AN OVERVIEW OF THE NATIONAL SCIENCE FOUNDATION BUDGET PROPOSAL FOR FISCAL YEAR 2019

HEARING

BEFORE THE

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
HOUSE OF REPRESENTATIVES

ONE HUNDRED FIFTEENTH CONGRESS

SECOND SESSION

MARCH 15, 2018

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AN OVERVIEW OF THE NATIONAL SCIENCE FOUNDATION BUDGET PROPOSAL FOR FISCAL YEAR 2019

THURSDAY, MARCH 15, 2018

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

The Committee met, pursuant to call, at 10:06 a.m., in Room 2318 of the Rayburn House Office Building, Hon. Lamar Smith [Chairman of the Committee] 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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An Overview of the National Science Foundation Budget Proposal for Fiscal Year 2019

Thursday, March 15, 2018
10:00 a.m.
2318 Rayburn House Office Building

Witnesses

Dr. France Córdova, Director, National Science Foundation

Dr. Maria T. Zuber, Chair, National Science Board

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

HEARING CHARTER

March 15, 2018

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

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

SUBJECT: Full Committee Hearing: "An Overview of the National Science Foundation Budget Proposal for Fiscal Year 2019"

The Full Committee on Science, Space, and Technology will hold a hearing titled *An Overview of the National Science Foundation Budget Proposal for Fiscal Year 2019* on Thursday, March 15, 2018 at 10:00 a.m. in Room 2318 of the Rayburn House Office Building.

Hearing Purpose:

The purpose of the hearing is to review the Administration's Fiscal Year 2019 (FY19) budget proposal and funding priorities for the National Science Foundation (NSF).

Witness List

- **Dr. France Córdova**, Director, National Science Foundation
- **Dr. Maria T. Zuber**, Chair, National Science Board

Staff Contact

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

Chairman SMITH. Everybody got quiet very suddenly, but before that, this was a very happy crowd.

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 "An Overview of the National Science Foundation Budget Proposal for Fiscal Year 2019." And I'll recognize myself for an opening statement.

Today, we welcome Dr. France Córdova, the Director of the National Science Foundation, and Dr. Maria Zuber, Chair of the National Science Board, to testify about the Administration's budget request and funding priorities for the National Science Foundation in fiscal year 2019.

Before its creation in 1950, the NSF's mission has been to promote fundamental scientific discovery. The NSF is the only federal agency that supports basic research across all scientific fields, including research in areas like national security, energy, quantum technology, biotechnology, STEM education and cybersecurity. Through competitive grants, the NSF funds more than 360,000 scientists, engineers, and students across the country. This helps make the United States a world leader in knowledge and innovation.

The Committee finished the last Congress by completing work on the American Innovation and Competitiveness Act, authorizing some of the NSF's activities, including work on STEM education and high-performance computing. The law made permanent transparency and accountability policies that require the NSF to describe the research projects it funds in nontechnical terms. The law also improved the NSF grantmaking process, affirming that research funded through the merit review selection process must be in the national interest.

I want to recognize Dr. Córdova for the steps the NSF has taken to improve accountability over the last three years and acknowledge Dr. Zuber's work on behalf of the National Science Board as well.

I have to say that sometimes in the past I have been critical of the NSF for funding too many projects that seem marginal or frivolous. When the NSF spent $700,000 on a Climate Change Musical or $1.5 million to study pasture management in Mongolia, it reduced investments in projects that could yield groundbreaking new knowledge and discoveries.

I believe there has certainly been improvement, but challenges remain. I am concerned that there are too many projects being funded in the social, behavioral, and economic sciences that are not worthy of taxpayers' dollars. For example, in the past year the NSF has spent $310,000 to study Congressional "Dear Colleague" letters, $450,000 to study why there is no single English word for "light blue," $330,000 to study cell phone use by Tanzanian women, $138,000 to study monkey responses to "inequity and violated expectation," $217,000 to document a language spoken in two villages of northern Pakistan, and $75,000 to "produce a description of Maku," an extinct Amazon language.

Social-behavioral science can help solve some complex problems that touch several areas of science. For instance, protecting computers and computer networks from hackers requires research in both computer and behavioral science. But when only one out of five requests for grants is being funded, there must be priorities. We cannot afford to misspend another dollar on low-priority or frivolous activities. Simply put, the NSF should fund useful research over the useless.

China now has the world's fastest supercomputer and has just passed the United States for the first time to lead the world in the number and total performance of supercomputers. China is also making rapid progress in artificial intelligence, quantum computing, human genome editing, and other crucial areas of science and technology. Unfortunately, as China leaps forward, the United States is slowing down investment in key areas of basic research like physics and computing. This will not change unless taxpayers' money is better invested.

I also am concerned about whether or not the NSF is developing its STEM workforce programs to meet the needs of our economy. The United States continues to lag significantly behind China and the European Union in science and engineering bachelor's degrees, with China producing more than twice the number of STEM undergraduates. In the physical and biological sciences, China produces four times more undergraduates in those fields than the United States.

The NSF plays a critical role in helping educate and train the next generation of STEM workers. We need to invest in young people who will go into fields where there is a national need and good-paying jobs.

Now that there is a two-year budget agreement in place, we have an opportunity to reauthorize the science agencies under our Committee's jurisdiction, including the NSF, to rebalance priorities and ensure that our nation's science agencies are on a trajectory to keep America at the forefront of scientific knowledge and discovery.

This Committee has demonstrated that there is broad support for basic and fundamental research and STEM education. Twenty of the twenty-two bills the Science, Space, and Technology Committee has brought to the House Floor this Congress have been bipartisan pieces of legislation. We are committed to maintaining America's leadership in science, thereby ensuring future economic prosperity.

[The prepared statement of Chairman Smith follows:]

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

For Immediate Release
March 15, 2018

Media Contacts: Thea McDonald, Brandon VerVelde
(202) 225-6371

Statement by Chairman Lamar Smith (R-Texas)

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

Chairman Smith: Today we welcome Dr. France Córdova, the director of the National Science Foundation (NSF) and Dr. Maria Zuber, chair of the National Science Board, to testify about the administration's budget request and funding priorities for the NSF in Fiscal Year 2019.

Since its creation in 1950, the National Science Foundation's mission has been to promote fundamental scientific discovery. The NSF is the only federal agency that supports basic research across all scientific fields, including research in areas like national security, energy, quantum technology, biotechnology, STEM education and cybersecurity.

Through competitive grants, the NSF funds more than 360,000 scientists, engineers and students across the country, which help make the United States a world leader in knowledge and innovation.

The committee finished the last Congress by completing work on the American Innovation and Competitiveness Act, authorizing some of the NSF's activities – including work on STEM education and high-performance computing.

The law made permanent transparency and accountability policies that require the NSF to describe the research projects it funds in non-technical terms.

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China now has the world's fastest supercomputer and has just passed the U.S. for the first time to lead the world in the number and total performance of supercomputers.

China is also making rapid progress in artificial intelligence, quantum computing, human genome editing and other crucial areas of science and technology.

Unfortunately, as China leaps forward, the U.S. is slowing down investment in key areas of basic research like physics and computing. This will not change unless taxpayers' money is better invested.

I am also concerned about whether or not the NSF is developing its STEM workforce programs to meet the needs of our economy.

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The NSF plays a critical role in helping educate and train the next generation of STEM workers. We need to invest in young people who will go into fields where there is a national need and good paying jobs.

Now that there is a two-year budget agreement in place, we have an opportunity to reauthorize the science agencies under our committee's jurisdiction, including the NSF, to rebalance priorities and ensure that our nation's science agencies are on a trajectory to keep America at the forefront of scientific knowledge and discovery.

This committee has demonstrated there is broad support for basic and fundamental research and STEM education. Twenty of the 22 bills the Science, Space, and Technology Committee has brought to the House floor this Congress have been bipartisan pieces of legislation.

We are committed to maintaining America's leadership in science, thereby ensuring future economic prosperity.

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Chairman SMITH. That concludes my opening statement, and the Ranking Member, the gentlewoman from Texas, Ms. Johnson, is recognized for her opening statement.

Ms. JOHNSON. Thank you very much, Chairman Smith, and good morning. I appreciate you holding this hearing, and I want to welcome Dr. Córdova and Dr. Zuber. I'm pleased that we have both of you here this morning to help us understand the fiscal 2019 budget request for the National Science Foundation and the potential impact of this request on NSF's ability to help support U.S. leadership in science.

Funding for the National Science Foundation peaked in 2010 at $7.7 billion. In the years since then, the budget has stagnated at or below $7.5 billion. This is the case despite the Obama Administration requesting increases each year. In stark contrast, last year, the Trump Administration proposed to cut NSF by 11 percent, and this year, until Congress passed the budget agreement, the proposed cut was closer to 30 percent. This Administration has demonstrated time and again how little they value science.

Given these trends, most of us are relieved when the NSF budget remains flat rather than cut. However, flat is a decline in real dollars, and it represents a terribly low standard for which to judge our nation's standing in science and technology. We will hear in Dr. Zuber's testimony how other countries are doubling down on their investments in R&D while we're cutting.

Having said that, I applaud Dr. Córdova and your team at NSF for being as bold and forward-looking as you could be, given the constraints imposed upon you by the budget of the White House. I will highlight just a few items of interest or concern that I hope we can discuss further in the hearing.

Advancing science to solve our national and global challenges increasingly depends on teams of scientists from various disciplines coming together in what is now commonly known as convergent research. However, for generations, universities and the National Science Foundation itself have been organized around disciplines. While advances in these core disciplines do and must continue, this organizational structure has created stovepipes and inhibited convergent research.

In fiscal year 2019 budget request, NSF takes a big leap to transcend those traditional boundaries through dedicated funding for its 10 Big Ideas. In that respect, this is an exciting budget proposal. However, having been forced into a zero-sum choice, the agency had to make cuts elsewhere, namely to the core research programs and to education and training programs at all levels. These tradeoffs merit further discussion before we can be comfortable that the benefits outweigh the potential harm.

This budget also represents the first time that the agency is singling out one of its research directorates for a disproportionate cut while every other directorate is nearly flat. The Social, Behavioral, and Economic Sciences Directorate, or the SBE, would be cut by 11 percent. I do not doubt this steep cut was dictated from the White House. However, this ongoing devaluing of the role of SBE in meeting our national challenges could have damaging consequences. I look forward to hearing from Dr. Córdova and Dr. Zuber on what steps NSF will take to mitigate this harm.

I'm pleased to see the Antarctic Infrastructure Modernization for Science, or AIMS, project in the request, along with a proposal for a midscale research infrastructure program. I look forward to hearing more about both of these proposals.

Finally, as I alluded to earlier, while there are a few bright spots in education and broadening participation funding, I am concerned about the overall cuts to education in this budget. Education and training programs across research account—would be cut by nearly 25 percent. Proven programs such as Noyce Teacher Scholarship Program, research experiences for undergraduates, and the graduate research fellowships would all receive steep cuts. NSF has a dual mission of research and education. We cannot afford to back away from our commitment to either one.

I thank you, Dr. Córdova and Dr. Zuber, for being here this morning to help us examine these issues and concerns in more detail.

I thank you, Mr. Chairman, for holding this important hearing, and I 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
"An Overview of the National Science Foundation Budget Proposal for FY 2019"
March 15, 2018

Thank you Chairman Smith for holding this hearing, and welcome back Dr. Córdova and Dr. Zuber. I am pleased that we have both of you here this morning to help us understand the Fiscal Year 2019 budget request for the National Science Foundation and the potential impact of this request on NSF's ability to help support U.S. leadership in science.

Funding for NSF peaked in 2010 at $7.7 billion. In the years since then, the budget has stagnated at or below $7.5 billion. That is the case despite the Obama Administration requesting increases every year. In stark contrast, last year, the Trump Administration proposed to cut NSF by 11 percent. And this year, until Congress passed the budget agreement, the proposed cut was closer to 30 percent. This Administration has demonstrated time and again how little they value science.

Given these trends, most of us are relieved when the NSF budget remains flat rather than cut. However, flat is a decline in real dollars, and it represents a terribly low standard by which to judge our nation's standing in science and technology. We will hear in Dr. Zuber's testimony how other countries are doubling-down on their investments in R&D while we just cut.

Having said that, I applaud Dr. Córdova and your team at NSF for being as bold and forward-looking as you could be given the constraints imposed upon your budget by the White House. I will highlight just a few items of interest or concern that I hope we can discuss further in this hearing.

Advancing science to solve our national and global challenges increasingly depends on teams of scientists from different disciplines coming together in what is now commonly known as convergent research. However, for generations, universities and the National Science Foundation itself have been organized around disciplines. While advances in these core disciplines do and must continue, this organizational structure has created stovepipes and inhibited convergent research. In the FY 2019 budget request, NSF takes a big leap to transcend those traditional boundaries through dedicated funding for its 10 Big Ideas. In that respect, this is an exciting budget proposal. However, having been forced into a zero-sum choice, the agency had to make cuts elsewhere, namely to the core research programs and to education and training programs at all levels. These trade-offs merit further discussion before we can be comfortable that the benefits outweigh the potential harm.

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I thank Dr. Córdova and Dr. Zuber for being here this morning to help us examine these issues and concerns in more detail, and I again thank the Chairman for holding this important hearing. I yield back.

Chairman SMITH. Thank you, Ms. Johnson.

Our first witness today is Dr. France Córdova, Director of the National Science Foundation. Dr. Córdova was sworn in as Director of the NSF in March 2014. She previously served as President of Purdue University from 2007 to 2012. From 1993 to 1996, Dr. Córdova served as the Chief Scientist at NASA, and she is the recipient of NASA's highest honor, the Distinguished Service Medal.

Dr. Córdova has a Bachelor of Arts from Stanford University and a Ph.D. in physics from the California Institute of Technology.

Joining Director Córdova today to assist in answering technical questions is Dr. Joan Ferrini-Mundy, Acting Chief Operating Officer of the National Science Foundation. Previously, she led the NSF Education and Human Resources Directorate and co-chaired the White House National Science and Technology Council's Federal Coordination and STEM Education Task Force. Prior to the NSF, she was a Distinguished Professor of Mathematics Education at Michigan State University. Dr. Derrini-Mundi holds a Ph.D. in mathematics education from the University of New Hampshire.

Our second witness today is Dr. Maria Zuber, 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 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.

We welcome you all and look forward to your testimony. And Dr. Córdova, if you'll begin.

TESTIMONY OF DR. FRANCE CÓRDOVA, DIRECTOR, NATIONAL SCIENCE FOUNDATION

Dr. CÓRDOVA. Thank you, Chairman Smith, Ranking Member Johnson, and Members of the Committee. I'm pleased to be here today to discuss the President's fiscal year 2019 budget request for the National Science Foundation.

The request is $7.47 billion, level with the fiscal year 2017 appropriation. This level of funding reflects the Administration's commitment to NSF's role in strengthening the Nation's economy, national security, and global leadership in sciences and engineering.

NSF funds basic research that advances and sustains American preeminence in the innovation economy. NSF accounts for approximately 27 percent of the total federal budget for basic research conducted at U.S. colleges and universities. For computer science, that number is 83 percent. For biology, 69 percent, for engineering, 46 percent. These investments produce invaluable benefits to our nation and the world.

Economists have noted that over 50 percent of America's economic growth over the past 50 years is attributable to technological innovation. Much of it is the fruit of the uniquely American research and innovation ecosystem among academia, industry, and government where ideas, artifacts, and people flow among these sectors. In information technology, this is embodied in this tire-tracks diagram. This extraordinary ecosystem has given rise to multibillion-dollar industries, and it all begins, as the diagram shows, with investment in fundamental long-term research often made with federal dollars and often made many years, even decades before it evolved into billion-dollar businesses.

MRI technology, gene editing, barcode technology, Google, 3–D printing, these are all areas NSF invested in early that have transformed our lives. Today, NSF is at the forefront of research in big data, quantum computing, artificial intelligence, cybersecurity, and robotics areas that will power the future economy.

Our fiscal year 2019 request also incorporates new and innovative ways of doing business that will position NSF at the leading edge of discovery. First, NSF will invest in our 10 Big Ideas. The Big Ideas represent unique opportunities to position our nation at the frontiers, indeed to define the frontiers of global science and engineering leadership. An investment of $30 million is requested for each of the six research-focused Big Ideas. Four other Big Ideas such as midscale facilities and the INCLUDES initiative focused on new approaches to increase opportunities for discovery and expand the STEM community.

Our success also requires innovative approaches to leveraging resources over all fields of science. In fiscal year 2019, NSF will initiate two convergence accelerators, new centers that will converge around important national challenges requiring interdisciplinary expertise. The accelerators will streamline operations and collaborations, focusing on results and outcomes that can be achieved quickly.

An investment of $60 million will support two convergence accelerators for two of the Big Ideas: Harnessing the Data Revolution for 21st-Century Science and Engineering and the Future of Work at the Human-Technology Frontier. These Big Ideas were chosen because of the readiness for convergent and translational research.

We expect to catalyze an additional $40 million in investment by external partners, including the private sector, other federal agencies, and international funders.

Equally important to our sustained global leadership in science and engineering are investments in STEM education. At NSF our education activities are integrated with research. In fiscal year 2019, NSF will continue to invest in CyberCorps, Computer Science for All, the Advanced Technological Education program, and other initiatives that support teachers, students, and researchers from K–2 to lifelong learning environments. We will not have the discoveries of tomorrow without a skilled workforce prepared for tomorrow.

Mr. Chairman, I had the honor of attending the 2017 Nobel Prize awards ceremony in Stockholm, Sweden. I was there to celebrate scientists in the fields of physics, economics, biology, and chemistry. All eight U.S. Nobelists were at some point in their careers supported by NSF. Three of them were honored for the LIGO discovery of gravitational waves, a discovery only made possible by 40 years of NSF support. In fact, NSF-funded researchers account for 231 Nobel Prizes, dating back to 1955. This is but one powerful example of why Congress' support for NSF and fundamental basic research is so vital.

Another is in the tire-tracks diagram, which exhibits some of NSF's contributions to the growth of new robust businesses. This Committee has played an important role in these successes. Through the AICA, it continues to make our agency stronger in its processes to deliver the best to the American people. Thank you for your continued support of NSF.

[The prepared statement of Dr. Córdova follows:]

Dr. France Córdova
Director
National Science Foundation

Before the
Committee on Science, Space, and Technology
United States House of Representatives

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

March 15, 2018

Introduction

Chairman Smith, Ranking Member Johnson, and Members of the Committee, it is a privilege to be here with you today to discuss the President's Fiscal Year (FY) 2019 Budget Request for the National Science Foundation (NSF).

