

So what we've been moving toward are a variety of efforts that signal our serious commitment to promoting science that cuts across disciplines in various ways.

We also do have a follow-up within our sort of options for continuing to propose interdisciplinary research that occurs and it's called RAISE. It's an interdisciplinary program that has some of the same elements as INSPIRE had. It's a way that people who bring an idea that doesn't squarely fit a particular discipline can at least follow a set of steps to bring that idea to the Foundation.

But what we are seeing in our efforts is a lot of interest that spans directorates, a lot of partnerships among directorates to encourage this kind of research.

Mr. LIPINSKI. And Dr. Yamamoto, do you think that this—you had talked about some things that you would like to see. Is there anything else that you believe NSF could do better in order to encourage this type of research?

Dr. YAMAMOTO. I think what NSF is doing is quite good. I think that my concern is that we're missing opportunities because programs, investigators, teams of investigators that come to the NSF with ideas that cross disciplinary boundaries are sort of viewed as secondary, secondary case. Not as secondary citizens but secondary case in which they really need to find, go out and find a home.

And what I would suggest is that NSF recognize this opportunity for transdisciplinarity by setting itself up to welcome and support every application that comes forward in this mode to ask where are the best ways, what are the directorates that can best support this kind of approach that's being brought forward to us so that it's not a special case, that every case that comes forward recognizes that we have an opportunity to use transdisciplinarity and that it's not something that's new or separate.

Mr. LIPINSKI. Thank you. I yield back.

Chairwoman COMSTOCK. I now recognize Mr. Hultgren.

Mr. HULTGREN. Thank you, Madam Chair. Thank you all so much for being here. I appreciate your work and I also appreciate you coming here, testifying today. This is a very important subject to me, I think for all of us. But I am grateful. Being from Illinois, the great ecosystem of science that we enjoy in Illinois, some wonderful universities, our great laboratories, the cooperation that we see between them, mutual benefit. And so with all of that, I think there's a reason why Illinois is well-represented on this Committee. I've got some great members that we really enjoy working together, getting good things done in science in Illinois.

One thing that has been important to me is access for researchers to the most advanced scientific infrastructures at facilities such as Blue Waters supercomputer at the University of Illinois. I've also had the opportunity to tour Stampede down in Texas last year.

Dr. Ferrini-Mundy, if I could address my questions to you, how does NSF look at the capabilities of a tool like Blue Waters when taking into account the different kinds of questions researchers are asking? Many researchers have described to me the issues with data management being more important than just raw speed for certain types of problems. Does NSF need to have differing capabilities in computing infrastructure, and how does NSF plan to address any type of gap when one of these tools goes off-line?

Dr. FERRINI-MUNDY. Thank you for your question, sir. NSF, through its Office of Advanced Cyber Infrastructure, supports the development, acquisition, and provision of state-of-the-art cyber infrastructure resources as you know. Those include tools and services, and they focus both on the high performance computing capabilities, such as those at Blue Waters, that are essential to the advancement of science and engineering research as well as—so we call that leadership computing. Those are the unique services and resources to advance the most computationally intensive work such as what is carried out at Blue Waters.

We also focus on what we call innovative high-performance computing resources. So these are a set of diverse, highly usable resources at large scale. The work at Stampede that you mention is in that category.

So regarding Blue Waters, it's not appropriate for me to comment here on any future solicitations or investments, but we are mindful of the importance of avoiding gaps in our leadership computing services. I also would point to a recent National Academy study titled Future Directions for NSF Advanced Computing Infrastructure. That has a number of recommendations, one of which is that NSF should provide one or more systems for applications that require a large, single, tightly coupled parallel computer. And we certainly take the strategic advice of the community very seriously.

Mr. HULTGREN. Okay. Thank you. Dr. Ferrini-Mundy, I'm going to continue with you if that's all right. But switching gears a little bit, the average age for a first-time principal investigator for NIH-funded research has risen to 43 years of age. Albert Einstein, as we know, was in his 20s when he presented his theory of relativity. He was 46 when he won the Nobel Prize. An average age of 43 for first-time PI seems to miss the most creative and productive years in a scientist's career. I wondered, do you know the average age of a scientist receiving their first regular NSF grant?

Dr. FERRINI-MUNDY. So thank you for the question. We actually do not request information about age or date of birth in our applications, and we do make an optional check box for people to indicate the date of their degree. So we can speak in terms of date of receipt of the Ph.D. in terms of age. And what we have seen is that in general, the early career, which would be people who are seven years or less from their Ph.D. at the time of proposal action, the funding rate for our early career folks in comparison to those who are past that time, who are later, is quite close, roughly 18 percent for our early career folks, 22 percent or thereabouts over the years for our people coming in from later careers. So that is, you know, like 18 percent of the early career applicants are getting awards versus 22 percent of the later career applicants.