Established by the National Science Foundation Act of 1950 (P.L. 81-507), NSF is an independent Federal agency whose mission is "to promote the progress of science; to advance the national health, prosperity, and welfare; to secure the national defense; and for other purposes." NSF is unique in carrying out its mission by supporting fundamental research across all fields of science, technology, engineering and mathematics (STEM) and all levels of STEM education. NSF is also committed to the development of a future-focused science and engineering workforce that draws on the talents of all Americans. NSF accounts for approximately 27 percent of the total Federal budget for basic research conducted at U.S. colleges and universities and has been vital to many discoveries that impact our daily lives and drive the economy. NSF seeks to be a respected steward of taxpayer dollars, operating with integrity, openness, and transparency.

A vibrant scientific workforce and breakthrough discoveries enabled by NSF investments sustain, accelerate, and transform America's globally preeminent innovation ecosystem. For example, last year, eight American scientists were awarded Nobel prizes in the fields of physics, economics, biology and chemistry. All eight of those world-class researchers were, at some point in their careers, supported by NSF. In fact, since the 1950's – only shortly after NSF's creation – NSF has funded more than 230 Nobel laureates. Last year's awardees included the Laser Interferometer Gravitational Wave Observatory (LIGO) scientists who in 2015 detected gravitational waves – first predicted by Albert Einstein a century ago – and opened a new and exciting chapter in astrophysics. Their work will enable new commercial applications and countless new discoveries.

Notably, LIGO represents a 40-year investment by the NSF and speaks to the importance of our ability to invest in high-risk, high-reward research and facilities that allow scientists to explore the frontiers of science.

The complex global and domestic challenges facing the Nation today require NSF investments. Federal investment in basic research and the STEM workforce, led by NSF, is vital to the Nation's continued global leadership. Other nations continue to increase their support of research, development, and STEM education, as they innovate in next-generation technologies. China and the European Union have invested significantly in quantum technology, and continue to invest billions of dollars in artificial intelligence research with an eye to a future of global leadership in these areas. There is unprecedented global competition for highly skilled, technical workers who will lead tomorrow's innovations. Continued U.S. support for basic research has never been more vital for the Nation and for the world.

The President's FY 2019 Budget Request is steady with what Congress enacted for FY 2017. While the funding level is the same as FY 2017, the content differs some since this budget reflects Administration priorities. With this level of funding, NSF will be able to support basic research across all fields of science and engineering that create knowledge while allowing us to invest in priority areas like:

- Advancing NSF's Big Ideas - bold questions that will drive NSF's long-term research agenda;
- Accelerating focused, cross-disciplinary efforts that will have impact in a short timeframe around two of the Big Ideas: Harnessing the Data Revolution for 21st-Century Science and Engineering; and the Future of Work at the Human-Technology Frontier.
- Initiating the Antarctic Infrastructure Modernization for Science project; and
- Building two Regional Class Research Vessels, a major component in the plan for modernizing the U.S. Academic Research Fleet.

In a world of converging disciplines and interdependencies among fields of research, NSF is making changes to our funding structure that will allow us to leverage resources and the science we fund. Increasingly, collaboration and convergence are necessary to achieving our mission, especially in a world of flat budgets. The Big Ideas and the Convergence Accelerators that we are prioritizing in the FY 2019 Budget Request are prime examples of funding across disciplines. We must leverage the science across all fields of NSF research to remain at the frontiers of science and engineering.

The President's Fiscal Year 2019 Budget Request

The FY 2019 Budget Request for the National Science Foundation is $7.47 billion, the same as the final funding for FY 2017. This level of funding reflects the Administration's commitment to NSF's role in strengthening the Nation's economy, national security, and global leadership, while also restraining non-defense spending across the government. NSF funds the basic research that advances cybersecurity, infrastructure, manufacturing, and military technology, and sustains American preeminence in innovation. NSF also makes critical investments in STEM education that prepare the Nation's future-focused workforce. At NSF, because our education activities are integrated with science and engineering, research and innovation, we recognize that combining the best that we know from research about learning and cognition with exciting opportunities to learn STEM is a winning combination for helping to effectively inspire the next generation STEM skilled workforce. In FY 2019, NSF would expect to evaluate approximately 50,600 proposals through its competitive merit review process and make approximately 11,100 new competitive awards. NSF expects that over 93 percent of its FY 2019 requested budget would be used to fund research and education grants and research infrastructure in the science and education communities.

NSF has made a strong commitment to agency-supported research infrastructure. NSF plans to invest in the Antarctic Infrastructure Modernization for Science (AIMS) project, a necessity for maintaining U.S. scientific and geopolitical eminence across the continent of Antarctica. The AIMS project is the primary component of the McMurdo Station Master Plan, with a specific focus on the core elements of this critical logistics hub following the recommendations in a 2012 Blue Ribbon Panel report. The project is funded in the Research and Related Activities (R&RA) account as the first stage of a long-term capital plan for all of NSF's Antarctic assets. It is feasible for the Office of Polar Programs to manage AIMS from R&RA since the program is unique in having no-year R&RA authority. All of NSF's current oversight requirements for major facility construction projects will apply to the AIMS project, as McMurdo Station is considered a "major facility" under the definitions contained in the American Innovation and Competitiveness Act.

The agency will begin support for rigorously-reviewed Mid-Scale Research Infrastructure, an effort that will address a gap between small existing research infrastructure instrumentation and existing large facility funding. Using funds in the Major Research Equipment and Facilities Construction (MREFC) account, NSF will fund the construction of two Regional Class Research Vessels, pivotal components in the modernization of the academic research fleet that helps scientists to understand numerous ocean processes along our coasts. Scientific infrastructure has long been a cornerstone of NSF-funded research across the Nation, and the FY 2019 Budget Request enables further such investment.

Complementing NSF's commitment to infrastructure is the agency's constant pursuit of innovation. In FY 2019, NSF will invest heavily in its 10 Big Ideas, research agendas that identify areas at the frontiers of science and engineering which promise to be among the most transformative in the coming decades. NSF will also initiate two Convergence Accelerators, which are new organizational structures that will leverage external partnerships for convergence science to produce results and outcomes in an accelerated timeframe, with streamlined operations that allow for nimbleness and mid-course adjustments to support the most innovative science. NSF's support for the Big Ideas and the Convergence Accelerators reflects the agency's ongoing commitment to advancing science at the frontiers, while supporting the core fundamental research that has advanced the Nation since the agency's founding. Collaboration and convergence are required across NSF to achieve the agency's mission and support the maximum number of researchers. No longer is any one research directorate the sole NSF funder of all science in a given field. Science and engineering today requires innovative approaches to leveraging resources across all fields of science.

NSF is essential to advancing American leadership in science and technology. NSF investments in all 50 states of the Union and all U.S. territories have resulted in both short- and long-term innovation and the robust creation of jobs. Over 50 percent of America's economic growth of the past 50 years is attributable to technological innovation. This innovation depends on significant investment in basic research. NSF had a role in the development of important advances such as the Internet, 3-D printing, and cell phones, and in responding to national and international crises, including the Ebola and Zika outbreaks, the Deepwater Horizon oil spill, Hurricane Katrina, and more recently, Hurricanes Harvey, Irma, and Maria.

NSF awarded $16.5 million in 192 grants after recent natural disasters to help quickly mobilize resources to aid in relief efforts, and to help understand how to better protect human lives, infrastructure, and resources during these crises. These awards helped scientists understand how best to respond to disasters in the future and how to provide immediate assistance when people need it most. NSF investments in disaster research have advanced understanding of the paths of tropical cyclones, improved water decontamination, deployed underwater rescue robots, and helped to understand the long-term psychological and emotional effects of disasters. For example, after hurricanes Harvey and Irma hit, researchers quickly used the NSF-funded Stampede2 supercomputer to create useful computer models that showed the likely depth and location of water in different regions, which helped first responders navigate flooded areas and allowed them to reach those most in need of assistance. Other researchers are studying the short- and long-term effects of extreme flooding in urban areas to understand the spread of diseases after floods.

Finally, NSF remains committed to investing in the basic research that helps the U.S. military both on and off the battlefield. This includes innovative military technologies to support those on the front lines. Years of NSF-funded research allowed the creation of the Worldwide-Integrated Crisis Early Warning System, which has helped the military predict where conflict is likely to break out, and how best to mitigate a potential crisis. NSF funding developed Hemogrip, a biopolymer foam that expands in a wound to minimize blood loss and save lives on the battlefield. NSF investments also work to improve the lives of veterans as they readjust to civilian life. NSF-funded research has created better prosthetics and improved screening and treatment of post-traumatic stress disorder, depression, and other issues afflicting America's veterans.

These priority funding areas, for which additional details are provided below, will help ensure that NSF and the Nation remain global leaders in innovation. The support of Congress has been, and will continue to be, vital to NSF's ability to continue innovating and pushing the boundaries of science.

NSF's Big Ideas

In 2016, NSF announced a set of bold questions that will drive the agency's long-term research agenda – questions that will ensure future generations continue to reap the benefits of fundamental research. These 10 "Big Ideas," supported in the FY 2019 Budget Request, aim to capitalize on what NSF does best: catalyze interest and investment in fundamental research, which is the basis for discovery, invention, and innovation, along with education. The Big Ideas define a set of cutting-edge research agendas and processes that are suited for NSF's broad portfolio of investments, and will require collaborations with industry, private foundations, other agencies, science academies and societies, and universities. They will provide platforms to bring together every field of study, from science and education, to engineering and astrophysics, to radically alter the conduct of science and engineering across the scientific enterprise in a manner that is not possible by simply continuing discipline-specific efforts at current levels. The Big Ideas represent unique opportunities to position our Nation at the frontiers—indeed to define the frontiers—of global science and engineering leadership and to invest in fundamental research that advances America's economic competitiveness and security.

About the Big Ideas:

Six of the Big Ideas focus on research, building on a foundation made possible by earlier investments in fundamental research. Four of the Big Ideas focus on process, and address NSF practices that could be altered or enhanced to capture the best research and to expand the Nation's science and engineering community.

Research Big Ideas:

- **Harnessing the Data Revolution for 21st-Century Science and Engineering:** Engaging NSF's research community in the pursuit of fundamental research in data science and engineering, the development of a cohesive, federated, national-scale approach to research data infrastructure, and the development of a 21st-century data-capable workforce.
- **The Future of Work at the Human-Technology Frontier:** Catalyzing interdisciplinary science and engineering research to understand and build the human-technology relationship; design new technologies to augment human performance; illuminate the emerging socio-technological landscape; and foster lifelong and pervasive learning with technology.
- **Windows on the Universe: The Era of Multi-Messenger Astrophysics:** Using powerful new syntheses of observational approaches to provide unique insights into the nature and behavior of matter and energy and to answer some of the most profound questions before humankind.
- **The Quantum Leap: Leading the Next Quantum Revolution:** Exploiting quantum mechanics to observe, manipulate, and control the behavior of particles and energy at atomic and subatomic scales; and developing next-generation quantum-enabled science and technology for sensing, information processing, communicating, and computing.
- **Understanding the Rules of Life: Predicting Phenotype:** Elucidating the sets of rules that predict an organism's observable characteristics, i.e., its phenotype.
- **Navigating the New Arctic:** Establishing an observing network of mobile and fixed platforms and tools across the Arctic to document and understand the Arctic's rapid biological, physical, chemical, and social changes.

Process Big Ideas:

- **NSF INCLUDES:** Transforming education and career pathways to help broaden participation in science and engineering.
- **Growing Convergence Research at NSF:** Merging ideas, approaches, tools, and technologies from widely diverse fields of science and engineering to stimulate discovery and innovation.
- **Mid-scale Research Infrastructure:** Developing an agile process for funding experimental research capabilities in the mid-scale range, spanning the gap in research infrastructure between the $4 million cap on NSF's Major Research Instrumentation program and the $70 million lower bound for projects supported by NSF's Major Research Equipment and Facilities Construction account. This is a "sweet spot" for

science and engineering that has been challenging to fund through traditional NSF programs.

- **NSF 2026 Fund:** Stimulating and seeding investments in bold foundational research questions that are large in scope, innovative in character, originate outside of any particular NSF directorate, and may require a long-term commitment. This Big Idea is framed around the year 2026, providing an opportunity for transformative research to mark the Nation's 250th anniversary.

Big Ideas Stewardship Funding Model:

The fundamental research underlying the Big Ideas has been supported through many NSF programs for several years, and in some cases, for decades. The FY 2019 Budget Request will accelerate NSF's progress on the Big Ideas through the following funding models.

In FY 2019, an investment of $30.0 million is requested for each of the six research Big Ideas, for a total of $180.0 million. This is in addition to the significant investments already being made by individual NSF directorates and offices in these areas. This additional investment for each of the Big Ideas will support convergent research that transcends traditional disciplinary boundaries of individual NSF directorates and offices. The research directions for each Big Idea will be overseen and managed collaboratively by a multi-directorate/office leadership team. Budget management and reporting will be the responsibility of the directorate to which the $30.0 million is assigned for a given Big Idea, with the multi-directorate/office leadership providing oversight.

The process Big Ideas are also emphasized in this Budget Request:

- NSF INCLUDES will establish the NSF INCLUDES Alliances, as NSF begins to move the NSF INCLUDES program to national-scale collaborations.
- NSF 2026 will initiate mechanisms to catalyze new research areas that may become future research Big Ideas.
- Growing Convergence Research at NSF will support research projects that span not only the Big Ideas but also new ideas, as NSF continues to break down barriers.
- An increased investment in mid-scale research infrastructure will be used to continue to span the midscale gap noted above.

Agency Reform

The landscape in which NSF executes its mission is constantly evolving. Today's research questions are increasingly interdisciplinary in nature, requiring new levels and forms of scientific and engineering collaboration. At the same time, the Nation is addressing pressing challenges, including maintaining the security of cyber systems and physical infrastructure, building resiliency to disasters, improving Americans' health and quality of life, educating and inspiring the next-generation workforce, and growing American jobs and economic productivity. To continue to achieve its mission, NSF must therefore adapt to this evolving environment.

In support of this adaptation, and in alignment with NSF's history of continued organizational improvement and the Administration's government-wide agency reform activities, NSF will focus reforms in five areas in FY 2019.

Convergence Accelerators:

The Convergence Accelerators are new structures that represent an evolution from how funding for research has been organized at NSF. The Convergence Accelerators will be time-limited structural entities intended to leverage external partnerships to facilitate convergent and translational activities in areas of national importance. An investment of $60.0 million in FY 2019 will support two Convergence Accelerators pursuant to two of NSF's Big Ideas: Harnessing the Data Revolution for 21st-Century Science and Engineering; and the Future of Work at the Human-Technology Frontier. These Big Ideas were selected for the initial Convergence Accelerators because of their readiness for convergent and translational research. The $60.0 million investment is expected to catalyze an additional $40.0 million in investment by external partners, including the private sector, other federal agencies, and international funders. The Convergence Accelerators will be launched through NSF's Office of Integrative Activities. Funding for the Convergence Accelerators will be separate from, and in addition to, the funding for the Big Ideas.

Make information technology (IT) work for us:

For NSF to continue funding cutting-edge science and engineering, leading-edge IT solutions that can adapt easily and quickly are essential. NSF will work to ensure that IT tools enhance employee productivity and satisfaction by enabling access, through easy-to-use interfaces, to reliable, readily available, and fully integrated data to support decision making. For example, NSF will continue efforts started under its Proposal Management Efficiency activity to automate proposal processing and improve mission-critical systems in ways that reduce workload, increase operational efficiency, and serve our clients more effectively.

In FY 2019, NSF will invest an additional $4.0 million in adoption of automated, intelligent tools that enable evolution of NSF's business processes, including its core business process of merit review; and accelerated modernization of NSF's IT infrastructure via adoption of cloud offerings, consolidated computing platforms, software-defined network infrastructure, and automated change management processes to improve overall resilience of NSF's systems.

Align NSF's workforce and work:

As the Nation's research enterprise evolves and NSF's proposal volume grows, the agency's workforce stands to benefit from enhanced capabilities that advance day-to-day business processes and enable the best service to the scientific community. In parallel with the IT-enabled business process improvements described above, NSF will optimize the alignment of staffing and position descriptions with the changing landscape. NSF will maintain its already lean workforce through continuous improvements in personnel training and utilization, and through effective performance management.

Expand public and private partnerships:

Private industry, foundations, and non-profits, together with other federal agencies and international funding organizations, bring additional expertise, resources, and capacity to NSF-funded research, which can accelerate discovery and translation of research to products and services that benefit society and grow the American economy. NSF will increase efficiencies in developing, implementing, and managing partnerships that maximize the scientific, economic, and societal impacts of its investments. In particular, NSF will revise policies to enhance partnership development, including implementing new and innovative models with external organizations in science and engineering areas ripe for leverage. NSF will also explore additional partnerships with the private sector, philanthropies, and other federal agencies.

Streamline, standardize, and simplify programs and processes:

Many NSF business processes are managed and executed locally within the agency's directorates and offices, posing efficiency and collaboration challenges. NSF will revise policies and business processes to increase standardization across NSF organizations and eliminate unnecessary complexity. There are significant opportunities for improvement relating to the merit-review process, NSF's core business process, and expanded use of shared services for business operations.

NSF-Wide Investments

NSF continues to bring together researchers from all fields of science and engineering to address today's cross-disciplinary questions and challenges through Foundation-wide activities. In FY 2019, NSF will support four continuing cross-Foundation investments.

Innovations at the Nexus of Food, Energy, and Water Systems (INFEWS)

$16.4 million is requested in FY 2019 for INFEWS, which aims to understand, design, and model the interconnected food, energy, and water system through an interdisciplinary research effort that incorporates all areas of science and engineering and addresses the natural, social, and human-built factors involved. INFEWS is the first program to study the interconnected food-energy-water nexus. This program is driven by pressing needs and challenges, such as growing U.S. and global populations, changes in land use, and increasing geographic and seasonal variability in precipitation patterns, all of which are placing an ever-increasing stress on these critical resources.

NSF Innovation Corps (I-Corps™)

$30.0 million is requested for the I-Corps™ program, which improves NSF-funded researchers' access to resources that can assist in bridging the gap between discoveries and technologies, helping to transfer knowledge to downstream technological applications and use at scale. In FY 2019, NSF will continue to support I-Corps™ Nodes and I-Corps™ Sites to further build, utilize, and sustain a national innovation ecosystem that helps researchers effectively identify viable market opportunities and augments the development of technologies, products, and processes that benefit the Nation. NSF will also continue to support I-Corps™ Teams that are provided access to experiential entrepreneurial education and mentoring in order to determine the readiness to commercialize technologies resulting from NSF-funded research.

The Secure and Trustworthy Cyberspace (SaTC)

$129.0 million is requested for SaTC. This investment aims to build the knowledge base in cybersecurity that enables discovery, learning, and innovation, and leads to a more secure and trustworthy cyberspace. Through a focus on long-term, foundational research, SaTC will develop the scientific foundations for cybersecurity research for years to come. SaTC also focuses on the training of the next generation cybersecurity workforce, especially for government. This program aligns NSF's cybersecurity investments with the national cybersecurity strategy.