In terms of the percentages, sort of how the balance of our portfolio looks, it's sort of about a 20/80 balance with about 20 percent of the awards going to the early career PIs and about 80 percent going to those of later careers.

Mr. HULTGREN. Would that be with regular awards or is that special set-aside programs?

Dr. FERRINI-MUNDY. Those are—that's across the full spectrum of awards. We do have a wonderful program called the Faculty Early Career Award Program that is meant to bring people in within some number of years of their Ph.D., and that's really a special program for us.

Mr. HULTGREN. I appreciate the conversation. I do think it's important for us to continue to discuss this——

Dr. FERRINI-MUNDY. Yes.

Mr. HULTGREN. —of making sure that we're maximizing opportunities to those who are younger, you know, more quickly after they've gotten their degree. Sounds like there's some steps there, but I want to make sure that we keep that focus. So thank you. My time's expired. I yield back. Thank you.

Chairwoman COMSTOCK. Okay. I now recognize Ms. Esty.

Ms. ESTY. Thank you, Chairwoman Comstock and Ranking Member Lipinski and to our members of the panel for this very important hearing today.

We had some discussion some of us last week at a briefing with NSF and the Department of Energy about the critical importance of infrastructure, the basic scientific infrastructure for attracting the best minds. There's been discussion, all of you to some extent, are talking about the importance of supporting researchers but encouraging and supporting that STEM workforce.

So Dr. Ferrini-Mundy, could you talk a little bit about that? I look at the fact that, for example, the discussions we had about the Hadron collider last week. I look at Yale University just outside my district and the work that's being done there on precision detectors and how that fits into these larger investments. Could you talk about that for a moment, please?

Dr. FERRINI-MUNDY. Sure. And there are so many factors that relate to these decisions. It's a lot about prioritization and how the National Science Foundation, in partnership of course with the scientific community, with the Congress, with the National Science Board, with the Administration, how we actually set priorities, and it's an activity that's under way constantly with us. And one very

strong commitment, of course, for the agency has been our investment in infrastructure over may decades through our Major Research Equipment Facilities Construction Account where we are always looking at advice from the community. So decadal surveys are quite critical for us as we think about what next infrastructure is needed.

But at the same time we need to take some risks, and we've heard about LIGO, and we know that there will be some piece of that infrastructure investment that needs to be focused towards the high-risk and potentially high-reward investments that we can't predict where the science will take us.

The other balancing piece in this business of prioritizing, of course, is in ensuring that we have the adequate resources to fund the basic research that occurs in that infrastructure. And so it's a constant calculation for us where we're considering lots of inputs and lots of factors. But suffice it to say, we're certainly committed to our role with scientific infrastructure as we have been for so long.

Ms. ESTY. Thank you, and I again want to underscore what many of you've talked about. And it has been a bit of a contention in the last few Congresses about whether Congress should be directing that research or not, and frankly, I think for the basic research, I would rather rely on scientists who have a better sense of where the science may be going and my commitment to continue to support that.

I know in fact many Members of Congress tend to be science-phobes. We may not be the best people to be directing that. That's not that we don't have an oversight role. Of course, we do. But I think as you've amply illustrated, that the United States has a leadership role in basic science, and we have to follow that where it takes us.

You've all also mentioned the importance of interdisciplinary and interdirectorate work. So a quick answer. If people have ideas, are there things Congress should or could be doing that would incentivize or remove barriers for that interdirectorate work?

Dr. ZUBER. Well, the most important thing that Congress could do is not take steps to create additional silos, okay? And so by specifying funding in directorates, that, of course, creates silos.

Ms. ESTY. Thank you. And again, that goes back to my earlier point about deferring somewhat to the scientific community to have the flexibility to move funding where the research takes us.

Dr. Spies, you talked a little bit, actually quite a lot, about the incentives to share work. This is something we discussed a lot over the last Congress or two. Can you help us think a little bit about—and this is probably a subject for another hearing—this problem about publication and the incentives to publish something novel and not to share results that don't turn out in a novel way or that don't actually lead to something directly actionable but in fact is really important for other people to know about because you may know this is not a profitable avenue. How do we square this right now? We have this problem about needing to publish to get research money, and yet if people are hiding their results because it doesn't seem actionable, it means you may have wasted money

with a lot of people kind of following down that same path. Anyone have thoughts on that point?

Dr. SPIES. Yeah. We have an incentives problem around publishing. And so we need to find a way to incentivize people to be more open, to take the risk, to be okay with failure, to put that out there and realize that that is adding to the corpus of knowledge. Any evidence is valuable in thinking about science.

And so there are ways to do this. We really need to think more about this and test some of these things. The field of metascience, we need more of a commitment to that to really understand what are the most efficacious ways to incentivize these things? Registered reports I think is a very good example where we review the work based on the impact of the questions and the soundness of the methodology. And then no matter what the outcome, you still get a publication. Scientists still get funding. They still get the publication. They still get that reward. And so they have no reason then to need to hide things or gloss over details to sell it to journals.

Ms. ESTY. Thank you very much. I'm seeing that I'm over, but maybe we could have a hearing on this issue because I think it is really important and it's something we could contribute in the field right now because a lot of scientists are very frustrated with the imperative right now. So maybe we could ask the Chairman and Ranking Member to do that. Thank you very much.

Chairwoman COMSTOCK. Thank you. And I now recognize Ms. Bonamici for five minutes. Oh, I'm sorry, Mr. Webster for five minutes. Sorry.

Mr. WEBSTER. Thank you, Madam Chair. Dr. Yamamoto, I had a question about one of the things you said. You talked about an additional organization layer, and we here in Congress are fantastic at doing that in government. And I'm just wondering, does that add to maybe an inefficiency to it or give me a little more explanation.

Dr. YAMAMOTO. Sure. Yeah, the kind of knee-jerk response to any additional bureaucratic layer is that it's going to slow things down or add complexity. The object of this additional layer is in fact to have research programs that float over the disciplinary directorates. And so it crosses those boundaries in a natural way. So that would be the idea of this additional layer and that they would define the elements of the different directorates that would come into play, that cooperate together to work in a given research programmatic area.

So that's the object, is to undo the damage, the natural damage, that bureaucratic boundaries do in setting up an organization that's necessary to have such separate entities. But anytime you do that, you've created a silo. And so this additional layer would float over those and cross those barriers.

Mr. WEBSTER. So would it be more free-flowing?

Dr. YAMAMOTO. That would be the idea is that every grant application, for example, that would come into the NSF, would flow first into these research areas. And that entity would then say this is an opportunity to draw from these two or three or four directorates that could best come together to address this.

So I would imagine, I would hope, that downstream what we would see increasingly is that teams of researchers composed of investigators with very different backgrounds and expertise would come to the NSF with ideas that definitely don't fit into any single directorate. But by going into this additional layer, they would always have a home and that that additional layer would then sort out which directorate would be able to contribute to that application.

Mr. WEBSTER. Thank you very much for that answer. Dr. Spies, would your—matter of fact, I liked what you had to say about an open process. We need some of that here, too. But my question would be would this open process add to or maybe remove from the subjectivity of the grants and resources and the distribution thereof?

Dr. SPIES. Open scientific process is going to be adding to what we know about science. And so as much as the quality of that is increased, I would think that it would increase decision-making. Related to subjectivity, the scientific process doesn't care about outcome. It's not an important part of it. The outcome is what happens from the scientific process. And so if we focus more on the process, more on the work flow, more on these other components that lead us to these outcomes, which we as humans really appreciate, which you appreciate in making policy, but if we focus on that process, then we can have more objectivity I think just across the board. And so again, if that can aid decision-making, then it should do so with regards to that process, to those methods.

Mr. WEBSTER. So you would believe that the better the process, the more perfect the outcome?

Dr. SPIES. The better the process, the smoother the way towards understanding, whatever that is. I won't say perfect. Science admits that it's never perfect. We are always incrementally moving forward. But process, good process, open process, can make that a more efficient track down that road.

Mr. WEBSTER. Thank you very much. I yield back.

Chairwoman COMSTOCK. Thank you. I now recognize Ms. Bonamici for five minutes.

Ms. BONAMICI. Thank you very much, Chair Comstock, and Ranking Member Lipinski. And thank you to all of the witnesses for being here today. It's been a very good discussion and kind of a continuation of our earlier hearing.

One of the things I wanted to follow up on, Dr. Ferrini-Mundy, you talked a little bit about risk taking. And that's something that we have to recognize as policymakers when—I share the concerns raised by some of my colleagues about the problems of having Members of Congress decide which directorates to fund at certain levels. Do we have oversight responsibilities as Ms. Esty said? Of course, but making those decisions when we don't know what's going to be at the end of the research is something that we have to keep in mind as we're deciding funding. Can administrations set priorities? Absolutely, but they shouldn't be at the risk of other areas.

So I've enjoyed several times participating in the Golden Goose Awards, an event that the American Association for Advancement of Science, AAAS, has helped launch and organize each year to rec-

ognize the importance of federally funded basic scientific research. We don't know what discipline the next innovative transformative research will come from, but we know that NSF-supported basic research has led to advances in technology, in medicine, agriculture, and many more fields.

Last year one of the Golden Goose Awardees was the honeybee algorithm. So in the late 1980s, several engineers collaborated with a bee researcher, and they studied how honeybee colonies allocate foragers. And years later then, two researchers applied that honeybee foraging model to shared web hosting servers, something that wasn't thought of in the early '80s when they were doing the original modeling. And their research resulted in an algorithm that speeds up the process every time we check our bank account balances, do an internet search, check the score of a March Madness game which some people might be doing at this moment.