Understanding the Brain (UtB)

$127.2 million is requested for this important initiative, which encompasses ongoing cognitive science and neuroscience research and NSF's contributions to the ongoing Brain Research through Advancing Innovation and Neurotechnologies (BRAIN) Initiative. The goal of UtB is to enable scientific understanding of the full complexity of the brain, in action and in context. There remains much to discover to attain a comprehensive understanding of the general principles underlying how cognition and behavior relate to the brain's structural organization and dynamic activities; how brain, behavior, and environment interact; and how the brain can recover from lost functionality. Investments that address critical research questions relevant to UtB are also central to the Big Ideas activities.

Education and STEM Workforce

NSF's education and STEM workforce investment, centered in the Directorate for Education and Human Resources (EHR), funds activities that support students, teachers, faculty, researchers, and the public. The EHR investment in core STEM education research is critical to building the Nation's knowledge base for strategic and impactful STEM learning. NSF's investments for FY 2019 focus on the following priorities.

The CyberCorps®: Scholarship for Service (SFS)

$55.0 million is requested for the CyberCorps® program, which supports cybersecurity education and research at higher education institutions. SFS also focuses on workforce development by increasing the number of qualified students entering the fields of information assurance and cybersecurity, which enhances the capacity of the U.S. higher education enterprise to continue to produce professionals in these fields to secure the Nation's cyberinfrastructure. FY 2019 activities will include engaging first- and second-year undergraduate students, with a focus on veterans.

Computer Science for All (CSforAll)

$20.0 million is requested for CSforAll to build on ongoing efforts to enable rigorous and engaging computer science education in schools across the Nation, to prepare the STEM workforce of the future. Funds will support the development of prototype instructional materials, scalable and sustainable professional development models, approaches to preservice preparation for computer science teachers, teacher resources, and the research to study their impact. CSforAll aims to provide high school teachers with the preparation, professional development, and ongoing support that they need to teach rigorous computer science courses and to give preK-8 teachers the instructional materials and preparation they need to integrate computer science and computational thinking into their teaching.

The Improving Undergraduate STEM Education (IUSE)

$102.5 million is requested for the IUSE initiative, which supports the development of the STEM and STEM-capable workforce by investing in the improvement of undergraduate STEM education, with a focus on attracting and retaining students and on degree completion. The initiative funds the development and implementation and the related research and assessment of effectiveness.

Advanced Technological Education (ATE)

$66.0 million is requested for the ATE program, through which NSF is able to reach technicians in undergraduate programs preparing for the high-technology fields that drive our Nation's economy. Funds will support partnerships between academic institutions and industry to promote improvement in the education of science and engineering technicians at the undergraduate and secondary school levels.

The Graduate Research Fellowship Program (GRFP)

$270.7 million is requested for the GRFP, which recognizes students with high potential in STEM research and innovation and provides support for them to pursue research across all science and engineering disciplines. GRFP fellows may participate in Graduate Research Opportunities Worldwide (GROW), which provides opportunities to conduct research with international partner countries and organizations, and Graduate Research Internship Program (GRIP), which provides professional development through research internships at federal agencies. In FY 2019, NSF will support 1500 new fellows.

Major Research Equipment and Facilities Construction (MREFC)

The FY 2019 Request includes funding to construct two Regional Class Research Vessels and to continue construction of the Daniel K. Inouye Solar Telescope and the Large Synoptic Survey Telescope.

Daniel K. Inouye Solar Telescope (DKIST)

The construction of DKIST will enable the study of magneto-hydrodynamic phenomena in the solar photosphere, chromosphere, and corona. It will allow scientists to study these phenomena at unprecedented spatial, temporal, and wavelength resolutions. These phenomena are associated with what is generally known as space weather, which can severely impact the Nation's infrastructure. $16.13 million is requested in FY 2019, which will be the final year of funding in an 11-year funding profile.

Large Synoptic Survey Telescope (LSST)

The LSST will be an 8-meter-class wide-field optical telescope capable of carrying out surveys of the entire sky. It will collect nearly 40 terabytes of multi-color imaging data every night to produce the deepest, widest-field sky image ever. It will also issue alerts for moving and transient objects within 60 seconds of their discovery. $48.82 million is requested in FY 2019, which will be year six of its nine-year construction funding profile.

Regional Class Research Vessels (RCRV)

The RCRV will provide scientific infrastructure that enables increased understanding of: the potential impacts of geohazards, such as storm surges and tsunamis; transportation and recreation; natural resource identification and extraction; and fisheries and aquaculture, among many other topics. $28.7 million is requested in FY 2019 for the construction of two RCRVs. This project is a major component in the plan for modernizing the U.S. Academic Research Fleet.

Implementation of the American Innovation and Competitiveness Act

Signed into law in January 2017, the American Innovation and Competitiveness Act (AICA) reflects continued strong support for NSF's investments in basic and collaborative research and STEM education that benefit the Nation and the world. The AICA affirms NSF's long-standing and world-renowned merit review process and addresses NSF's implementation of issues of importance such as increased transparency and accountability, and management of multi-user facilities and mid-scale projects, while maximizing research and education opportunities that help create the innovations that fuel our economy. The AICA promotes the Foundation's commitment to diversity in STEM fields, incentivizes NSF's programs that encourage private-sector involvement, and re-affirms NSF's continued commitment to entrepreneurship and commercialization.

The AICA does not change NSF's portfolio of investments or the way we do business – in research, education, infrastructure, and administration – rather, it enhances and strengthens it, and serves to codify how NSF invests in science, innovation, and education. NSF has taken an agency-wide approach in the implementation of AICA requirements. In May 2017, an AICA Coordinating Committee was established to ensure an effective and efficient agency response to the AICA. The Coordinating Committee was charged to: coordinate and oversee the implementation of NSF's response to the AICA; produce an agency-wide action plan to identify AICA sections requiring policy development or executive management decisions; and develop a central repository of AICA-related tasks, deliverables, and documentation.

Recognizing the importance of the public's confidence in our work, the AICA requires that the research goals of funded projects are clearly identified in a manner that can be easily understood by all audiences. Over the past year, NSF has re-emphasized the need for clarity and strong justifications so that the public can understand what we are funding and, most importantly, why we are funding it. Each award now explains the project's significance and importance in clear language.

The AICA also focuses on strengthening oversight and accountability for large facilities and support for "mid-scale projects." In response, NSF has maintained a Large Facilities Office and appointed the agency's first Chief Officer for Research Facilities. This position reports directly to the Director. These steps, and others such as requiring independent cost estimates, will lead to even greater outcomes in our large facilities portfolio.

NSF has also evaluated the existing and future needs for mid-scale projects as defined by the AICA. A request for information was issued to assess the demand for projects that could cost between $20 million and $100 million. NSF received 191 responses totaling a demand of at least $10 billion. Based on the demand evident from the responses, $55.0 million is included in the FY 2019 Budget Request for mid-scale research infrastructure. Separate tracks within the Mid-scale program will fund acquisition, design/development, and implementation.

Title III of the AICA highlights some areas of STEM Education that have been key investments for NSF for many years and where we are seeing positive impacts. The law also demonstrates a commitment to drawing more people who are talented into STEM fields by inspiring them early on with excellent learning opportunities, including engagement in computer science.

NSF, in collaboration with other agencies, is forming a STEM Education Advisory Council as required by the AICA. We solicited nominations and the response was impressive – NSF received over 500 nominations, including many with support from Members of Congress. Appointments are likely to be made in the next month or two.

The AICA also highlighted the I-Corps™ program. Since the I-Corps™ program was established in 2011, NSF has facilitated the formation of over 450 companies that have collectively raised over $250 million in seed capital. The I-Corps™ program is helping to focus efforts on ideas that are commercially viable and avoiding expenditures on those that are not. This efficiency, in addition to the entrepreneurial skills I-Corps™ teaches, has made it a highly sought program. NSF currently has memorandums of understanding with nine other federal agencies and the State of Ohio. The funding requested in the FY 2019 Budget Request will continue and build upon that track record of success.

Conclusion

In summary, the FY 2019 President's Budget Request for NSF represents a $7.47 billion investment in strengthening the nation's economy, security and global leadership through research in cutting-edge science and engineering and investments in STEM education and the future workforce. At this proposed level of funding, steady with FY 2017 congressional appropriations, NSF would continue its work supporting research that advances national priorities such as growth in manufacturing, defense, and cybersecurity.

Robust NSF investments in discovery research have returned exceptional dividends to the American people, expanding knowledge, improving lives, and ensuring our security. To keep those benefits flowing, we need to constantly replenish the wellspring of new ideas and train new talent while serving as good stewards of the public trust. That is the fundamental and continuing mission of NSF.

Through strong federal leadership, we can not only maintain the standing of our businesses and universities, but also 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 the role of the United States as the world leader in innovation.

Mr. Chairman, I can say with certainty that the results of frontier research funded by NSF have a long record of improving lives and meeting national needs. With the support of this Committee and Congress, NSF will continue to invest in the fundamental research and the talented people who make the discoveries that transform our future.

Thank you for the opportunity to testify today and for your continued support of NSF. I will be pleased to answer any questions you may have.

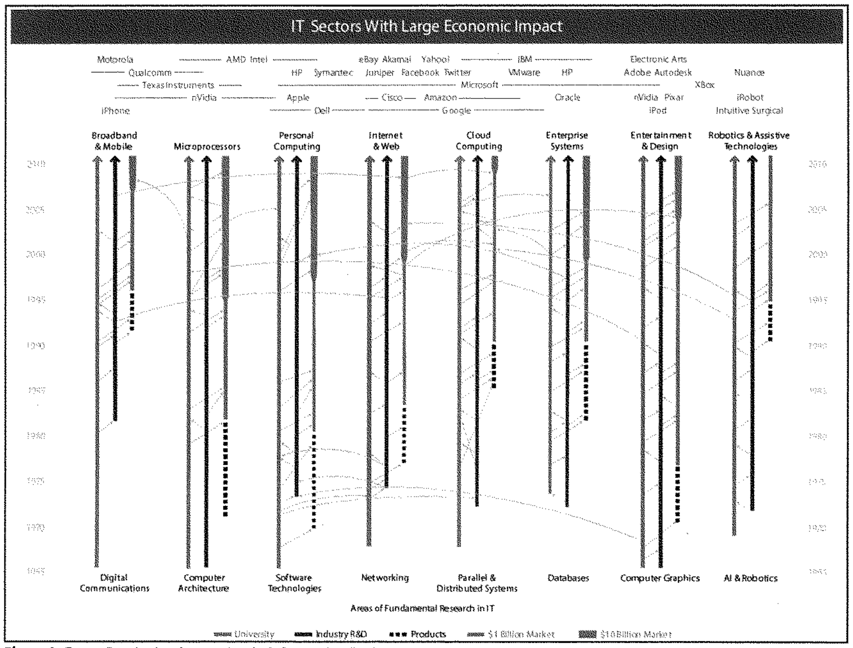

Figure 1. From *Continuing Innovation in Information Technology* Workshop Report, National Academies of Sciences, Engineering, and Medicine, 2016.

Dr. France A. Córdova
Director
National Science Foundation

France A. Córdova is an astrophysicist and the 14th director of the National Science Foundation (NSF), the only government agency charged with advancing all fields of scientific discovery, technological innovation, and science, technology, engineering and mathematics (STEM) education. NSF is a $7.5 billion independent federal agency; its programs and initiatives keep the United States at the forefront of science and engineering, empower future generations of scientists and engineers, and foster U.S. prosperity and global leadership.

Córdova is president emerita of Purdue University, and chancellor emerita of the University of California, Riverside, where she was a distinguished professor of physics and astronomy. Córdova was the vice chancellor for research and professor of physics at the University of California, Santa Barbara.

Previously, Córdova served as NASA's chief scientist. Prior to joining NASA, she was on the faculty of the Pennsylvania State University where she headed the department of astronomy and astrophysics. Córdova was also deputy group leader in the Earth and space sciences division at Los Alamos National Laboratory. She received her Bachelor of Arts degree from Stanford University and her doctorate in physics from the California Institute of Technology.

More recently, Córdova served as chair of the Board of Regents of the Smithsonian Institution and on the board of trustees of Mayo Clinic. She also served as a member of the National Science Board (NSB), where she chairéd the Committee on Strategy and Budget. As NSF director, she is an ex officio member of the NSB.

Córdova's scientific contributions have been in the areas of observational and experimental astrophysics, multi-spectral research on x-ray and gamma ray sources and space-borne instrumentation. She has published more than 150 scientific papers. She has been awarded several honorary doctorates, including ones from Purdue and Duke Universities. She is a recipient of NASA's highest honor, the Distinguished Service Medal, and was recognized as a Kilby Laureate. The Kilby International Awards recognize extraordinary individuals who have made "significant contributions to society through science, technology, innovation, invention and education." Córdova was elected to the American Academy of Arts and Sciences and is a National Associate of the National Academies. She is also a fellow of the American Association for the Advancement of Science (AAAS) and the Association for Women in Science (AWIS).

Córdova is married to Christian J. Foster, a science educator, and they have two adult children.

Chairman SMITH. Thank you, Dr. Córdova. Do you happen to have a hard copy of the PowerPoint that was just up on the screen? And if so, I'd like to make copies for members maybe even before the questions.

Dr. CÓRDOVA. Yes.

Chairman SMITH. Okay. If we could——

Dr. CÓRDOVA. If you have someone I can hand it to——

Chairman SMITH. Okay.——

Dr. CÓRDOVA. —I would be happy to do that.

Chairman SMITH. That would be great.

Dr. CÓRDOVA. Thank you.

Chairman SMITH. And, Dr. Zuber?

TESTIMONY OF DR. MARIA T. ZUBER, CHAIR, NATIONAL SCIENCE BOARD

Dr. ZUBER. Chairman Smith, Ranking Member Johnson, and Members of the Committee, I appreciate the opportunity to speak with you about the President's fiscal year 2019 budget request for the National Science Foundation. "An investment in knowledge always pays the best interest," declared Benjamin Franklin, our nation's founding innovator. Since World War II, the United States has led the world in research, transforming our lives, driving economic growth, and underpinning national security. Sustained bipartisan commitment to investing in fundamental research helped establish and maintain U.S. leadership in science and technology.

But the global science and technology landscape is rapidly changing. Other nations are upping their game. For the first time in over a half-century, our S&T leadership is being challenged. According to the Board's 2018 Science and Engineering Indicators Report, China's spending on R&D has grown by an average of 18 percent since the year 2000, while ours has grown by only four percent. Since 2000, China has tripled the number of STEM bachelor's degree awardees, and between 2013 and 2016, just three years, venture capital in China climbed from 5 to 27 percent of the global share, the fastest increase of any economy.

Although these trends are not new, in some cutting-edge areas of research, the trajectory is more pronounced. Within the last year, China erased the U.S. advantage in supercomputing, claiming more than 200 of the fastest 500 supercomputers to our 143. Over the next five years, China plans to invest 100 times more in artificial intelligence than the United States did in 2016. At the same time, total federal R&D funding has been declining from $127 billion in 2011 to $120 billion in 2015. Federal R&D spending as a share of GDP is now the lowest it has been since 1953. These choices have concrete consequences. If current trends continue, China will surpass the United States in total R&D expenditures sometime this year.

Despite these ominous trends, the Board is encouraged by Congress' agreement on a budgetary framework and the President working within those caps to prioritize NSF's mission of discovery in research and the national interest. With the requested level of funding in fiscal year 2019, NSF will support basic research across all fields of science and engineering that create knowledge, while allowing investment in priority areas.

The Board recognizes the fiscal challenge with—that Congress wrestles. In such difficult times, there can be a tendency to play it safe, but as America's innovation agency, NSF is not going to play it safe. First, the agency is embracing our nation's entrepreneurial spirit in trying something new. As the Director has just described, NSF proposes to break out of academic silos by investing in new elements to promote cutting-edge interdisciplinary research at the frontiers of science and technology: the Big Ideas and convergence accelerators. Much transformative research happens at the intersection of scientific fields. The Board believes this proactive approach is essential if NSF is to succeed in its mission to advance the frontiers of science.

Next, our nation's ability to discover, invent, and innovate relies on our ability to leverage America's greatest competitive advantage: our people. To ensure that Americans are equipped to thrive in a globally competitive knowledge economy, NSF will work with Congress, the Administration, business leaders, educators, and others to create to create a STEM-capable workforce. Our workforce of the future must leverage the hard work, creativity, and ingenuity of women and men of all ages, education levels, and backgrounds. NSF will continue to build this workforce through initiatives such as INCLUDES, ATE, and CyberCorps.

Finally, NSF is committed to innovating and improving our internal processes. The Board takes its responsibility to taxpayers seriously. We are now taking a fresh look at the merit review report, working with NSF to advance formal risk-thinking and strategic planning and priority-setting, and strengthening our oversight of major research facilities.

And I would be remiss if I did not thank you, Chairman Smith, for your leadership and holding us to the highest standards of accountability and transparency.

Investing in discovery research now will give us the keys to meeting unpredictable national security, economic, and health challenges of tomorrow. As President Trump warned, losing our innovation and technological edge would have far-reaching negative implications for American prosperity and power. We need a renewed and committed strategy to hold onto this key national asset.

But in challenge there is also opportunity. If we capitalize on the strong foundations of our innovation ecosystem and the talents of our people, we can pursue grand visions, enable revolutionary ideas, and reap the unexpected advances that emerge from dreaming boldly and fearlessly to pursue fundamental science.

Thank you and I look forward to your questions.

[The prepared statement of Dr. Zuber follows:]

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

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

March 15, 2018

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

Introduction

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

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

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

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

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

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

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

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

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

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

NSF: The Innovation Agency

Innovations in Research: Big Ideas and the Convergence Accelerators

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

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

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

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

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

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

The STEM Workforce: Developing our Nation's Future Innovators

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

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

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

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[2] Zuber, M.T., "Falling Short on Science", New York Times, January 28, 2018. (https://www.nytimes.com/2018/01/26/opinion/falling-short-on-science.html)

[3] National Science Board (2018), "Our Nation's Future Competitiveness Relies on Building a STEM-Capable U.S. Workforce." (https://www.nsf.gov/nsb/sei/companion-brief/NSB-2018-7.pdf)

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

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

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

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

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

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

Innovating within the Agency: Improving Our Processes

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

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

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

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

NSB's Budget Request

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

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

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

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

Conclusion

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

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

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

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 faculty 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.

Chairman SMITH. Thank you, Dr. Zuber.

I'll recognize myself for questions and address the first one to Dr. Córdova.

Dr. Córdova, last year, I think you had 40,000 grant proposals that were not funded. You clearly have an abundance of projects to choose from. And as I mentioned in my opening statement, you only approve about one out of every five proposals. How do you assure us, how do you assure the American people, that only the best projects are being funded? I mentioned in my opening statement a half-dozen that I thought were questionable. It seems to me that none of them should have been funded. I don't see the justification myself. But how do you screen proposals? How do you ensure that they are in the national interest?