So a question for all of the panelists, that the honeybee algorithm is a great example of obscure or perhaps silly sounding basic research that led later to technological advances. So what might be lost by withholding federal funding from research areas where we don't know what the benefits will be at the outset? We don't know where that research will go.

So what are the problems? What do we lose by withholding funding because of that uncertainty or that risk? Dr. Ferrini-Mundy, let's start with you.

Dr. FERRINI-MUNDY. Sure. Thank you. Thank you for the question and the great explanation of the honeybee algorithm. Very helpful.

First of all, it needs to be—we need to be clear that all at NSF take very, very seriously the responsibility of carefully investing taxpayer dollars——

Ms. BONAMICI. Of course.

Dr. FERRINI-MUNDY. —and being prudent and responsible. At the same time, as you point out, it's very difficult to tell with certain basic research proposals what the long-term impact and payoff on the country, on our economy might actually be.

And so we have so many wonderful examples. You've pointed out one, but there are wonderful boons to industry that started with no obvious commercial applications. And we have results about GPS, the internet, AI and computers where at any stage some of that basic funding in its proposal form might have not looked like it would lead to anything.

So I think I certainly agree that we need to stay open. We need to use the expertise of the scientific community to select the, you know, one in five grants that we are able to fund, both for those that will continue to move science along incrementally as is needed and for those that look like long shots but that have great promise in terms of their basic contribution. There's one other point I'd want to make on this which has to do with choosing among areas of science. It's a tricky business because keeping the basic investment going in all areas of science, the fundamental research investment, is quite important so that there is this constant pipeline and flow of new ideas accumulating, new theories being developed, which may then find their use someplace else.

Ms. BONAMICI. Thank you. I'm going to try to get in another question. Dr. Ferrini-Mundy, the social, behavioral, economic sciences grants have funded ground-breaking research across the nation including at Oregon State University some important research on how communities research extreme weather events. If funding for the SBE grants at NSF were to be cut significantly, some are suggesting by 50 percent, this would also result in fewer SBE program officers within the agency. So given the breadth of research in the directorate currently, there could be gaps in expertise. So is that a reasonable assumption and how might this affect the ability of the agency to review SBE grants for their merit or potential to benefit the nation? And maybe we can get Dr. Zuber in the last couple seconds as well.

Dr. FERRINI-MUNDY. So I just want to reiterate our central commitment to the importance of the social, behavioral, and economic sciences investments. The benefits coming that we have seen in cybersecurity, disaster preparedness, detecting reading problems early on—all of these fan from fundamental research that would be missing if we were not able to invest in the ways that we do.

Dr. ZUBER. Again, if I could just add, you know, trying to think about research that actually serves the nation, a couple of things in SBE—facial recognition studies actually went into the analysis, the algorithmic analysis of identifying the marathon bombers in Boston. And another recent study, that violent extremism, the tendency to go into it, isn't just an economic thing, that there are actually moral imperatives. So if one is trying to dissuade young people from joining extreme groups, one needs to find a moral alternative.

And another thing that I think is really the 800-pound gorilla is that we need to think about jobs and job retraining. And that is squarely a social science issue. And so I think at this time where we have so many issues in the country that really affect people, okay, that the social sciences really has an ever more important price to pay.

Ms. BONAMICI. Thank you. My time is expired. I yield back. Thank you, Madam Chair.

Chairwoman COMSTOCK. Thank you. And I now recognize Mr. Beyer for five minutes.

Mr. BEYER. Thank you, Madam Chair, very much. And thank all of you for being here. This is—the best part about being on the Science Committee is being able to talk to you.

I wanted to pile on to Congressman Hultgren's comments about the age mismatch. Some quick research. Albert Einstein was 27, 1906, in Bern, Switzerland, when he came out with Brownian motion, photoelectric effect, special relativity. Werner Von Heisenberg was 26 when he articulated the uncertainty principle. Marie Curie was 30 when she articulated, discovered radioactivity.

And I'd be very grateful if you and Dr. Cordova would look at the 80/20 mix and figure out where to make it 20/80. It's sort of part of the—I'm not a mathematician, but I've heard again and again that there are very few genius mathematicians beyond age 30. Almost all prodigies are young. Doctor?

Dr. FERRINI-MUNDY. Thanks so much, and I would just add to that, we have a significant investment in young professionals

through the graduate student programs and through post-doctoral programs, too. So we really are working very hard to make sure that we keep that next generation ready and able to lead us in science in the future.

Mr. BEYER. Great. Thank you. Dr. Yamamoto, I'm going to pick on you because you're a professor of cellular and molecular pharmacology. And I love the physical sciences, you know, particle physics and cosmology and relativity and biochemistry. But equally important are all these social sciences, the SBE that we've talked about.