Dr. CÓRDOVA. As Dr. Zuber mentioned, our merit review process is really the answer to your question, Chairman Smith. Every one of the proposals that we receive—and we receive approximately 50,000 a year—go through our world-lauded merit review process—which many countries of the world have copied because it is a process of very high integrity.

I want to address just for a second your specific question on particular proposals. I think our very first meeting a week after I took this job—so that would be four years ago—was about such proposals. And I took this very personally to examine how these proposals were approved and personally looked at the individual proposals. Then, we had a team of people look at the whole merit review process that was associated with each one. I was convinced in the end—a process that I had to do myself—I was convinced in the end that each one met our very high standards of intellectual merit and broader impact.

Chairman SMITH. I understand the merit review process. Would you get—let me just pick one out. Would you get back to me as to why the merit review process found $450,000 to study why there is no single English word for "light blue?" Will you get back to me on why that was in the national interest, for example?

Dr. CÓRDOVA. Yes, of course. For each one of the projects that's been questioned, we have written a report. They're all online.

Chairman SMITH. Okay.

Dr. CÓRDOVA. I do not know about that particular one, but of course we will get back to you.

Chairman SMITH. Okay. I appreciate that.

Dr. Zuber, we have talked about this before, but China is reportedly investing $10 billion in quantum research, far more than the United States. How can the United States stay competitive, and isn't that a threat and a danger for China to keep outspending us in so many of these research areas?

Dr. ZUBER. Well, quantum is of course incredibly important for national security but also on the financial system as well since cybersecurity affects financial transactions and actually personal transactions, the energy grid, et cetera. So there are a variety of places in the U.S. government that invest in cybersecurity and also the private sector as well, and we need some communication there.

But I think a key thing that we have to have is we need coordination among—of—among different agencies. Some are the on the classified side, some are on the unclassified side——

Chairman SMITH. Right.

Dr. ZUBER. —but the basic research, you know, is done on the unclassified side, and there needs to be some crosstalk in terms of what is actually needed early on. And then that could be communicated and then, you know, the classified side can take it over.

Another thing that I would say is that we need to be thinking about our education system as well and evolving it, so we—you know, how many programs have quantum engineering? Okay. MIT doesn't even have quantum engineering as a discipline. And we need to be——

Chairman SMITH. Can't you——

Dr. ZUBER. —thinking about——

Chairman SMITH. Can't you change that?

Dr. ZUBER. —although—we certainly are teaching those sorts of things, but we don't have a specific program on it——

Chairman SMITH. Okay.

Dr. ZUBER. —and I think research universities ought to be thinking about developing those programs——

Chairman SMITH. Okay.

Dr. ZUBER. —to train the next generation of researchers that are needed to take on these problems.

Chairman SMITH. Let me go to my next question. I assume you'll have some influence in trying to persuade MIT to have a program in quantum engineering, right?

Dr. ZUBER. I think I might be able to.

Chairman SMITH. Okay, good. My last question is this, the FBI recently shared concerns that countries like China are exploiting U.S. academic institutions and are taking advantage of the federal research funding. They're also trying to indoctrinate students. Do you share the FBI's concerns?

Dr. ZUBER. There certainly is some legitimacy to those concerns. Certainly, the United States needs to interact with China. They're a global power. There are things that it makes sense for us to collaborate on. It makes sense for us to attract talented Chinese students. We ought to work hard at keeping the best people in the United States after they get their degrees. But we ought to—we need to do a much better job in terms of training those students and actually our professors about issues of intellectual property so that we can respect the inventions and achievements of our people in the universities.

Chairman SMITH. Okay. Thank you, Dr. Zuber.

I will go to the gentlewoman from Oregon, Ms. Bonamici, for questions.

Ms. BONAMICI. Thank you very much, Mr. Chairman, and thank you Dr. Córdova, Dr. Zuber, and Dr.—is it Ferrini-Mundy? Thank you all for joining us today. And thank you, Chairman Smith and Ranking Member Johnson.

I just wanted to mention I know, Chairman Smith, in your opening you mentioned a couple of NSF-funded projects that you thought were questionable. I hope this year you can attend with us the Golden Goose Awards. The Golden Goose Awards are bipartisan recognition of scientists whose federally funded basic research has led to innovations with a significant impact on society, and it's often research with odd-sounding titles or names. So I hope you can join us for that because it's a really inspiring event.

This is a really important conversation we're having. We do want the United States to continue to be a leader, but unfortunately, this budget is, I believe, about the ninth year of flat funding. If we want to continue to be the leader, we should be increasing investments, not decreasing investments in the National Science Foundation.

Dr. Córdova, Oregon State University is leading efforts to design and construct the next generation of NSF regional class research vessels. The ships are designed to operate primarily in coastal waters and bays and estuaries on the West, East, and Gulf Coasts. They reflect an important long-term investment to advance marine transportation, sound fisheries management, national security priorities. This research is essential for any coastal region.

And I appreciate the NSF efforts in the short term to balance investments in research and infrastructure, but I am disappointed that the NSF budget request supports the construction of only two rather than three research class vessels. Without Congress investing in the three ships, many of the Nation's oceanographic scientists will be forced to rely on older ships that are less efficient to operate and maintain and that lack the technological and scientific capabilities for conducting research safely with the most advanced methods of the 21st century.

Additionally, because of economies of scale, the second ship is less expensive than the first, and the third would be less expensive than the second. So could you please explain to the panel how funding for a third vessel would contribute to the work of the NSF in the advancement of ocean sciences?

Dr. CÓRDOVA. Thank you, Congresswoman. The two RCRVs which are in our budget will significantly improve the support of science over their current capabilities, and this number of new vessels is in line with the minimum number recommended in the National Academies Sea Change report. Two vessels will support research in all major coastlines through the existing coastal research vessels program, and that is what is in our budget request.

Ms. BONAMICI. Thank you. I just want to say for the record that because a third would be less expensive than a second and it would be beneficial to have the third, I hope that somehow we can get to three vessels.

Also, NSF is proposing a steep cut of 11 percent to the social, behavioral, and economic sciences, SBE. I'm disappointed but actually not surprised that the Administration is targeting this program, but one of America's greatest strengths is innovation. It's not enough to educate world-class engineers, technologists, and scientists; we also need creative and critical thinkers. Our propensity for being entrepreneurial and cutting-edge is fostered through the arts and social science education. In fact, the Weather Forecasting Innovation Act I worked on and was signed into law last year included language about incorporating social sciences in community readiness and resilience efforts, especially in how we communicate that.

So, Dr. Córdova and Dr. Zuber, you've both made strong statements about the value of SBE sciences in the past. Can you tell us more about SBE sciences and how they intersect with issues of national importance, and can you ensure members of this Committee that the NSF is committed to its mission of supporting all fields of science and engineering including social sciences?

Dr. CÓRDOVA. Yes, I will start and I am sure Dr. Zuber can add to this. Last year, we asked the National Academies to do a study on the value of the social and behavioral, economic sciences. They did a study very quickly, in just a few months' time, that had a wonderful group of examples about how important these sciences have been to national needs.

The second point I want to make is that we have in this new structure that we described today that's in the fiscal year 2019 budget of the Big Ideas that all of the Big Ideas are convergent ideas. They bring together all the disciplines, and social and behavioral sciences will be a big part of that contribution, so there will be many opportunities under those Big Ideas to further the value of the social sciences.

Ms. BONAMICI. Thank you.

Dr. ZUBER. And I would——

Ms. BONAMICI. Microphone.

Dr. ZUBER. Excuse me. So there are—you know, there are many obvious examples of areas where the social and behavioral sciences are important for economic competitiveness and national security. So for—you know, when you talk about in weather forecasting, you know, having—what's the right time to put out a siren, you know, to have people take shelter. If you do it too often, people will tend to ignore it. There are cases in opioid abuse there where we need information on the social and behavioral sciences to understand trends and threats. You know, facial recognition software actually was used by a laboratory that I see, Lincoln Laboratory, that was actually used to then apprehend the marathon bombers.

So one can go on and on about the value of these, and I think we actually need to go by more than just the titles because when we go in and we actually see what the actual research in—is in these grants, I agree with the Director that it is—it's been through rigorous peer review and it's substantive.

And the final thing that I would say on this is that we're actually at the forefront of a revolution in the social and behavioral sciences. So in SBE right now, they're using the computer power that mathematical and physical sciences used a decade ago. So this entire field is really moving into a much more quantitative regime, and so, you know, that will just allow, you know, a lot of really objective important work to take place in support of the other areas of science within NSF.

Ms. BONAMICI. Oh, thank you. I see my time is expired. Thank you, Mr. Chairman.

Chairman SMITH. Thank you, Ms. Bonamici.

The gentleman from California, Mr. Rohrabacher, is recognized.

Mr. ROHRABACHER. Thank you very much, Mr. Chairman.

I have been very concerned that we are not putting enough emphasis on trying to secure the world in case we would spot an asteroid heading toward the Earth. And over the years I've been very conscious of this because that could happen tomorrow. And I've talked about it over the years, and it seems to me that we are not taking the steps that we could so that if an asteroid is seen, that we know what we're going to do, how to deflect it, et cetera.

One of the tools that is vital in that goal, in achieving that goal of being able to identify the course of some object in space that could do incredible damage to the world, one of the elements is the Arecibo Observatory in Puerto Rico. It actually provides us the ability to go years out in charting the course to see if it is dangerous to the world. We've got a bunch of young people here, and we want you to have the world that we had, and we need to be prepared for a possibility that an asteroid could actually come in and destroy that world.

Are we—what are we doing to make sure that what Arecibo has been doing in providing that service and that ability to chart those, how are we making sure that that is still getting done?

Dr. CÓRDOVA. As you know, a lot of that work is done by NASA as a participant at Arecibo Observatory. We have just recently announced a new partnership with the University of Central Florida, which will be gradually taking over the management of Arecibo. And this was a good solution, we feel, to our divestment planning for that observatory, which will take place over several years' time. We think it's in very good hands with the University of Central Florida as a steward.

The hurricanes, as you know, did wreak some damage on the observatory, it wreaked a lot more damage on the entire island, which everybody is trying to recover from. We are now back up with the observatory up and running. There are certain things that we still can't do, but we have supplemental funding request included in the Bipartisan Budget Act for necessary repair expenses to repair——

Mr. ROHRABACHER. So are you committed to——

Dr. CÓRDOVA. —our facility.

Mr. ROHRABACHER. —making sure that the Arecibo telescope and its capabilities of spotting these types of objects that could threaten the planet, that it will still—however you restructure the system——

Dr. CÓRDOVA. Right.

Mr. ROHRABACHER. —it still will provide that capability to those people who are concerned about this issue?

Dr. CÓRDOVA. As long as we have our partnership with NASA, yes. They are the ones that are really doing that program with us at Arecibo.

Mr. ROHRABACHER. Okay. So it's a qualified yes?

Dr. CÓRDOVA. Yes.

Mr. ROHRABACHER. All right.

Dr. CÓRDOVA. Thank you.

Mr. ROHRABACHER. Yes, all right. I was wondering—and we're talking about the budget—sometimes when the Chairman justifiably says, "wait a minute, what kind of study is this? Why did you do that?" And you know, when I was younger my father was a military officer and he took me outside at a certain time of year and said, "See all those planes flying around? I was ordered to send those planes flying around because we had to use up the fuel allotment, and we had to use our budget, totally use it up or they were afraid that they would lose the budget the next year." Now, are—

how many of these types of nonsensical studies that we're talking about are simply at the end of the fiscal year and being used to make sure that they use up the budgets so that at the same amount next year?

Dr. CÓRDOVA. I appreciate your concern, but I think the answer would be none of them. Again, going back to our merit review process, we have on any given day several hundred people from the external community at NSF reviewing the proposals and grading them very strictly. We leave about $4 billion worth of proposals rated excellent on the cutting room floor because we don't have enough to fund them. So you can be sure that the ones we do fund have gone through a very rigorous process.

I also want to take this opportunity to add that, as of March 1 of this year, new language has been inserted in all NSF award abstracts, and this says, and I quote, "This award reflects NSF's statutory mission and has been deemed worthy of support through evaluation using the Foundation's intellectual merit and broader impacts review criteria," and it's a pause for every division leader who has the ultimate approval of programs that are approved within the division by the program officers or recommend for funding. They have the final signoff. They ask does this fulfill national needs? Does it really pass the merit review criteria?

Mr. ROHRABACHER. Well, as the Chairman noted, there are some projects that passed, and obviously, somebody's judgment was impaired or, as I say, people were looking to use their budget. But we'll be watching. We're——

Dr. CÓRDOVA. Okay. Thank you.

Mr. ROHRABACHER. But we wish you well.

Dr. CÓRDOVA. Congressman Rohrabacher, I'd be pleased to visit you in your office and go through all—we've written a response to every proposal that's been criticized. Those responses I share these responses with people that publish the criticisms, and they're all online. And I think once we talk about it——

Mr. ROHRABACHER. Sure, I'll take a look at it.

Chairman SMITH. Dr. Córdova, I just looked at the justification for $450,000 for light blue. If you find anything in the national interest in your justification, let me know. I did not see it.

The gentlewoman from Connecticut, Ms. Esty, is recognized for her questions.

Ms. ESTY. Thank you, Mr. Chairman, and thank you so much for joining us today for these incredibly important issues that have those short-term and long-term impacts for all Americans.

Millions of Americans are unquestionably better off because of the basic research that the National Science Foundation has funded over decades. It's helped spawn, as you noted, Dr. Córdova, some of the giant companies, the cutting-edge companies in this country like Google and Symantec and QUALCOMM. But I have to tell you and in my district recently one of the state universities, Central Connecticut State University, just received a $5 million grant to reach out to underrepresented and minority students to encourage their participation in the sciences. So I know from the ground level how important that is both to the students but also to the companies in the area who need to see that talented pipeline of students.

But that's one of the reasons why I'm so concerned that the President's budget is not going up but rather going down. And the purchasing power has been steadily eroded for quite a number of years now. Since 2000, China has grown its R&D budget by approximately 18 percent annually. In the United States, that has increased by four percent. We are seeing the impacts of that across the board. I'm hearing from companies that—and I'm hearing for research institutions, they cannot retain their top scholars because other countries are offering them more predictable funding for longer periods of time and greater flexibility.

So I'm deeply concerned about that. We try to get the best and brightest. Some of them are homegrown; some of them are from around the world. But then for—and sometimes immigration reasons they're not allowed to stay, and that's a different—I realize not your department, but if you care to talk about the impact that's having on our higher ed and research, I'd welcome that.

But particularly, this impact on not having consistent high-level funding is making our research institutions like UConn and Yale in my State of Connecticut are having increasing difficulty in retaining the top-tier talent. And that has spillover effects, and that means then the companies don't want to say stay because they aren't seeing the best research. Can you tell us a little bit about what you're hearing and what you're seeing on that front?

Dr. CÓRDOVA. To turn for a response to our Chief Operating Officer who was, as you know, at one time head of our Education and Human Resources Directorate.

Dr. FERRINI-MUNDY. Thank you. Thank you for the question. A big piece of our investment, as you have noted of course, is developing pathways for talent for STEM, which is a piece of creating an ecosystem that enables a healthy STEM enterprise to occur in States and universities and in the Nation. We are very pleased with the breadth of our STEM education investments. They include our new big idea INCLUDES program, which is very much focused on making certain that we are tapping the full diversity of our nation, the full talent of our nation to ensure that we have a set of people who will be able to take leadership roles in universities, in the private sector going forward. So, we see this as a very important piece of our overall investment.

I would add that our restructuring within this particular budget to focus on the innovations that will be possible through our Big Ideas we hope will be very exciting to the research community and will intrigue scholars across the Nation because of the new convergence possibilities within this area.

Ms. ESTY. But we're also looking at the fact that—and, Dr. Córdova, you mentioned this—the number of project proposals that receive excellent ratings and yet can't be funded because there simply isn't enough money to go around. And I have to say I'm concerned about that because when we do have top-tier talent and we do have top-tier research projects that we're unable to fund, then we get brain drain out of this country and it's hard to bring them back. Dr. Zuber?

Dr. ZUBER. Yes, so if I could comment on that. So I don't—you know, I don't personally know what the right level of funding for NSF should be because there are of course many competing worthy the priorities. But I do know that of the NSF's $7.4 billion budget if we look at the number of proposals that received very good or excellent reviews, which means they were in the top the top-rated proposals that went unfunded because of the lack of funds, that's another $3.92 billion. So that would correspond to an NSF budget one and a half times what the current budget is without compromising in the least bit on quality.

Ms. ESTY. Thank you very much, and I yield back.

Chairman SMITH. Thank you, Ms. Esty.

The gentleman from Florida, Mr. Posey, is recognized.

Mr. POSEY. Thank you, Mr. Chairman, and I thank the witnesses for coming today, fascinating testimony.

I share the interest in planetary defense with Congressman Rohrabacher, and I'm glad to know that Arecibo will continue to monitor for our planetary defense. Have you publish any studies on our planetary defense?

Dr. CÓRDOVA. I'm not aware of any, but I will check and find out. I'm sure that other agencies have, but I'm not aware of studies——

Mr. POSEY. If you have, I'd appreciate it if you'd send it to my office. And I might state clearly that I do appreciate the direction that you're taking the agency now compared to the last Administration, and as the Chairman pointed out, the $700,000 on Climate Change Musical or $1.5 million to study pasture management in Mongolia, I remember medieval basket weaving, studying why one certain segment of women are fat.

I mean, compared to the China budget that somebody was talking about before, I think we'll find that we spend more real resources on research than they do, and I think if they got caught wasting the money on some of the things we have done, they'd probably put some people to death over there for it. All we can do is struggle to protect the taxpayers from stuff like that in the future.

You mentioned the opioid crisis. My driving question was going to be whether or not we have put any study toward the behavioral sciences. Have we ever looked at the opioid crisis or the root causes of violence in our schools?

Dr. FERRINI-MUNDY. Certainly within a variety of our directorates, including our social, behavioral, economic sciences, studies of behavior have been crucial in helping us to understand why various trends happen in society, how to make change, how to change people's behavior. That is part of the fundamental work in the social, behavioral sciences. So we certainly have some investment in those kinds of things, and we can follow up with some very particular kinds of examples for you if that would be useful.

Mr. POSEY. I would like information on particular resources you've developed on the opioid crisis and also the violence in our schools.

Dr. FERRINI-MUNDY. Certainly. And again, these would be resources that are funded principal investigators have produced with NSF funding, and so we can certainly survey what we have and get that to you.

Mr. POSEY. Okay. Any insight you could give us now as to what they revealed?

Dr. FERRINI-MUNDY. I think we need to get back to you with details to be sure that we get it to be accurate.