I'm especially thinking, you know, Daniel Kahneman, in his Thinking Fast, Thinking Slow, has gotten so much attention about how we make decisions which, given that we're here in U.S. Congress, is phenomenally important.

Can you look at it as a biologist, chemist, physicist, on what you think the importance of the social and behavioral sciences are?

Dr. YAMAMOTO. I can approach this through an issue that's very important to me. I was involved in launching this notion of precision medicine. And precision medicine has at its heart an understanding of biological processes that is founded in understanding the mechanisms of the ways that those processes function. And so when you start thinking about disease, you come up right against the complexity of biological systems and realize that the Human Genome Project, for all the things that it brought us, the genome is just one element that goes into the risk of an individual for getting a disease, the course of that disease when they get it, and so forth and other elements. There are many other elements that come into play, objective, scientific elements like small molecules that are in the bloodstream, the microbiome that inhabits all of us. But in addition, the impact of environmental factors, social and behavioral elements that very much contribute. So what precision medicine says is that we need to mound all of these layers of information in a Google Maps like way that allows us to see correlations and connections that were otherwise invisible when the disciplines are maintained separately.

And so if we can do that, build that Google Maps and be able to establish what the links are between a given behavioral component or environmental component and what we see in the gene or small molecule or a microgut's inhabiting of the organism, then we can begin to better understand what the various components that contribute to a biological process or a disease.

So it's a long way of saying that I think it's really essential that as biological scientists that are sort of bound by collecting objective evidence, that these other components are just as important and we really need to build that in.

So it's great that the National Science Foundation understands that and has a directorate that really is focused in that way.

Mr. BEYER. Thank you, Doctor, very much. And Dr. Zuber, just a few seconds of building on that. Looking at psychology, especially as a so-called soft science, SBE, as Chairman of the National Science Board, what's your perspective on the importance of investing that for America's mental health?

Dr. ZUBER. So obviously it's crucially important, and NSF of course does the fundamental science, the basic science, that then

feeds into the more directed, health-related work that's done at the NIH, okay, and there really is very good cross-agency discussions on these and other basic science/more disease-related problems.

But I just wanted to make the point here that we are on the verge of a real revolution in the social sciences. So right now, computation in the social sciences, high-performance computing, they're using as much in those fields as math and physical sciences that NSF used ten years ago, okay? So something that's considered a soft science is really becoming very data-driven, very quantitative. And you know, we're essentially at the beginning of a golden age here. So it would be a shame to cut it back.

Mr. BEYER. Thank you very much. Thanks, Madam Chair.

Chairwoman COMSTOCK. Thank you. And I know Dr. Zuber and I had talked about young people yesterday and the importance of having them engaged. And I just wanted to, in addition to having Eric Young here from Dominion High School, shadowing us here today, I know we had some other students here. But I wanted to just mention, because this is such an extraordinary young man who I was able to meet with yesterday, I think he's interested in the precision medicine area and has now been accepted at MIT but has a few other options available. But let's see. He just won—his name is Pratik Naidu. It's N-a-i-d-u if I'm not doing it justice. But he is a senior at Thomas Jefferson High School, and he was one of the ten finalists in the Regeneron Science Talent Search, one of our nation's oldest and most prestigious science competitions for seniors in high school. And he created a machine learning software that can now examine how cancer genomes interact and help with new drug therapies. He was working with researchers up in Boston. So he is partnering with them from his high school up in Boston. So I'm sure they'll be thrilled if he goes to MIT and is up in that area. It was titled The DNA Looper. And this device can actually learn and give new insight in the ongoing search for cures for cancer.

And then just for an add-on because he was such a charming young man, he happened to be an Eagle Scout in eighth grade. So clearly an overachiever here. And then also on the side he had founded a reading group for veterans, and he called it The Classics Project where he was studying classical war texts and how they relate to our current society. And he was—of course, he took Latin so he was reading these I guess in the original, Homer's Odyssey, and then taking that and working with our veterans.

So I think that kind of leads to the overlapping of how you have somebody like this who whatever project he might come to in the future, we'll want to have some type of box to fit him in. But he clearly was a very talented young man here. So I think it kind of brings to life all the testimony that you all have given today. Dr. Yamamoto, if you'd like——

Dr. YAMAMOTO. I wonder if I could just comment on this age issue. I think it's terrific that NSF, NIH, other agencies are building programs to single out early investigators that are coming to these agencies for funding. But in my view, the harder the problem is not that we're not giving enough grants for young investigators. It's that they're getting to the system too late. The training is taking far too long, and I think that we need to go back and look at sort of first principles of what is needed for a Ph.D., for example,

in the sciences? And there's a National Academy study that is just getting going. I'm on the committee to look at STEM graduate education and see if we're really doing the right thing. That is, are we really providing students with what they need to then emerge as Ph.D.s and go out and be successful? How important is the postdoctoral study period? What should be in that element and how does it contribute or not? Are we just aging our trainees because we need them to be the workforce to do experiments in our laboratories, for example? And I think that going back and looking at those principles is really critical. In my view we could shorten the training period a lot and really—my own goal would be to say can we develop a system that goes from the first day in graduate school to being independent investigators from what it is now to something in the four- to six- to eight-year range, getting registered to being an assistant professor applying for an NSF grant? And I think that that's a very doable thing. We've been remiss in not looking at those principles, and I think that we've fallen into the trap of thinking that we need this mass of people to man our laboratories and carry out our experiments, rather than thinking about what is it that they need, when can they use their energy and creativity in the most efficient way?

Chairwoman COMSTOCK. Right. I think that was that ecosystem that you talked about creating. So, thank you for that additional insight. And I'm sorry, we had two people come back. So we recognize Ms. Rosen for five minutes.

Ms. ROSEN. Thank you, Madam Chair, Ranking Member Lipinski, and to our panel for being here today. And Dr. Yamamoto, my husband did his medical residency at UCSF along with many of his friends. And so we have a soft spot in our household for UCSF. And I thank you for all the work you do there and the kind of graduates I know you produce. So I'll just go to that.

So I'd like to hear—I love my husband. So I have to put that plug in, right? So I'd like to hear your thoughts on several related topics on how we consider evaluating and funding scientific research, the value of course our basic research core areas and how they relate to our national interest. Because oftentimes it's unclear. You know, I'm a former computer programmer systems analyst who started writing software in the 1970s. No PCs. No cell phones. There's more right here than we could have ever imagined when I was at University of Minnesota writing on computer card decks in the BASIC lab in the math department, right?

So we've come a long way, and we couldn't predict it. So we want to be able to allow for these kinds of research that have no—that we can't even imagine what's going through. So following up on Representative Bonamici's question, I'd like to ask you all, what is lost to the nation if we stop funding research in a whole discipline because somebody doesn't see the potential? If we stop funding core fields like biology, chemistry, or physics because we think all the discoveries have been made, which they have not. And like you go to the mistakes, a lot of mistakes turn out to be the foundation for something else in the future. And if we refuse to fund a field we've never heard of, that might be a key that unlocks mysteries that are yet untold.

So the wholesale defunding of particular fields of science, is that really a wise way for us to go?

Dr. YAMAMOTO. I think it's a disaster. I think that the existence of the National Science Foundation as proposed by Vannevar Bush really puts a stake in the ground for basic research, research where you actually don't know where it's going to lead. And we are very far from—you know, the amount that we don't know still so vastly outweighs what we do know, that stopping any of those investigations would mean that our future for being able to have knowledge that we can then apply will go away. So we absolutely have to maintain this.

I might just say one more thing about reproducibility that bears on your question and that is at least in the biological sciences. There's an element of reproducibility that hasn't been addressed here that I think bears mentioning and that is that because of past successes, we are now able to work in experimental systems including populations of human beings that are vastly more complex than we've been able to work on before.

So the scientific ideal for planning an experiment is to control all the variables except the one you're trying to test, right? We're very far from that now, and it's good news that we are, that we understand enough to work on more complicated systems. But we need to acknowledge that when we do that, that when we control all the variables we can think of, underneath that is a vast number of variables that we don't know about, right? I call it the Rumsfeld effect. And acknowledging that says that the attempt to reproduce an experiment, ending up with a different result, doesn't mean that either experiment was wrong. I have to point out that it also doesn't mean that either experiment was right. And it simply means that the robustness of being able to reproduce it is not there. It very often will be it's not there because there are unknown variables below what you've tested. So just to give you a silly example that I think makes it easy to understand is that no reviewer of a grant application or a finished product that is submitted to a journal for publication would say, oh, this looks really terrific. You've really carried it out. It's a beautiful set of experiments. Could you please go back and do them all again at a tenth of a degree lower temperature, right? And that could be the variable that would change all the results and make two attempts, two very solid attempts to reproduce the study, come out with different results.

And so remembering this is that we don't know about the robustness of a lot of these complex studies because of those unknown variables. And I think it calls into question in a way attempts to fund studies, to simply try to reproduce complex results, understanding robustness is critical. But being able to label something as right or wrong based on whether it's reproducible I think is problematic.

Ms. ROSEN. Thank you. I appreciate that. And I thank you for what you're doing, especially in creating a quicker path for people in STEM, people like myself who started their career. It's so important that we build that people pipeline, create opportunities as early as possible in the youngest grades so people know it's creative and innovative and not boring in the least sense and that they can

all do it and not be science-phobes as someone else said. We need to generate that excitement. So I thank you for what you're trying to do with a lot of the programs you're working on. I yield back.

Chairwoman COMSTOCK. Thank you. I now recognize Mr. Tonko for five minutes.