Mr. POSEY. Okay. Thank you, Mr. Chairman. I yield back.

Chairman SMITH. Thank you, Mr. Posey.

And the gentlewoman from Nevada, Ms. Rosen, is recognized.

Ms. ROSEN. Thank you, Chairman Smith. Thank you to the distinguished panel here today. I really appreciate your work and your—all the advancements that you've made and your commitment to science.

You know, I want to really talk about computer science because it's really critical right now. I'm a former computer scientist myself. But as our economy changes and we become increasingly driven by technology and data analytics, whether it's hard science or behavioral science in order for us to move our country forward in meaningful ways, this committee really has tried to ensure that we're educating the next generation of computing experts.

I'd like to thank Chairman Smith and Ranking Member Johnson. We did get my bills passed, "Code Like a Girl" and the "Building Blocks of STEM" to help in our education for young girls in early childhood.

But one of my top budget requests is for the computer and information science and engineering program which supports both computer information science and engineering research. It's going to cut—the President's budget is cutting this STEM+C by $19 million. So, Dr. Córdova, I really want to see if you could address the changes NSF is making in its approach to supporting computer science, especially in the lower grades, to ensure that we have the people pipeline coming through. How do we best support—you talk about the evolution of our education that needs to happen. It can't just happen at the university level. We have to prepare these kids coming up. We're getting these big budget cuts. How can we do that?

Dr. CÓRDOVA. Thank you, Congresswoman Rosen, and thank you for your passion on this subject. So these are two things I want to say. One is that computer and information science and engineering is not really being cut because they're an enormous part of the Big Ideas. In fact, of the two convergence accelerators, one is Harnessing the Data Revolution is all in that area, and the other one is the Future of Work at the Human-Technology Frontier, and that's about artificial intelligence, machine learning, neural networks, and so on. So, they are an integral part of shaping those accelerators and of the big corresponding fundamental Big Ideas.

In K–12, we have several programs in computer science. I'll just run through the names of them and we can send you follow-up details, but Computer Science for All supports researcher-practitioner partnerships that foster the need to bring computational thinking to schools at that level. We have STEM+C, computing partnerships in K–12, Innovative Technology Experiences for Students and Teachers, Discovery Research PreK–12. Those are all K–12 programs that promote the interests of students and their capabilities to participate in the STEM and computer science workforce.

Ms. ROSEN. Thank you. I really appreciate that because I think if we don't build our natural people pipeline starting in kindergarten, especially with young girls and minorities, people who don't think that they can do this or these things aren't open to them, then we are really losing a valuable asset to our future growth, so thank you for your work.

I yield back.

Chairman SMITH. Thank you, Ms. Rosen.

And the gentleman from Arizona, Mr. Biggs, is recognized for his questions.

Mr. BIGGS. Thank you, Mr. Chairman. I appreciate that, and I appreciate each one of you being here today. I'm glad to have you and appreciate the very interesting testimony. And I was very interested in the Puerto Rican observatory, and I'm grateful to hear what's going to happen there.

One thing that seems to have been highly emphasized here today and it's appropriate to emphasize is the budget because we're talking about budget today. But what I continue to hear is the detriment that's going to happen to the budget for my friends across the aisle. But it's okay to point out problems; I don't mind pointing out problems. Let's tackle them. Let's take them head-on.

But when we talk about percentage of growth in, say, tech spending in China versus tech spending in the United States, nobody talks about what the baseline is because if you're going to make an assessment that's on comparability of funding, you really need to know what the baseline is when you start talking about percentages. And China over the last 30 years has increased dramatically in their overall funding and tech spending, but their baseline was very low to begin with and now the projections are sometime in the early '20s, that they will actually meet somewhere near where the United States is. But as far as real dollars go, the United States continues to be a leader there, and I think that's critical to understand.

And the other thing I would say is there's a lot that goes into creating a national budget. And China already is overall matching E.U. spending according to the reports that I just read because I was curious when I started hearing all this, I thought, I'm going to pull up some reports and see what I can get. But there are other things—other variables not in consideration here, for instance, are we tacitly subsidizing anybody else who's doing research because we're spending for defense and military in protecting those countries so they can put money elsewhere. What level of taxation do my friends want to support the spending level they seek? And then are there other programs within the federal government that they might wish to reduce to backfill what they view as a reduction for the NSF?

So these are some thoughts that I raise before I get to my question, but I appreciate that you're here and actually for a forum to kind of vent on what solutions are being brought to the table because I'm just hearing problems brought to the table.

The federal government has been funding STEM education for decades, Dr. Córdova. Every year, larger emphasis is placed on the subject, and every year we hear how we're falling further behind. I'm interested in knowing what have we learned from previous investments in STEM about what is working, what is not working, how can we be confident that new investments are being put in the right place for the right activities? In other words, how can we become the most efficient, the most effective?

Dr. CÓRDOVA. Great. Thank you. You have a whole range of things covered there. I will start with solutions because that's where you're going, and then I'll ask Dr. Ferrini-Mundy to answer your last question about STEM and efficiencies and especially evaluation and assessment, which is our middle name. NSF is well known for doing that for all its programs.

On solutions, that's why we have structured a different budget for fiscal year 2019. We have a number of National Academy reports, reports out of committees of the National Science and Technology Council, advice of our advisory councils, and advice of the National Science Board that we need to be especially strategic in this day and age to meet challenges. And to deliver solutions for the country as quickly and as efficiently as possible. That is why we came up with this idea, which is now a structural idea in our budget of convergence accelerators to try to target those areas that are most ready because they have the most public interest and the most industry participation and really go after some near-term solutions in that space that we can bring to people very quickly.

NSF welcomes all proposals. It's what we call our core funding. And we fund blue-sky ideas. We take some risk. Some of them, like the LIGO that we funded for 40 years, after 40 years, they produce Nobel Prize-winning results. But we also need to reserve a part of our budget to be very strategic and very focused on solutions, so we're doing that. And I hope that you will like the results that we get from this.

Let me turn to Dr. Ferrini-Mundy about evaluation and assessment.

Dr. FERRINI-MUNDY. Thank you. So that's a really important topic for us. We want to be sure that our investments in STEM education, are strategic and are likely to have impact. And for that reason, for many decades now, NSF has funded not only attempts at intervening and improving STEM ed but attempts to study and evaluate and assess the effects of those kinds of efforts.

And I'll cite just a few key results where we really have a solid basis in research to talk about change and improvement in STEM education. One is at the undergraduate level, and we have got academy reports that help with this. We've learned very firmly through research that to retain undergraduates in STEM, a very key principle is to engage them actively in their learning to be sure that instruction is really designed to bring those students in, to give them research experience as a part of what they are doing in their undergraduate courses, and to make sure that they have the chance to really see what STEM looks like in practice.

That sounds fairly straightforward. It turns out to make that kind of a change in our nation's universities is not straightforward, but it's something that we know we should be headed toward.

At K–12 we know a lot about teachers and about what will help teachers be most effective in getting kids to learn well, and some of that has to do with the nature of how they understand the STEM subjects and how particularly elementary teachers in such fundamental areas as mathematics are prepared to be effective in meeting children where they are and moving them toward deep understanding of mathematics. So we have an array of findings, and we're applying those in how we actually design our programs.

Mr. BIGGS. Thank you. I've far exceeded my time.

Chairman SMITH. Thank you, Mr. Biggs.

Mr. BIGGS. Thank you, Mr. Chairman.

Chairman SMITH. The gentleman from California, Mr. McNerney, who may well be in contention for having one of the best attendance records of any Member of this Committee.

Mr. MCNERNEY. Well, I thank you for that shout-out, Mr. Chairman.

I certainly appreciate the work the NSF has done over the years, together with the NIH and the NASA, really put America as an undisputed leader of science for the past half-century, but we see that that may be changing and we need to worry about that.

I appreciate your statement, Dr. Córdova, that we will not have the discoveries of tomorrow without the workforce of tomorrow, but then I see a 15 percent reduction in the graduate research fellowships and also research experience for undergraduates. Now, being a graduate student is pretty tough to make ends meet. To get grants is a very big deal. How can we kind of square that? Because we see when you're a graduate student in the sciences, your contemporaries are out there making 10 times as much money as you are. And you get your Ph.D. and you become a postdoc, and again, they're increasing and you're slowly flat. So how can we sort of square that against a desire to have more people move into the STEM fields?

Dr. CÓRDOVA. We fund graduate students in a great variety of ways. The biggest program that we have is for graduate research assistantships, and that comes through our grants programs when a professor is awarded a grant and they can support graduate students on that. That's indeed how I was funded once upon a time.

We have other programs like the Graduate Research Fellowships Program, which is a very—a distinctive program that we are very, very proud of. Until just a few years ago, we funded 1,000 students per year, and then we raised it for a few years to 2,000 and now it's at 1500, which is still higher than it was before.

We have introduced a new program called Research and Traineeship programs in specific areas like computer science and nanotechnology to train cohorts of graduate students. The traineeship of students and the ability to get into the research world at an early stage and be funded to do that research just couldn't be more important. And you yourself were one of those students at one time, and all three of us were as well.

Mr. MCNERNEY. Well, I didn't mean to put you on the hot seat there, but I did want to raise that deduction in the research fellowships and undergraduate research.

Dr. ZUBER. Yes, could I just add to that? So China has made a commitment—and this is extraordinary—to devote 15 percent of their GDP to talent development, okay? And so part of that is going into—they don't define exactly what talent development is in all ways, but certainly, the Thousand Talents program that they've implemented is to bring back Chinese scholars who have studied outside of China, to bring them back to China and set them up in a research career.

So one of—I had a postdoctoral fellow who worked with me, and he was hired back to a university in China, given a startup package that was the equivalent of a full professor. And he was—he got an assistant professorship position. So they are—you know, they are investing very aggressively to bring their talent back home——

Mr. MCNERNEY. Thank you. And——

Dr. ZUBER. —and we need to be aware of that.

Mr. MCNERNEY. And I don't want you to use all my time on the question. The opioid crisis, it's multipronged. It's a human behavioral issue. Is there research that the NSF could do that would help us understand and maybe deal with that crisis? And also you can add gun violence into that answer if you wish.

Dr. CÓRDOVA. Our head of social and behavioral, economic research program Dr. Fay Cook is a member of the Administration's Opioid Task Force, and they are working on interagency solutions to address this. We would be happy to look into particular research that we're funding along those lines, Dr. McNerney, and get back to you.

Mr. MCNERNEY. Thank you. A guess I have another half-minute. NSF has shown over time a commitment to cooperation with international scientists, but you've recently announced the closures of offices in Beijing, Brussels, and Tokyo by this summer. Can you kind of explain how that was decided?

Dr. CÓRDOVA. This was a strategic move to be more with the times as far as approaching the question of where could we make the biggest scientific advances internationally and international collaborations. Having one person at each of the three offices is arguably not the way to do that. It puts a huge demand on their intellectual capacity and also to cover an enormous sector of the globe, because we had only three offices.

In fact, what we see more and more today, for example, in financial institutions, is that teams of experts go to countries to evaluate the possible portfolios to judge what is the quality of assets, what kinds of people are running the assets, and where collaborations that are win-win collaborations for all the countries involved and really contribute to intellectual merit can be had.

So this is our plan. We have two groups already in formation—one will go to Europe and one to Asia—to study very specific areas which we think are vital for economic growth in our country. We want to see what other countries could bring to the table. We think it's a better plan and is more in keeping with the times. It's the way industry does it.

Mr. MCNERNEY. Well-answered. I yield back.

Chairman SMITH. Thank you, Mr. McNerney.

And the gentleman from Florida, Mr. Dunn, is recognized for his questions.

Mr. DUNN. Thank you very much, Mr. Chairman, and I thank the panelists for being here. Dr. Córdova, it's great to see you again. I think last time we were together we were standing on an ice sheet in Greenland. It's still pretty cold by my Floridian standards there, I'll be honest with you.

I will tell you that I've enjoyed the time I've had chatting about science with Dr. Córdova. I'm sorry I haven't had a chance to chat with the other panelists on a more personal basis. And certainly the Chairman knows that I will spend the whole time here talking about science with you if I could, but we're here to talk about the budget, so here we go.

In all the major corporations and government agencies that I've been associated with, they have an audit process and plan for auditing the processes and the finances both inside an organization. I would like to know a little bit about your audit plan and processes.

Dr. CÓRDOVA. This is a perfect topic for my Chief Operating Officer.

Mr. DUNN. Okay.

Dr. FERRINI-MUNDY. And also possibly for our Board Chair to pick up because this is something that is done jointly with the National Science Foundation and the National Science Board, but our major audit is our annual financial statement audit. That occurs each year and is quite consuming for the agency overall in that we begin the minute that it's completed with the preparation of materials and our interactions with the external auditors for—

Mr. DUNN. Okay. So that's good to hear. So you have external auditors as well——

Dr. FERRINI-MUNDY. Yes.

Mr. DUNN. —as the GAO involved in this?

Dr. FERRINI-MUNDY. Absolutely.

Mr. DUNN. I guess this is GAO, am I right?

Dr. FERRINI-MUNDY. Well, no, no, these are private——

Dr. CÓRDOVA. The inspector general has a private firm come in and do it——

Dr. FERRINI-MUNDY. Right.

Dr. CÓRDOVA. —under the auspices of the inspector general.

Mr. DUNN. Excellent. Excellent. And do you alternate those some—you know, a few years with one firm and then another firm——

Dr. FERRINI-MUNDY. Yes, we have a firm now.

Dr. ZUBER. Yes, it was alternated last year.

Mr. DUNN. Okay. Great. So this annual report, I'm not privy to that. Is that something that's in our package? It's not in the one that I received. No?

Dr. CÓRDOVA. I believe it's online. We can certainly send you——

Dr. FERRINI-MUNDY. We can get you——

Dr. CÓRDOVA. And the agency of course writes its own response and the Board——

Dr. ZUBER. The—yes, the Inspector General's Office comes up through the Oversight Committee of the National Science Board, and I—I'm happy to say that NSF has received an unqualified audit report so—

Mr. DUNN. Excellent.

Dr. CÓRDOVA. For 20 years, we've had a clean report, and this year we had no significant deficiency. So, Chairman Smith, I'm very proud of that——

Mr. DUNN. That's——

Dr. CÓRDOVA. —our facilities has gone away so—

Mr. DUNN. Yes, I think that's important. You know, the taxpayers —we are constantly, in our offices, bombarded with complaints, outrageous complaints about, you know, this study was studying something useless and meaningless and wasting taxpayer dollars. So how do you answer those complaints when you get them?

Dr. CÓRDOVA. Okay. Well, it's a little different than the financial report of some of our—

Mr. DUNN. Oh, yes. I'm—I didn't——

Dr. CÓRDOVA. —financial systems but—

Mr. DUNN. I mean—I think an audit should look at not just finances, also processes——

Dr. CÓRDOVA. Right.

Mr. DUNN. —and also product.

Dr. CÓRDOVA. Right. And certainly, the Board is one of the best places for looking at the quality of what we're doing and——

Dr. ZUBER. Yes, so the—you know, the National Science Board oversees the Foundation, and the Director is a member of that board. So—and, you know, we look through—NSF compiles information on peer review, and that is given to the Board, and the Board looks at that with great scrutiny and always pressing the National Science Foundation to improve its processes because, you know, I think the process for peer review is quite robust, but it can always be improved. The Chairman has made it a point to keep after the agency on that, and we're very serious in our oversight role. And NSF agrees that, you know, constant improvement is worthwhile.

Dr. CÓRDOVA. And Congress has to take a lot of credit because through reports like the AICA that they've gotten us to also look more intensely at our processes and to adopt new ones. So as a result of the AICA and the NAPA report and a report from our own Business and Operations Advisory Committee, I instituted the position, starting this past January, of Chief Officer for Research Facilities. This is one example because in the research facility areas we've had a number of critiques over the past few years. So this has dramatically—in just a few months' time dramatically improved our oversight, and it allows me as Director to really see the agency and what's happening and all the different facility areas immediately.

Mr. DUNN. I'm running out of time, but I just would like to say I would like to see the report that the Board sees if we could on the finances processes and the products, but that's very good. Thank you very much. It's always good to see you, Doctor.

Dr. CÓRDOVA. We will provide that to you.

Mr. DUNN. I yield back.

Chairman SMITH. Thank you, Mr. Dunn.

The gentleman from New York, Mr. Tonko, is recognized.

Mr. TONKO. Hey, thank you, Mr. Chair, and thank you to our witnesses for being here today and for the very important work that you do.

I want to be clear. We should not be flat-funding education, and we should not be flat-funding research. Flat funding for almost a decade will mean cuts certainly to critical programs.

And I listened as Representative McNerney was quizzing you about the education cuts. I would have to say it goes further than that because the research cuts are a critical component. And I just want to do that through the eyes of a brilliant student that I represent in the capital region of New York. And it illustrates exactly why education and research funding should be a national priority.

Erin Byrne Rousseau is from Burnt Hills, New York, in the capital region, 20th Congressional District of New York. She grew up in the capital region and went to college at the University of Albany where she studied nanoscale science. She is currently working toward a Ph.D. in medical engineering at Harvard-MIT Health Sciences and Technology. Erin is a member of the Science Policy Initiative, a student group created to support the next generation of scientists and engineers and contributing to robust science-based policymaking.

Erin is grateful for the federal support that allowed her to excel at her studies. As an undergrad, she was inspired by her university where many programs and research were made possible by federal funding such as NSF, NIH, DOE, and more. She is an NSF graduate research fellowship awardee, and the research she has worked on was possible in part from NIH funding.

In the lab she used technology that would not exist if it were not for DOE funding. Erin is working on research to study the neurological basis of mental health disorders, and her research has implications for our understanding in the treatment of mental health and addiction.

Erin is truly an impressive—is truly impressive, and she's just at the beginning of what I believe is a great career. Erin thanked me for supporting funding for science and research, and, Erin, let me say thank you for all that you are doing for all of us and all you will do.

And to my colleagues, we need more Erins who are going to be inspired to choose a STEM pathway and who will repay our nation's commitment by moving science forward and changing our world.

Dr. Córdova, do you agree that NSF has the power to inspire our next generation of scientists and engineers? And if so, what effect would budget cuts or flat funding have on our future workforce?

Dr. CÓRDOVA. Yes, of course I think that NSF has the opportunity and the privilege to inspire the next generation of scientists and engineers, and they can come from anywhere. They can be Erins, they can be young children, they can be people looking for transitions in the jobs that they already have.

And we've mentioned a couple of times here that there are a lot of proposals that are judged at the very highest level the rating of excellent that we simply are not able to fund within our budget.

Mr. TONKO. I would hope that we would understand that as we put a budget together because these cuts are severe. Flat funding sounds kind, but it is brutal.