Mr. TONKO. Thank you, Madam Chair, and I find this discussion very uplifting, especially in light of President Trump's budget presentation which seems to disinvest in America, which is a troublesome notion.

I'm concerned, Dr. Ferrini-Mundy, that cuts to the geosciences could hurt our national security, our economic security and our public health and safety. Are you aware of any NSF-funded research that came out of the geosciences directorate that produced valuable results?

Dr. FERRINI-MUNDY. Thank you for the question and of course the research that goes on in our geosciences directorate spans a very broad range of topics and areas. Fundamentally, we fund research that helps us better understand our planet. And so let me just give a couple of examples. We fund research to understand how the physical and chemical processes in the ocean and the atmosphere affect how ecosystems operate. And that not only brings us fundamental understanding of how heat redistribution happens, but it generates knowledge about marine ecosystems that ultimately can have applications about informed management of the fisheries industries, for example.

Another area where we do terrestrial research has to do with knowledge generation that gets us understandings of groundwater and surface water systems that contribute to informed decisions about the use of water resources and therefore have implications for agriculture, potable water supplies, and recreations.

Those are just a couple of areas where investment in the geosciences has affected our country in serious and important ways.

Mr. TONKO. Thank you. And Dr. Zuber?

Dr. ZUBER. Yes, since I'm in earth science, I can add a few things to this. So one example is that subsurface prospecting and the study of subsurface materials really has provided the scientific framework for hydraulic fracking, okay, which has brought this country really far in the direction of energy independence.

And I will also add that NSF's earth science program also includes the space environment surrounding Earth. And so for example understanding solar storms and their effects on, you know, if the GPS constellation goes out, if our cell phones go out, if the electric grid goes out, obviously that's bad for America, okay? And those studies are crucial in understanding that.

Also the health of the oceans, coastal erosion factors that affects so many people that live along our coasts. And finally I would add that the geo program supports the polar programs including fully the Antarctic program.

Mr. TONKO. Sounds like very valuable information that can guide us with some very important actions that we may need to put into place.

New York State has had a number of devastating natural disasters in recent years including devastation from Super Storm Sandy, certainly Hurricane Irene, and Tropical Storm Lee. In New York's

20th District, my home district, we used to talk about storms that came once every 100 or once every 500 years. This type of talk is no more with devastating weather events happening time and time again.

I've sat with families who have lost everything and have witnessed the exorbitant costs that we are still trying to pay off from these extreme events. Extreme weather events are incredibly expensive to our communities and our nation. So my question to the panel is does research in the geosciences help to ensure better predictions or better understanding of natural environmental hazards? Dr. Zuber?

Dr. ZUBER. Okay. Well, the answer to that is yes. So actually, there are studies that are being done and the state of prediction, near-term weather prediction and extreme storms, that work is underway. And it's critically important and we need to invest greater in it. There have been some studies done and they need to be verified that as severe storms move up the East Coast, they typically go out to sea, okay? However, with the loss of sea ice, okay, over the Arctic Ocean, it changes the wind patterns so that there's a higher probability of a storm coming up the coast, not taking a right turn.

And so one can just envision what the economic consequences would be if we have more Hurricane Sandys coming up and hitting the East Coast. And that's just a single example. You know, obviously severe storms, droughts, and floods, are devastating to the economy. And so this requires field work. It requires data collection. It requires greater investment in high-performance computing. So it's really, really cross-discipline.

Mr. TONKO. And I would hope it would instruct us and issues of climate change and greenhouse gas emissions.

Dr. ZUBER. Well, certainly, but so you know, understanding weather on a short-term timescale is really fundamental in understanding if we're going to be able to extend those models to understand future climatic situations.

Mr. TONKO. Dr. Zuber, I thank you. And Madam Chair, I yield back.

Chairwoman COMSTOCK. Thank you. And I thank today's witnesses for their testimony and the Members for their questions. We really appreciate your insight and ideas, and I think we certainly have more food for thought for future hearings also. So thank you. And thank you for your good work in this arena. And the record will remain open for two weeks for additional written comments and written questions from Members. This hearing is now adjourned.

[Whereupon, at 11:44 a.m., the Subcommittee was adjourned.]

Appendix I

Additional Material for the Record

STATEMENT SUBMITTED BY FULL COMMITTEE
CHAIRMAN LAMAR S. SMITH

COMMITTEE ON
SCIENCE, SPACE, & TECHNOLOGY
Lamar Smith, Chairman

For Immediate Release
March 21, 2017

Media Contact: Kristina Baum
(202) 225-6371

Statement of Chairman Lamar Smith (R-Texas)
National Science Foundation Part II: Future Opportunities and Challenges for Science

Chairman Smith: Thank you, Chairwoman Comstock. And welcome to our witnesses.

The American Innovation and Competitiveness Act, or AICA, the last bill from the 114th Congress signed into law, took several steps to maximize the nation's investment in research. It assures taxpayers that they will get their money's worth from National Science Foundation (NSF) scientific research projects.