I'm disappointed to see also that the large proposed cut that are levied at social, behavioral, and economics research, cuts to social and behavioral science will ripple out across many science, technology, engineering, and mathematics research fields, hurting those fields as well. Behavioral sciences have had widespread positive impact on our nation and the world. In fact, every winner of the Nobel Prize in economics since 1997 has been a recipient of a social, behavioral, and economic sciences grant at the National

Science Foundation, the very divisions some suggest we should slash.

We must continue our investment in behavioral sciences, and we should continue the long bipartisan tradition of funding and conducting research across the federal government. That research by very definition will have many failures, but failure is the down payment on success. Can you speak to the value of the Social, Behavioral, and Economic Sciences Directorate to issues of national importance?

Dr. CÓRDOVA. Yes, we have many, many examples of the huge impact of the social and behavioral sciences, and again, the National Academies report that came out last spring cited a long list of those. Among them are the auctioning of the electromagnetic—auction of the airwaves spectrum by the FCC, the Oregon kidney donor exchange programs that grew out of game theory, the predictive policing that is proving so helpful in some of our big cities and towns. They've done a lot of research on risk and resilience to natural disasters like hurricanes and tornadoes and other disasters that befall the planet.

And in the areas of learning, they can be especially important in how children of different backgrounds and experiences, how they learn, and how they assimilate their knowledge and create new knowledge. And I turn to my colleague Dr. Zuber for some other examples.

Dr. ZUBER. So studies—you know, there have been studies of why do children from excellent families go off and experience terrorism, okay? And so it turns out that it's, you know—there's research into that that has been useful in identifying that. And even, you know, young people who turn to terrorism from poor economic—the poorer part of the economic spectrum, it was found that, you know, there's some moral and idealistic causes that are motivating them, you know, as opposed to economic causes. So it's not just a case of getting them into a better economic circumstances, that one needs to look at moral imperatives that are different from terrorism, that are more productive, so that's another example.

Mr. TONKO. Well, I think the information that comes from neuroscientists and cognitive scientists can be very, very useful in responding to many of the needs we have out there.

And with that, I yield back, Madam Chair.

Mrs. COMSTOCK. [Presiding] I now recognize Mr. Hultgren for five minutes.

Mr. HULTGREN. Thank you, Madam Chair. Thank you all so much for being here, grateful for your work and grateful for the opportunity for us to talk about the great work that NSF is doing and the really requirement that we must continue to fund and grow funding.

I've had the chance to visit universities across the State of Illinois, have had the chance to work and see what NSF is doing there and other great places. I'll actually be at Northern Illinois University this Saturday with my STEM Scholars. It's 30 young people from around the seven counties that I represent that I meet with every single month, and a wonderful group, incredibly bright, very excited to—out of the 30—almost 30—I think about 18 or 19 of them are young women. Ten or 11 are young men, so we're encouraged by that, too, that we need everybody to be interested in science and STEM fields.

But we're going to be traveling to NIU where we are going to visit the Sub-Ice Rover, which was used to explore Antarctica, as well as the STEM maker lab. And our group is going to be only the second group to use new laser cutters, which we're really excited about.

I've had a good opportunity also through FIRST Robotics to meet with some great young people in my area, just a couple years ago met with a young woman from my district who was able to earn a full-ride scholarship to the University of Alabama in aerospace engineering. But one of her main concerns as I've continued to visit with her and talk with her and learn from her is for her to see peers who are very excited about STEM become discouraged and change degrees in the first few years of college, bright young people who were so used to getting straight A's and now all of a sudden they're getting B's and C's and decide this isn't for me. You know, since I'm not getting an A, I must need to switch to some other course.

So I just wanted to check, Dr. Córdova, if maybe you could address what work is NSF doing to make sure that students going through these kinds of tough fields are able to maintain their passion and avoid washing out of these programs when maybe they aren't getting the A's that they were used to through high school?

Dr. CÓRDOVA. I'm going to turn in just a moment to Dr. Ferrini-Mundy.

Mr. HULTGREN. Great.

Dr. CÓRDOVA. She's very familiar with the research that we're actually doing in this area.

But so let me just rewind to when I was a University President and really worried about that, and I was worried about what we called gateway courses that you would, look to your left, look to your right, and one of the people sitting there won't be there at the end of the semester kind of thing.

So I think universities have a lot of responsibilities, and I think Dr. Zuber being from MIT will agree with me that ensuring that instructors are actually motivating students to get through rather than weeding them out. I think there have been a lot of programs that universities are changing in this direction.

We had, in engineering at Purdue University, some engineering education department within the college of engineering, which is huge, that is specifically trying to look at new methodologies for getting students through these kinds of courses. Not just in engineering but university-wide. And I think when I see the retention rates and, as a University President, I would look at the retention rates between the first and the second year, and we increased that from the kind of low levels you're describing to something like 97, 98 percent of students would continue on.

Mr. HULTGREN. Good. That's great.

Dr. CÓRDOVA. So things are improving.

Dr. FERRINI-MUNDY. I can't add a lot other than to say congratulations to you on your STEM Scholars.

Mr. HULTGREN. Thanks.

Dr. FERRINI-MUNDY. That's a wonderful investment of time.

Mr. HULTGREN. It's really been fun.

Dr. FERRINI-MUNDY. I should think so. You know, as Dr. Córdova mentions, it's those gateway courses that are quite critical for retention, and we are funding some interesting experiments in changing up the content of those courses——

Mr. HULTGREN. Great.

Dr. FERRINI-MUNDY. —starting with the statistics or quantitative reasoning kind of approach rather than always calculus, which is the tradition, and that's showing some terrific results.

Mr. HULTGREN. Good.

Dr. FERRINI-MUNDY. And a variety of other approaches to helping faculty improve their instruction so that they are inspiring students and strengthening K–12 education.

Mr. HULTGREN. Yes. That's so important, too.

Let me jump on just in my last minute, Dr. Córdova, as you know, accelerator physics is a field where industry and even our DOE labs find a short of shortage of trained workers. We're only graduating about 15 Ph.D.'s a year. There are only a few universities that have accelerator physics programs to train these workers. Many of the students go out of their way to be able to get the schoolwork necessary to advance in these fields.

We're fortunate with NIU being relatively close to Fermilab having some opportunities there. Stanford has SLAC close by, which is great. But when a university is not near one of the national labs, many students actually have to take part in intense two-week accelerator school programs every summer where students come to one location to get their graduate-level training.

It's my understanding that NSF will be discontinuing their accelerator science program. It's a program that was started in 2014 to address the workforce shortage and ensure that the United States was maintaining their position at the forefront of this field. This has not been a large program by any means, but I think it is an important one for the field.

I'm also concerned that broader physics grants will not take into account the need for basic scientific research in accelerator science. I wonder if—I'm already over time—but maybe we can follow up some more, if you have a thought or two on this of what we can do to continue to see this as important and making sure that we have the people to fill these important roles?

Dr. CÓRDOVA. I can just say that I agree with you. Accelerator physics is what inspired me to become a physicist. We are of course a big participant in the CERN accelerator physics program——

Mr. HULTGREN. Yes.

Dr. CÓRDOVA. —as you've seen it. Fermilab, because we've seen each other there on tour——

Mr. HULTGREN. Right.

Dr. CÓRDOVA. —that we are funding a lot of research there, Stanford University of course in their efforts. And I'll follow up with—on the details of the accelerator science program.

Mr. HULTGREN. Great. Thank you so much. Thank you all. Thank you, Chairwoman. I'll yield back.

Mrs. COMSTOCK. Thank you. And I now recognize Mr. Foster for five minutes.

Mr. FOSTER. Thank you, Madam Chair.

And thank you for your service.

You mentioned that the NSF top line budget was overall flat, but that, I understand, was not the original proposal. That was the number they got adjusted after Democrats insisted on having proper funding for that section of the budget. And so what was the number before the final addendum came out?

Dr. CÓRDOVA. Minus 30 percent.

Mr. FOSTER. So a 30 percent cut, and then the Democrats negotiated it up to flat. Is that a fair summary of what happened?

Dr. CÓRDOVA. The President's supplement came out, a $2.2 billion supplement, so that's—

Mr. FOSTER. Yes, okay. You don't have to——

Dr. CÓRDOVA. The caps were raised—

Mr. FOSTER. —go into the details of the negotiation, but I think that's an important point.

Now, one of the features of your proposal is you're going to be closing the NSF offices abroad, that you've announced I guess last month that offices in Tokyo, Brussels, and Beijing were being closed. You also said in your—in I guess all of your testimony is that the rest of the world is catching up and in some cases passing us. And so what is it—you know given that we'll have a lot more to learn scientifically and in collaboration with other countries, what's the motivation for closing the foreign——

Dr. CÓRDOVA. So exactly right, Dr. Foster. We have a lot more to learn, and we think that having one person in each of three offices abroad is not the most efficient way to learn about the science that we can really do in a high-quality, directed, focused way with other countries. That demands a lot of them in terms of intellectual breadth, in terms of covering a vast geography. We are adopting a practice that is well used in industry these days, which is sending expert teams of scientists and engineers from different parts of the country, and they'll be accompanied by a couple of NSF people to certain areas where we think that there are assets that could be complementary to our assets. And the assets include physical ones, as well as human capital.

We are looking in depth at what the nature of a collaboration could be. So take like quantum research or artificial intelligence or we're disposing a team soon to look at synthetic biology. With careful background study of what are the areas and invitations from other countries to look at these, we think that we can have more win-win collaborations where we really understand what they bring to the table and what we do. It's a new strategic approach.

Mr. FOSTER. So this is not—doesn't represent a drop in your interest in international collaboration——

Dr. CÓRDOVA. It represents—

Mr. FOSTER. —or just a more—what you hope to be a more efficient deployment of resources for that? Okay. Thank you. That's important. How much do you end up spending on research into handgun violence?

Dr. FERRINI-MUNDY. I don't believe it's a direct topic for us. We could look across various programs to see—

Mr. FOSTER. Is it——

Dr. FERRINI-MUNDY. —if there's fundamental research.

Mr. FOSTER. —prohibited or do you have any calls for proposals at any point?

Dr. FERRINI-MUNDY. I would have to look into our background to—

Mr. FOSTER. Okay. If you could——

Dr. FERRINI-MUNDY. —find out more about that.

Mr. FOSTER. Yes, I'd be interested to know if you are also handcuffed in this area, as other areas of federal research.

Dr. FERRINI-MUNDY. My hunch would be we have some fundamental social science research that would certainly inform questions in that area, but I would have to check to be certain.

Mr. FOSTER. Yes, but even prohibitions on chameleon basic statistics, for example, are things that we run into in other areas.

You also mentioned the workforce thing and the need to make sure that we keep the best and brightest of other—from other countries that we educate here. And, Dr. Córdova, you're a physicist. Have you ever in your career had two first-author Physical Review Letters published in the same year?

Dr. CÓRDOVA. No, I published in The Astrophysical Journal.

Mr. FOSTER. Okay. All right. Well, same question, yes.

Dr. CÓRDOVA. Okay. Same question, have I ever had two papers—

Mr. FOSTER. Two in a year——

Dr. CÓRDOVA. —published in—

Mr. FOSTER. —just——

Dr. CÓRDOVA. Oh, absolutely.

Mr. FOSTER. As the first author yourself?

Dr. CÓRDOVA. As a first author probably. I could—

Mr. FOSTER. Okay. Well, no, it just——

Dr. CÓRDOVA. Yes, I published—

Mr. FOSTER. —because——

Dr. CÓRDOVA. —a lot in my day.

Mr. FOSTER. —I encountered a situation—okay.

Dr. CÓRDOVA. Yes.

Mr. FOSTER. Well, I encountered a situation recently where you, as I, have probably penned letters for an Einstein visa for, you know, very talented people. Yes, I see some nods from the other—that—and what you see—you know, you're in this heartbreaking situation where someone that you just know should be a keeper and you can't—the one that I was unsuccessful at getting recently had two—been first author in two Physical Review Letters, a postdoc—as a postdoc, was first author in two PRLs which are, you know, the premier peer-reviewed journal. And yet that was insufficient to get an Einstein visa.

And so my question is when you see—you know, in the presence of, you know, that sort of failure I think that we've all had from time to time in getting people permission to stay and then you read that, you know, a model was given the Einstein visa for probably non-STEM-associated skills. You know, do you—does it strike you that we're just way off the mark in what we're trying to accomplish with getting high-skilled immigrants into the United States?

Dr. ZUBER. Excuse me. Thank you for the question, Dr. Foster. So I don't know the qualifications of any of the other people who, you know, were awarded the Einstein visa, so I can't really do a comparison because there are needs in many different areas, but I will certainly say that the individual that you mentioned, it is—that's an absolutely top journal in the field, and, you know, obviously that individual is very accomplished.

What I would say is that certainly within this country there is additional capacity to keep the top highest-achieving individuals from all over the world and in fact, you know, that has been our modus operandi in this country to attract the best and the brightest from around the world. And I hope that we continue to do that.

Mr. FOSTER. And find a way to keep them. And thank you. I yield back.

Mrs. COMSTOCK. Thank you.

And I now recognize Dr. Babin for five minutes.

Mr. BABIN. Yes, ma'am. Thank you, Madam Chairman. And thank you, witnesses, for being here and for your valuable testimony.

And, Dr. Córdova, good to see you again. And I'd like to ask you a couple of questions if you don't mind. The United States is one of the most if not the most innovative and technologically advanced nation in the world, yet we lag behind other industrial nations in ensuring that American students receive the requisite skills for success in a 21st-Century workforce. How would you each—I'm asking you, too, Dr. Zuber—both of you. How would you each define success in the field of STEM studies and computer science education, and do you think we can achieve this and when? Let's start with Dr. Córdova.

Dr. CÓRDOVA. Clearly, we must because it is a skill that everyone really needs to have for all sorts of occupations, not only STEM alone. We have a great variety of programs that we fund over all ages from K–12, undergraduate, graduate, postdoc, and early career and beyond to try to give people the opportunity to really increase their STEM and computer science capabilities. In fact, our real goal is to provide access to everyone, and that's why we call one of our programs Computer Science for All.

We also have interestingly for the past 24 years Advanced Technological Education program that is mainly housed in our community colleges nationwide. Thus far, we've sponsored 1,500 awards and have over $300 million in industry support because there are partnerships with industry in retraining workers for skilled jobs. And a lot of that curriculum has to do with computer science as well.

Mr. BABIN. Okay. And, Dr. Zuber?

Dr. ZUBER. And so let me just add one can look at computer science a couple of different ways. There is an—advancing that specific field, okay, and then there is infusing the results of that, those skills, into a whole variety of other different fields. And so both of those actually need to occur, and they need to occur not only at the level of students who get four-year degrees but also in what we call the skilled technical workforce, so workers who—we call this STEM awareness, okay, who don't necessarily have a STEM degree, but virtually any job that you can think of today—many—a whole variety of jobs that you can think of require some amount of STEM skill and computation skill or computer skill, so even, you know, working at a grocery store—

Mr. BABIN. Right.

Dr. ZUBER. —you know, the electronic readers. And so this is addressed in the ATE program, which deals with community colleges, and it's also a focus of the National Science Board to look at these skilled technical workforces to look at what it's going to take to provide points of entry to students at various levels to get into these programs to get training and then to realize that there needs to be, you know, retraining and retraining—

Mr. BABIN. Right.

Dr. ZUBER. —to improve skills.

Mr. BABIN. Okay. I need to ask one more question, get it in before my time is expired. I saw on the news this past weekend that some American scientists were stranded in Antarctica when a U.S. vessel could not reach them. And fortunately, NSF, working with Argentina partners who had an icebreaker and a helicopter, were able to successfully rescue them. First, congratulation on the rescue; but second, it brings up whether or not the United States has sufficient icebreaking capacity. What is the status of NSF's efforts to ensure the continued availability of an icebreaker for our polar programs? Dr. Córdova?

Dr. CÓRDOVA. Thank you. We have a number of vessels with different icebreaking capability. None with very deep icebreaking capability, so we rely on the U.S. Coast Guard for that. We lease time from them in order to help us to support our mission. I know that there is some funding to the Coast Guard, perhaps it's in the proposal stage, but I think there is some advanced funding for them to look into having more capability in this area.

Our preferred mode is not to own a deep-ice-cutting vessel—and they're not research vessels, but they are for that purpose—but to keep renting them. And otherwise, we have, as I said, a number of actual research vessels that have very modest cutting capability. Thank you for mentioning that example. We are very happy that five researchers are fine.

Mr. BABIN. All right. My time is expired, Madam Chairman. Thank you. Thank you very much.

Mrs. COMSTOCK. Thank you.

And I now recognize Mr. Beyer for five minutes.

Mr. BEYER. Thank you, Madam Chair.

I want to thank all of you for being willing to come into a public forum on the Ides of March. You're very brave.

You know, the—with appropriate respect for the Chairman's criticisms of specific research awards, the elephant in the room is still the flat budget. You know, nine years in a row the structural—the steadily falling percentage of excellent projects approved, United States losing its global leadership to China and perhaps to others, you know, I think this is the most necessary oversight responsibility the Science Committee has is to keep American science strong, which means keeping the National Science Foundation strong.

So, Dr. Zuber, a cultural question for you as Chair of the National Science Board. What can you do, what can we do, what should we be doing to build public support for additional federal funding for the National Science Foundation? Especially given that our lives are so transformed by the science that you have developed, why don't we value it? How do we increase that sense of value in our lives?

Dr. ZUBER. Yes, so I think—you know, so, first of all, thank you for those comments, and thank you for your support on this crucially important topic for the Nation. I think the Director and her team have taken great efforts to try to make the science that NSF does understandable broadly to people in the country, but there's still a lot to be learned. And I think—I frankly think that NSF is an underappreciated agency for what it does. So people have heard of the NIH because they know it does medical research, and people may have heard of the NSF, but they don't realize the—just the broad scope of science that it covers, everything from, you know, the polar science to high-energy physics, you know, to astrophysics, you know, to the earth sciences, biological sciences, and beyond.

So one of the things that I say every time you see a NASA image of space that has a NASA logo in the center—and we encourage the NSF to start getting the word out of, you know, branding NSF. So when you—you know, when you go out and you have conversations with people and you let them know the kind of work that NSF does, you know, they generally seem broadly supportive, but the question is, you know, with all of the noise that we have around us today, how do you reach those people and get the message? And we're always looking for opportunities to do that.

Mr. BEYER. It sounds like getting the most robust communications department would help.

Dr. ZUBER. Yes.

Mr. BEYER. Maybe sponsor a NASCAR vehicle with NSF on the side.

Dr. ZUBER. Well, some of the videos that the Office of Legislative and Public Affairs have put together have been absolutely spectacular and have won national awards, and that's been very helpful.

Mr. BEYER. There's an old political idiom that nothing happens in politics unless you tell somebody about it. This may be the same thing here.

So on that line, this may be a dangerous suggestion, so forgive me for a dangerous suggestion, but it may make sense at some level to have a nonpartisan, nonideological person look at the grants one final time before they go out just to make sure that we don't put a Chairman, whether a Democrat or Republican Chairman, in the position of saying, "That sure doesn't sound legitimate," you know, a nonscientific eye as something that's going to go out to the general public.

Dr. CÓRDOVA. Largely because of this Committee I think we have really upped our transparency and accountability processes, and we're very sensitive to titles and abstracts because we—unlike many other agencies, we publish everything online, so it is really open and people can see immediately what it looks like. We have now a non-technical abstract, which is geared towards public consumption. We think that we have really improved our readability of what we're doing and also brought cognizance to the entire agency that people are looking and they're really evaluating the value of the benefit to the nation just on a few sentences that are there describing the research and its potential benefits. We have taken a lot of steps in that direction.

As far as your suggestion of whom to have on the committees that finally approve that, I think that's an interesting suggestion and I will take it back and we'll consider it. Thank you.

Mr. BEYER. All right. Thank you very much.

Madam Chair, I yield back.

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

I think we earlier had some students from Paul VI High School. I don't know if we have any left, but I thank them for joining us.

And I wanted to start out by thanking Dr. Córdova for your strong statement about zero tolerance for sexual harassment that you recently made in light of some of the things that this Committee, as well as others, have looked at. So as you may know, we had a hearing on sexual harassment in science, and sort of the role that some of the grants and people who really can determine your future in terms of whether you're going to get into the fields that you want, and how that's impacted because of harassment.

And I was—I think we also—we didn't get into it as deep as we might, but I think it's something we do need to look at more, the long-term wage impact because we know that when women are harassed in a specific field, they are very likely to leave that field and not get back into it, particularly when you have some avenues here that if they're closed off, you may not have someplace else to go.

I was wondering if you could just—in light of your very strong statement—I just wanted to give you the opportunity to address that, and maybe for the others, since we are blessed to have three women panelists here today, I thought it might be a good opportunity to hear directly from you.

Dr. CÓRDOVA. Thank you very, very much Chairwoman Comstock, for your passion, your interest, for having the hearing, and of course we all listened to the hearing remotely, and it was very good to get it all out on the table. Some very, very important points were made.

The important thing to recognize about our statement—and now, of course, our statement has turned into a notice in the Federal Register that is open for public comment for 60 days, and we will be absorbing all those comments as we go. We're not waiting to the end of the period, so we've already started that. We also have robust processes to send compliance team reviews to universities to say, "Hey, are you doing what you're supposed to do?" And we review their cases. The team talks with a lot of individuals at all levels of the university from the students to the administration and all, and that's——

Mrs. COMSTOCK. I was wondering, do we have percentages—and my apologies if I should know—what percentage of these grants and projects are female-led?

Dr. CÓRDOVA. We can certainly find that out. I mean, I know we—well, for one thing, in—earlier, we talked a little bit about the merit—annual merit review report that the agency produces for the National Science Board, and there we have the proposals as a function of gender and also minorities' representation that are given to us in how many we approve, and so we can then make the assumption that if you're the lead investigator, that you are also leading the research.

So yes, we have the statistics, and actually women do very well. I think about one percentage point higher success rate than male gender.

Mrs. COMSTOCK. All right. And, Dr. Zuber?

Dr. ZUBER. Yes, so if I could just add, so the National Science Board fully supported the Director in wanting to get out ahead of this issue, and we're particularly—there was a lot of discussion about this, but we were incredibly supportive of the fact that it's very, very important to have due process, but if a university has a process and an investigation takes place where it's—enough evidence is deemed that it goes to a full-out investigation, that it needs to be reported to NSF. And this is because it might make sense to get a substitute principal investigator in there, and this is to really, you know, care about the personal situation of the person who has been experiencing the harassment.

We consider this to be a real step forward, and NSF as an agency has really taken the lead on this. And what I hope is other agencies I think are also looking at policies, and I hope we don't get a different policy for every agency. I hope that—you know, I personally think that the NSF policy—it's very thought-out because, you know, the Director had a great deal of experience unfortunately in dealing with issues like this in—you know, on panels and such that have made recommendations throughout her career. And—but it would be very cumbersome if all the agencies just came up with different ways of dealing with it.

Dr. CÓRDOVA. And can I say one more thing? This is only the beginning for us, that we are having biweekly meetings that Dr. Ferrini-Mundy chairs within the agency to talk about what else we can do in this area, for example, codes of conduct at all our field sites, whether it's Antarctica or environmental field site, we have hundreds of them. And are all the codes of conduct all start with similar language? And then do they fulfill the basic needs, namely that if something happens at a field site, that you know exactly what is to be posted in an open, public place where to go, how to get help, and how to follow through.

We are just consistently going to keep working on this until we're satisfied that we have done everything we can, and we're hoping that in the public comment period there will be even more suggestions about what else we might——

Mrs. COMSTOCK. So this information will be out there so the students, the young women themselves, will just have more of an awareness about it, where to go, how to proceed if something happens?

So I know as we're talking about the pipeline, you know, I think this week I was at a STEM charter school, and they had a STEM club that had been started by the young girls there. Then they we're teaching the boys how to have one, too, so they had the first one.

And fourth-graders, Coco and Miriam, who escorted me around their lab and told me about all their programs, it just was a real—I think we do have a different atmosphere going on in so many of our schools—these kids were showing me the first-graders who were coding already, and you really don't see a difference at that age because the kids haven't learned to have any differences yet hopefully, and they had a lot of great role models like we have here.

So just, you know, any way we can get that message through and then sustain it so that we are keeping that pipeline because it really did seem, as we went through the process of the hearing—and if you watched it, you saw it—but the wage gap could very much be a much bigger part connected to sexual harassment than we have recognized in the past. Okay. Well, I think I am up with my time but——

Ms. LOFGREN. Yes, I'll—it's playing cleanup here. It's been a delight to listen to all of you. And this is one of the most important agencies in the United States really, I mean, not always appreciated but driving innovation and allowing for really smart people to research and to lead us forward to better times.

I think we're sort of at a very serious inflection point in our country, and you addressed some of the issues, are other nations competing more vigorously, the flat budget for multiple years, that with a flat budget, costs increase, you can buy less. I'm concerned—we have had—this is a figure I got from the Judiciary Committee staff—since 2015 a 40 percent drop in foreign students into the United States, which is not a piece of good news when it comes to science research. And so when you put that altogether, you've got—you know, we used to have where we were the center of science research, people from all over the world coming here, robust funding for science, and now a very different picture.

So I have some very serious concerns. I know that you all are doing your very best to make the resources that have been made available go as far as they can. This is not a criticism of your fine efforts.

One of the things I'm interested in, Dr. Córdova, is how many of the highest-rating—highest-rated proposals don't get funded? What's the sheer number, do you know?

Dr. CÓRDOVA. It's almost $4 billion worth of proposals per year we say are on the cutting room floor. They are rated excellent, which is the top rating or very good to excellent. I would say excellent is about $2 billion, about half of that, the other $2 billion between very good and excellent, but definitely worthy of funding, and we are not able to fund them.

Ms. LOFGREN. At some point I remember George Miller, who spent so many years on our Education and Labor Committee, went over and read the proposals that couldn't be funded, and it put him into a depression for a while of all of the things we could have learned had we been able to actually award funding to the most meritorious proposals. I'd like at some point to see if we couldn't organize members of the Science Committee who have an interest to do that, take a look at what got left on the cutting room floor.

And just a final comment, I think Congressman Beyer was mentioning having somebody look at a last cut as not scientists. Here's I think sometimes a problem. At least the scientists I know tend to be—you know, really smart people have great senses of humor, and you can have a very serious subject matter and a light touch on the title that may belie the seriousness of the inquiry. So it may be that the lighthearted titles may want a review because they could be misleading, and that's just the thought that I have because smart people do tend to have a great sense of humor.

So with that, I'm going to close this hearing with these comments. I think we're very, very lucky as a nation to have all of you, the service that you are providing to our country. I'm grateful to you for it, and with that, Madam Chair, I yield back.

Mrs. COMSTOCK. Thank you. And I would second that again.

And I thank the witnesses for their testimony and the Members for their questions. And the record will remain open for two weeks for additional written comments and written questions from Members. And the hearing is adjourned.

[Whereupon, at 12:04 p.m., the Committee was adjourned.]

Appendix I

ANSWERS TO POST-HEARING QUESTIONS

ANSWERS TO POST-HEARING QUESTIONS

Responses by Dr. France Córdova

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

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

Dr. France Córdova, Director, National Science Foundation

Questions submitted by Ranking Member Eddie Bernice Johnson, House Committee on Science, Space, and Technology

1. NSF is proposing to fund the Big Ideas directly, at $30 million each, and fund two convergence accelerators at an additional $30 million each to support two specific Big Ideas. Can you elaborate on this concept of convergence accelerators and how that funding will be used differently than the dedicated funding to the Big Ideas themselves?

   Answer: The proposed Convergence Accelerators are new structures within NSF, designed to create and leverage external partnerships with industry, foundations and other non-profits, and other federal agencies to facilitate translational activities in two critical areas: NSF's Big Idea on the Future of Work at the Human-Technology Frontier, and NSF's Big Idea Harnessing the Data Revolution. An investment of $30 million will support the establishment and execution of each Convergence Accelerator; we anticipate that this investment will be matched by an additional $20 million through external partnerships for each Convergence Accelerator.

   Convergence Accelerators are distinguished from the corresponding Big Ideas by the nature of their research, the time scale of the activities supported, and a more agile approach to project support. The accelerators will focus on translational, use-inspired convergence research with more directed deliverables using an approach that rewards innovation and risk-taking. We anticipate using a milestone-based assessment approach that will allow for timely adjustments of resource allocation and direction based on progress. Accelerators will include mechanisms to help academic researchers working in the associated Big Ideas to engage with non-NSF partners - commercial entities, non-profits, other state or federal agencies – who are interested in contributing to new research projects that are based on ideas emerging from foundational Big Idea research.

   Convergence research is a means of solving vexing research problems. It can be characterized as research that requires the deep integration of knowledge, techniques and expertise from multiple fields. Convergence research is generally inspired by the need to address a specific challenge or opportunity, whether it arises from deep scientific questions or pressing societal needs. NSF's proposed Convergence Accelerators will catalyze new research directions and advance scientific discovery and innovation.

2. I am concerned about the proposed cuts to the Graduate Research Fellowships Program, the National Research Traineeships, and Research Experiences for Undergraduates. I assume these cuts were at least in part to find more funding in the budget for the Big Ideas. In what ways will the Big Ideas and other convergence efforts be used to support education and dedicated training programs and/or funds for graduate and undergraduate students?

   Answer: As we look ahead to the coming decades, NSF is considering the bold questions that will drive NSF's long-term agenda for research and education investment. This is the reason NSF developed the 10 Big Ideas. These ideas capitalize on what NSF does best: catalyze interest and investment in fundamental research, which is the basis for discovery, invention and innovation. The Big Ideas 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 the 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.

   Indeed, through the Big Ideas, NSF is funding efforts to determine how to best educate the next generation of scientists. All the ideas will require a changing future workforce, making education and lifelong learning important priorities, and all will invest in the preparation of that workforce.

   Graduate and undergraduate education continues to be an agency-wide priority and the major source of support for students across the foundation is through research assistantships on research grants. NSF also supports undergraduate students and graduate education through programs identified in the fiscal year (FY) 2019 CoSTEM inventory found at: https://www.nsf.gov/about/budget/fy2019/pdf/14_fy2019.pdf.

3. As recently as late 2016, the Social, Behavioral, and Economic Sciences Directorate (SBE) was planning to lead the Future of Work at the Human-Technology Frontier Big Idea that they originally proposed, not the Engineering Directorate. In the Fall 2016 SBE Advisory Committee meeting, the SBE Director, Dr. Faye Cook, discussed this Big Idea at length, including the important role of SBE research. But in your budget you propose to make the Engineering Directorate the lead for this Big Idea, and as lead, Engineering controls the $30 million in funding.

   a. What do you see as SBE's role in the Future of Work at the Human-Technology Frontier Big Idea?

b. Given the persistent cultural chasm between engineers and social scientists, how will you ensure that SBE is a valued and real partner in this Big Idea, both intellectually and in terms of funding?

Answer: In a world of converging disciplines and interdependencies between fields of research, NSF is proposing to invest in innovative areas of research that integrate the social, behavioral and economic sciences with other areas of basic science and engineering research. NSF's Big Idea: The Future of Work at the Human Technology Frontier (FW-HTF) aims to catalyze interdisciplinary science and engineering research to understand and build the human-technology relationship; design new technologies to augment human performance; illuminate the emerging sociotechnological landscape; and foster lifelong and pervasive learning with technology. To ensure the success of the future human-technology partnership, SBE scientists will be deeply engaged in this research so that the human and social aspects are appropriately understood and incorporated.

NSF's FY 2019 investments in The Future of Work will build upon a foundation of research from core programs across the agency as well as targeted FY 2018 investments. Under the stewardship concept that NSF will employ to manage the Big Ideas, while budget management and reporting will be the responsibility of the directorate to which the $30 million is assigned for a given Big Idea, each directorate/office that is a co-lead will be providing leadership and oversight. Therefore, while the $30 million for this Big Idea is requested under the Engineering Directorate, the SBE Directorate will be a co-lead and the Big Idea will be overseen and managed collaboratively.

The recent solicitation Future of Work at the Human-Technology Frontier: Advancing Cognitive and Physical Capabilities (FW-HTF) 18-548 explains: "Because research proposals must establish their potential to shape and improve the future of work, principal investigators are urged to assemble cross-disciplinary teams capable of evaluating the nature of, and the potential for, social impact."

4. The budget proposal includes a cut to the STEM+Computing Partnerships program by over $19 million, a 37 percent drop from spending in FY 2017. The proposal explains this reduction by stating that STEM+C will not run a new competition in FY 2019, but will provide co-funding to other programs. Please explain the changes NSF is making to its approach to supporting computer science teaching and education research.

Answer: NSF supports computer science education through a range of programs that provide research and develop resources for preK-12 teaching and learning. The STEM+C program was one of several NSF programs that address the integration of computational thinking and computing activities in early childhood through high school.

As computing has become integral to the practice of the STEM disciplines, researchers are increasingly addressing the immediate challenges facing preK-12 STEM integrated with computing, as well as challenges that anticipate radically different structures and functions of preK-12 teaching and learning. For these reasons, NSF released a Dear Colleague Letter encouraging the submission of Discovery Research PreK-12 (DRK-12) research proposals studying the integration of computing and/or computational thinking in disciplinary STEM learning and teaching. In FY 2019, NSF plans to invest in research and development supporting computer science education, including research on computational thinking and the integration of computing with other STEM disciplines, as follows:

- Computer Science for All: Researcher Practitioner Partnerships provides high school teachers with the support they need to teach rigorous computer science courses and K-8 teachers with needed instructional materials and preparation to integrate computer science and computational thinking into their courses.

- Innovative Technology Experiences for Students and Teachers supports projects to promote preK-12 students' interests and capacities to participate in the STEM and information communications technology workforce of the future.

- STEM+C recently released a Program Description inviting research and development proposals related to new approaches to pre-K-12 STEM teaching and learning related to Harnessing the Data Revolution, Convergence Research and the Future of Work at the Human-Technology Frontier.

- The CyberCorps®: Scholarship for Service program at NSF and the National Security Agency support GenCyber, a program that sponsors summer camps across the nation designed for elementary, middle and high school students and teachers that focus on engaging the learners with sound cybersecurity principles and teaching techniques.

- Programs such as EHR Core Research, Discovery Research PreK-12 (DRK-12), and Advancing Informal STEM Learning seek to significantly enhance the learning and teaching of STEM, including computer science and computational thinking. NSF released a Dear Colleague Letter encouraging the submission of DRK-12 research proposals studying the integration of computing and/or computational thinking in disciplinary STEM learning and teaching.

Together, these programs aim to provide *all* U.S. students the opportunity to participate in computer science and computational thinking education at the preK-12 levels. NSF's focus on computer science education addresses an important workforce development need, and enables students to develop critical skills and competencies in problem-solving, critical thinking, creativity and collaboration that will help them excel in today's increasingly digital and computational world.

5. In response to Congressional direction in the American Innovation and Competitiveness Act, NSF released a request for information on the demand for mid-scale research infrastructure funding opportunities last year. What insights did you gain from submissions to the RFI regarding the need for mid-scale infrastructure projects?
    a. Do some research disciplines have higher demand for mid-scale research infrastructure than others do? If so, which?
    b. The FY 2019 budget proposal requests $60 million for Mid-Scale Research Infrastructure and includes it as one of the Foundation's ten Big Ideas. How many proposals does NSF expect to fund with this budget?

Answer: In 2017, NSF issued a request for information on potential mid-scale research infrastructure projects in the $20 million to $100 million range. NSF received nearly 200 replies from areas of science covered by all of NSF's seven directorates. Approximately 60 percent of the replies were predominantly associated with the Directorate for Mathematical and Physical Sciences (about 30 percent) and the Directorate for Geosciences (about 30 percent), with the remaining 40 percent distributed among the other five directorates.

As you note, mid-scale research infrastructure is included as one of NSF's Big Ideas and the Administration has requested $60 million for mid-scale research infrastructure in the FY 2019 budget request. Separate tracks within the mid-scale program will fund acquisition, design/development and implementation. NSF will also conduct strategic discussions of the long-term development of mid-scale research infrastructure with our advisory committees and the National Science Board. An increased investment in mid-scale research infrastructure will be used to continue to span the "mid-scale gap." NSF will invest in instrumentation above the current $4 million upper limit of the Major Research Instrumentation (MRI) program as well as funding the design and development of mid-scale research infrastructure with potential costs ranging up to the Major Research Equipment and Facilities Construction (MREFC) lower limit of $70 million. Our preliminary estimates are that NSF might fund 3-8 instrumentation acquisition proposals above the current MRI threshold and 8-15 design and development proposals for larger capabilities with construction costs ranging up to the $70 million MREFC threshold. These numbers would depend on the exact contents of a solicitation that is currently under development, as well as the quality of proposals received.

6. During the hearing, Representative Babin asked about NSF's need for icebreaking capabilities in Antarctica. Please elaborate on the role of icebreakers in NSF's ability to support science in Antarctica, and the importance of building and maintaining reliable U.S. icebreaking capabilities for that purpose.

Answer: Presidential Memorandum 6646 (1982), directs NSF to manage all United States activities in Antarctica as a single, integrated program, making Antarctic research possible for scientists supported by NSF and by other agencies. The United States Antarctic Program (USAP) research activity supported by NSF also supports leadership by the U.S. Department of State in the governance of the continent and Southern Ocean under the aegis of the Antarctic Treaty System. NSF's Office of Polar Programs (OPP) supports investments in research and education and provides support for research infrastructure, such as permanent stations and temporary field camps. OPP's Antarctic Sciences Section supports research to 1) expand fundamental knowledge of the Antarctic region; 2) improve understanding of interactions between the Antarctic region and global Earth systems; and 3) utilize unique characteristics of the Antarctic continent as an observing platform. Research that crosses and combines disciplinary perspectives and approaches is encouraged.