The law included:

1. An explicit national interest requirement embedded permanently in NSF's merit selection process;

2. A requirement for NSF to justify in writing and in non-technical terms how each project that it funds meets the highest standards of scientific merit and the national interest;

3. Reforms to improve NSF's financial controls and oversight for major research facility construction, and prevent incidents, like the one at NEON, that resulted in a nine-figure loss on this one project; and

4. A requirement for NSF to take additional steps in response to proven instances of research fraud.

At our first hearing on NSF two weeks ago, NSF Director France Córdova told us about initiatives the agency continues to take to move forward in these areas.

We look forward to regular updates from NSF about its rapid implementation of the national interest criteria, accountability standards, and financial management reforms.

As NSF nears the 70th anniversary of its founding, we must ask, how does NSF best meet its opportunities and challenges over the *next* 70 years?

Since its creation in 1950, NSF has served a mission that helps make the United States a world leader in science and innovation. But the fields of science and technology consistently change.

To meet these challenges, NSF must be as nimble and innovative as the speed of technology development, and as open and transparent as information in the digital age.

These are not easy tasks for any government organization. I hope to hear how NSF keeps up with the pace of rapidly evolving science as well as recommendations for how the Foundation can do better.

One challenge I would like to take a moment to highlight is research reproducibility.

Reproducibility addresses and can prevent fraud and poorly designed and executed research. Unfortunately, there is evidence of the increasing frequency of non-reproducible experiments, particularly in certain fields of science.

A recent survey by *Nature* magazine found that more than 70% of researchers have tried and failed to reproduce another scientist's experiments, and more than half have failed to reproduce their own experiments. Additionally, over half of the researchers surveyed called it a "significant crisis" for science.

That should be of concern to every scientist and advocate for science. If a critical mass of scientists and research becomes untrustworthy, Americans may soon be more skeptical about the science coming from our science agencies.

As an illustration, there is the recent case of two highly regarded social scientists who conducted a project aimed at linking political ideology to mental illness.

The researchers concluded that conservatives were much more likely to manifest a personality pattern typified by aggressiveness and interpersonal hostility than liberals.

However, this conclusion was based on a mathematical error that even a grade school student should have been able to spot. In fact, the research data actually indicated the opposite – that liberals, not conservatives, were disposed to these behaviors.

It was three full years after their mathematical error was brought to the researchers' attention until they acknowledged their mistake and retracted their findings.

In the meantime, several peer-reviewed journals featured their work and dozens of other articles cited it. Corrections received no where near the same coverage.

This episode does point to both individual and media bias, which may well hurt the scientific community's credibility.

The new AICA law requires NSF to contract with the National Research Council to better understand the root cause of failed research reproducibility and replicability and to present recommendations to address the problems associated with it. The National Research Council will begin that work this year.

I look forward to hearing the witnesses' thoughts on these and other issues as we move toward reauthorizing the National Science Foundation.

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STATEMENT SUBMITTED BY SUBCOMMITTEE
RANKING MEMBER DANIEL LIPINSKI

NSF OIG Research Misconduct Statistics for FY05 through FY16

Allegations and Investigations

FY	RM Allegations Received[1]				RM Investigations Opened[2,3]			
	P	Fab	Fal	Total	P	Fab	Fal	Total
2005	86	11	3	**100**	66	3	2	**71**
2006	67	8	7	**82**	48	3	5	**56**
2007	90	8	6	**104**	67	6	0	**73**
2008	132	7	10	**149**	99	5	6	**110**
2009	108	0	11	**119**	83	0	10	**93**
2010	90	4	10	**104**	70	3	3	**76**
2011	85	17	15	**117**	58	15	8	**81**
2012	96	9	8	**113**	80	7	5	**92**
2013	84	10	11	**105**	80	8	10	**98**
2014	37	7	5	**49**	35	7	5	**47**
2015	64	9	11	**84**	64	9	11	**84**
2016	35	10	11	**56**	24	6	9	**39**
Totals	974	100	108	**1182**	774	72	74	**920**

Notes:

1. Key to allegations: P = Plagiarism; Fab = Fabrication; Fal = Falsification. Allegations were made against both funded and declined NSF proposals.

Over the reporting period FY05-16, we used 3 different methods of capturing allegation data. The periods were: FY05 through FY12; then FY13, when we were granted Statutory Law Enforcement authority, through FY15; and finally FY16 onward, when we switched to a new Investigative case management system. For this reason, you cannot make a meaningful comparison or identify trends related to allegations across the entire reporting

2. We define an investigation as any case in which investigative activity occurred, including case activity defined as "Inquiry" in the RM regulation.

3. There are a small number of allegations involving RM which result in Criminal or Civil investigations. We have not included those allegations in this report at this time.

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