The USCGC *Polar Star* (WAGB-10) is America's only operational heavy icebreaker and operates annually in the Antarctic to break a channel through McMurdo Sound to open a passage for the USAP resupply ship and fuel tanker. A heavy icebreaker is required because Antarctic sea ice at McMurdo is routinely 2 or more meters (6 feet) thick and can become as much as 6 meters (20 feet) thick at times. No other U.S. vessel has this icebreaking capability. *Polar Star* is 122 meters (400 feet) in length. The ship can carry two helicopters, accommodates 20 scientists and has a crew of 154. The ship was built in 1976, is home ported in Seattle, Washington, and is scheduled in cooperation with the University-National Oceanographic Laboratory System. On occasion, USAP must contract with a commercial icebreaker to help with channel breaking when the *Polar Star* is unavailable. This creates uncertainty and dependence on foreign nations for icebreaking services. The 2018 Omnibus appropriations bill (P.L. 115-441) provided $150,000,000 to the United States Navy under Shipbuilding and Conversion for design and preliminary activities to acquire a polar icebreaker. When completed, this vessel will enable the U.S. to have dependable icebreaking capabilities into the future, since the *Polar Star* is past her life expectancy.

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

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

Dr. France Córdova, Director, National Science Foundation

Questions submitted by Representative Randy Hultgren, House Committee on Science, Space, and Technology

1. It is my understanding that NSF will be discontinuing their Accelerator Science Program. This program was started in 2014 to address the workforce shortage in the field and ensure that the United States was maintaining our position at the forefront of this field. It is my concern that broader physics grants will not take into account the need for basic scientific research in accelerator science.

    a. What was the rational for this decision by NSF?

    b. How will NSF be addressing the workforce needs for trained accelerator scientists and operators?

    c. How does NSF plan to address the research needs of this community through other grants if the program is discontinued?

Answer: The accelerator science program at NSF was launched to promote research at universities on basic accelerator science questions that are not tied to specific accelerator designs or possible upgrades. Mechanisms exist for funding these latter activities; for example, as part of mid-scale research infrastructure efforts.

A primary goal of the program was to encourage the community to think about truly innovative approaches to accelerator design. An analysis of the most competitive proposals received during the three years the program held a competition showed a trend toward more incremental efforts driven toward improving existing designs, not the truly innovative approaches the division had hoped for. Therefore, the Physics Division of NSF's Mathematics and Physical Sciences Directorate concluded that the program was not sufficiently achieving its primary goal, certainly not to a sufficient extent to warrant a separate, stand-alone program. The few proposals that do address this goal can be evaluated by the competitive review process in the division disciplinary programs most closely related to the suggested innovation rather than by maintaining a stand-alone program. Some examples of disciplinary programs include the Nuclear Physics, Elementary Particle Physics and Plasma Physics programs.

The Office of High Energy Physics at the DOE has been given the responsibility for the stewardship of accelerator science in the US. As part of this effort the DOE has created the Accelerator Stewardship program. Information about the program can be found at https://science.energy.gov/hep/research/accelerator-stewardship/. The DOE Office of High Energy Physics also funds a special program in Advanced Technology R&D, https://science.energy.gov/hep/research/advanced-technology-rd/. A significant fraction of this program is directed toward accelerator development.

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

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

Dr. France Córdova, Director, National Science Foundation

Questions submitted by Representative Bill Posey, House Committee on Science, Space, and Technology

1. Has the NSF published any studies on planetary defense? If so, can you send them to the committee?

   Answer: NASA is the lead agency on planetary defense through its Planetary Defense Coordination Office (PDCO). The PDCO exercises that coordination through the National Science and Technology Council (NSTC) chartered Interagency Working Group for Detecting and Mitigating the Impact of Earth-bound Near-Earth Objects (DAMIEN). NSF is represented on DAMIEN by the Division Director and Deputy Division Director of NSF's Division of Astronomical Sciences, because of the value of NSF-supported, ground-based observing facilities in the detection and characterization of near-Earth objects (NEOs). Attached is the report on NEO strategy from the NSTC DAMIEN working group, published in December 2016.[1]

   NSF owns and operates several relevant facilities, including the Arecibo Observatory, Green Bank Observatory and the future Large Synoptic Survey Telescope (LSST), currently under construction in Chile. One of the three primary missions of Arecibo Observatory is to characterize and improve determination of the orbits of previously discovered solar system objects, including NEOs and potentially hazardous asteroids. This mission, funded by the NASA PDCO, utilizes the Arecibo Observatory planetary radar, sometimes in tandem with NSF's Green Bank Observatory and/or NASA's Goldstone Deep Space Communication Complex.

   The LSST, with funding support from NSF and the Department of Energy, will make significant contributions to discovering and tracking NEOs. To ascertain the effectiveness of LSST in fulfilling NASA's mandate to discover NEOs 140 meters and larger, a study was conducted by a team of NSF-funded scientists closely associated with the LSST, including scientific staff from the LSST project and NSF's National Optical Astronomy Observatory. The pre-publication version of that report is attached.[2] NASA also requested a complementary study from a group at NASA's Jet Propulsion Laboratory, which reached a similar conclusion, that the LSST can move the completeness level of NEO discoveries in the 140-meter to 300-meter size range from 42 percent to 73 percent during its 10-year mission.

2. What resources has the NSF developed on the opioid crisis and violence in schools?

   Answer: In October 2017, the Administration officially declared the opioid crisis a national public health emergency and signed a Presidential Memorandum outlining the efforts the federal government would undertake to address the crisis. As part of that important work, the Office of Science and Technology Policy initiated the Opioid Fast Track Action Committee (Committee) to coordinate health-focused federal government research and development activities related to the opioid crisis. NSF co-chairs the Committee, which will connect research and development efforts across the executive branch and link them with private sector and intergovernmental capabilities and needs.

   NSF has a long history of supporting interdisciplinary basic research that spans the biological sciences; social, behavioral and economic sciences; mathematical and physical sciences; engineering; computer science; and education. NSF is in the excellent position of being able to leverage this culture of convergence and join our colleagues at mission-driven agencies to contribute to combating the opioid crisis. NSF has supported many critical studies that have contributed to remarkable advances in a range of powerful technologies applied to measure, interrogate and repair brain function. New empirical methods and new datasets used by labor and health economists could be used to assess long-term developmental outcomes, and studies of both legal and illegal markets for opioids will help to understand how various policy alternatives can restrict access to illicit drugs. Quantitative-based analysis of these data is becoming increasingly important to understand the causes, pathways, diagnosis, prognosis and treatment of addiction.

   In addition, NSF programs such as Integrative Approaches to Neural and Cognitive Systems and Next Generation Networks for Neuroscience bring together mathematicians, physicists, computer scientists and engineers with strong backgrounds in biological research with psychologists and neuroscientists -- groups of scientists whose research fields do not traditionally intersect. The goal of these programs is to catalyze understanding of the brain at the convergence of quantitative, biological and behavioral research.

   These types of activities are also strengthened by interagency partnerships. For example, in partnership with the National Institutes of Health and several international funding agencies, multiple NSF directorates support collaborative research. NSF's longstanding support of chemistry, bioengineering, nanotechnology, microfabrication and materials research pave the way for the development of designer drugs that can target pain receptors without engaging the signaling pathways that result in the development of addiction.

These existing NSF activities serve well to help combat the opioid crisis through: (1) catalyzing new scientific breakthroughs, (2) unleashing the power of data, and (3) accelerating the delivery of new therapeutics to patients.

Regarding violence in schools, NSF has been quite active in supporting basic research that illuminates the developmental, neurological, cognitive, social, familial, economic and demographic factors that can contribute to – or diminish – the likelihood of violent anti-social behavior. NSF does not have prevention of violence as part of its fundamental mission. Rather, the basic science NSF supports lays the theoretical and empirical groundwork for downstream translation into applications that can be brought to bear on this goal.

A review of the NSF award abstracts database reveals many awards that have implications for understanding the causes of youth violence. Undoubtedly many more awarded projects than those captured using specific keywords, contribute to the knowledge base in ways that are informative. Basic research on ostracism or peer-rejection, intergroup dynamics, and self-regulation of impulsive action are just a few of the areas supported by a number of NSF's programs that have indirect implications for understanding and preventing youth violence.

In 2013, NSF convened a Subcommittee on Youth Violence of the Advisory Committee to the Social, Behavioral and Economic Sciences Directorate. The Subcommittee drafted a report titled, Youth Violence: What We Need To Know. A copy of the report is attached for your review.[3] The report emphasized violence by youths has numerous predisposing risk factors – as well as protective factors. Additionally, 'youth violence' is not a monolithic problem but an anti-social action that stems from many causes. For example, 'rampage shootings' differ from 'street violence' and the seeds that lead to these horrific outcomes can be quite varied.

Following the release of the report, NSF also released a Dear Colleague Letter on Youth Violence, highlighting NSF's interest in receipt of basic research projects which address topics relevant to youth violence. As noted, NSF's Social, Behavioral, and Economic Sciences directorate, as well as the Computer and Information Science and Engineering directorate, has long supported pertinent research.

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

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

Dr. France Córdova, Director, National Science Foundation

Questions submitted by Representative Bill Foster, House Committee on Science, Space, and Technology

1. Has the National Science Foundation funded research to understand handgun violence or gun violence more generally?

2. Have there been particular efforts in NSF to fund research on gun violence?

3. Are there any impediments or prohibitions to the NSF funding gun violence research?

Answer: NSF does not have a proposal or award policy related to scientific research into the causes and prevention of gun violence. Solicitations are typically general, disciplinary-based announcements intended to permit NSF to invest in a robust and diverse portfolio of scientific research projects. NSF cannot predict the types of proposals the research community will submit to the agency when a general solicitation is released; for example, NSF's Social, Behavioral & Economic Sciences Directorate supports research that builds fundamental knowledge of human behavior, interaction, and social and economic systems, organizations and institutions. NSF is focused on funding national needs at the frontiers of science and engineering, as considered through the agency's merit review process.

Examples of research funded by the National Science Foundation related to gun violence, 1996-present.

Award Number	Title
9515327	Situational Contexts of Gun Use By Young Males
9727882	Violent Incidents Among African-American Public School Students: A Proposal for Research
9808050	Why Northern New Englanders Seldom Commit Murder: Violent Crime and Violent Death in New Hampshire and Vermont
9910223	SGER: Coping with Community-based Traumatic Events: The Columbine High School Shootings and the 9/11 Terrorist Attacks
0242106	Gun Control and the Cultural Theory of Risk
0215551	National Consortium on Violence Research
0750762	Social and Behavioral Dimensions of Violent Crime
0735471	SGER: Campus Violence: Exploring a Community's Response to Tragedy

0737940	SGER: Coping, Adjustment, and Resilience Among College Women Following the Mass Shooting at Virginia Tech
0921619	Doctoral Dissertation Research in Political Science: The Logic of Armed Violence in Drug Wars
1060949	Testing Competing Theories of Violence
1151449	CAREER: "Crime Victimization Patterns in American Cities"
1422327	Collaborative Research: Threat Perception Following Mass Violence Events
1624296	RAPID: Risk Perception, Threat, and Anxiety Decay in Lone-Wolf Terrorist Events in the US
1602672	Doctoral Dissertation Research: Mass Shootings and the Gun Control and Gun Rights Movements
1613947	EAPSI: A Psychology of Gun Ownership

More detailed information, including the award abstract, researcher names, institutions, programs and other data associated with the awards listed above can be found at http://nsf.gov/awardsearch/.

APPENDIX

1 "*National Near-Earth Object Preparedness Strategy*," Interagency Working Group for Detecting and Mitigating the Impact of Earth-Bound Near-Earth Objects (DAMIEN) of the National Science and Technology Council, 2016

2 "*Defending Planet Earth: Near-Earth Object Surveys and Hazard Mitigation Strategies*," National Academies of Sciences, Engineering, and Medicine, 2010

3 "*Youth Violence: What We Need to Know*," Subcommittee on Youth Violence of the Advisory Committee to the Social, Behavioral, and Economic Sciences Directorate of the National Science Foundation, 2013

NATIONAL NEAR-EARTH OBJECT PREPAREDNESS STRATEGY

PRODUCT OF THE
INTERAGENCY WORKING GROUP FOR DETECTING AND MITIGATING THE IMPACT OF EARTH-BOUND NEAR-EARTH OBJECTS (NEOS) (DAMIEN)
OF THE NATIONAL SCIENCE AND TECHNOLOGY COUNCIL

DECEMBER 2016

About the National Science and Technology Council

The National Science and Technology Council (NSTC) is the principal means by which the Executive Branch coordinates science and technology policy across the diverse entities that make up the Federal research and development (R&D) enterprise. One of the NSTC's primary objectives is establishing clear national goals for Federal science and technology investments. The NSTC prepares R&D packages aimed at accomplishing multiple national goals. The NSTC's work is organized under five committees: Environment, Natural Resources, and Sustainability; Homeland and National Security; Science, Technology, Engineering, and Mathematics (STEM) Education; Science; and Technology. Each of these committees oversees subcommittees and working groups that are focused on different aspects of science and technology. More information is available at www.whitehouse.gov/ostp/nstc.

About the Office of Science and Technology Policy

The Office of Science and Technology Policy (OSTP) was established by the National Science and Technology Policy, Organization, and Priorities Act of 1976. OSTP's responsibilities include advising the President in policy formulation and budget development on questions in which science and technology are important elements; articulating the President's science and technology policy and programs; and fostering strong partnerships among Federal, state, and local governments, and the scientific communities in industry and academia. The Director of OSTP also serves as Assistant to the President for Science and Technology and manages the NSTC. More information is available at www.whitehouse.gov/ostp.

About the DAMIEN IWG

The DAMIEN IWG was convened in January 2016 to consider options to mitigate impacts from NEOs, including detection, characterization, trajectory determination, impact analysis; senior U.S. decision making, international cooperation and communications; long-term and short-term mitigation options, as well as quantification of success and risks from different mitigation options; public outreach, and disaster planning, operations, and recovery. The IWG's primary goal was to provide focused input, via this National Strategy, into the National Planning Framework called for by the Presidential Policy Directive 8 (PPD-8): National Preparedness (2011).

About this Document

This document was developed by the Interagency Working Group (IWG) for Detecting and Mitigating the Impact of Earth-bound Near-Earth Objects (NEOs) (DAMIEN). The Strategy seeks to improve our Nation's preparedness to address the hazard of near-Earth object (NEO) impacts by enhancing the integration of existing national and international assets and adding important capabilities that are currently lacking. The Strategy builds on efforts at the National Aeronautics and Space Administration (NASA) to better detect and characterize the NEO population as well as recent efforts at the Department of Homeland Security (DHS) to prepare for and respond to a NEO impact. The document was published by OSTP.

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NATIONAL SCIENCE AND TECHNOLOGY COUNCIL
COMMITTEE ON HOMELAND AND NATIONAL SECURITY
INTERAGENCY WORKING GROUP FOR THE DETECTING AND MITIGATING THE IMPACTS OF EARTH-BOUND NEAR-EARTH OBJECTS (DAMIEN) NATIONAL SCIENCE AND TECHNOLOGY COUNCIL

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Executive Summary

The *National Near-Earth Object Preparedness Strategy* (Strategy) and the forthcoming *National Near-Earth Object Preparedness Action Plan* (Action Plan) together seek to improve our Nation's preparedness to address the hazard of near-Earth object (NEO) impacts by enhancing the integration of existing national and international assets and adding important capabilities that are currently lacking. The Strategy and Action Plan build on efforts at the National Aeronautics and Space Administration (NASA) to better detect and characterize the NEO population as well as recent efforts at the Department of Homeland Security (DHS) to prepare for and respond to a NEO impact. Together, they aim to foster a collaborative effort in which the Nation can better understand, prevent, and prepare for the effects of a NEO impact. The Nation must continue to leverage existing networks of expertise and capabilities, both public and private, and pursue targeted enhancements to improve the ability to manage the risks associated with NEOs.

Seven strategic goals underpin the effort to enhance the Nation's preparedness to NEO impacts:

1. **Enhance NEO Detection, Tracking, and Characterization Capabilities.** Objectives include: developing a capability roadmap to inform a strategy for investing in both U.S. and foreign abilities for detection, tracking, and characterization; improving observation capabilities for more complete and rapid observation of the entire population of NEOs; and updating existing observatories with capabilities to improve characterization assessments.
2. **Develop Methods for NEO Deflection and Disruption.** Objectives include: developing capabilities for fast-response focused reconnaissance and characterization; researching deflection and disruption capabilities for NEOs of varying size, mass, composition, and impact warning times; and researching technologies required for deflection and disruption concepts.
3. **Improve Modeling, Predictions, and Information Integration.** Objectives include: ensuring that adequate modeling capabilities are developed for each topical need, especially for modeling NEO trajectories to reduce orbit uncertainties and predicted impact effects; determining what outputs are required by whom; and establishing an organizational construct to coordinate the development and dissemination of modeling results.
4. **Develop Emergency Procedures for NEO Impact Scenarios.** Objectives include: promoting a collaborative national approach to defend against, mitigate, respond to, and recover from a NEO impact event; and developing coherent national and international communication strategies to facilitate NEO impact preparations.
5. **Establish NEO Impact Response and Recovery Procedures.** Objectives include: establishing national and international protocols to efficiently respond to a NEO impact, whether in deep ocean, coastal regions, or on land; and facilitating international cooperation and planning to recover from a NEO impact in a timely manner with minimal disruption.
6. **Leverage and Support International Cooperation.** Objectives include: building international support and policies for acknowledging and addressing the potential Earth impact of a NEO as a global challenge; fostering consultation, coordination, and cooperation channels and efforts for the planning for, impact emergency preparedness before, and response to a NEO impact; increasing engagement with the international community on observation infrastructure, data sharing, numerical modeling, and scientific research; strengthening international coordination and cooperation on NEO data and

analyses; and promoting a collaborative international approach to preparedness for NEO events.

7. **Establish Coordination and Communications Protocols and Thresholds for Taking Action.** Objectives include: coordinating the communication of detected impact threats within the U.S. Government, as well as with other governments, media, and the public; developing a set of thresholds to aid U.S. decisions in whether to implement deflection or disruption missions; developing decision flowcharts for NEO hazard scenarios incorporating benchmarks and decision thresholds; and developing protocols for international interactions regarding NEO impacts outside of U.S. territory.

Introduction

Near-Earth Objects (NEOs) are asteroids or comets with heliocentric orbits that come near or intersect Earth's orbit.[1] They range in size from small "meteoroids" of only a few meters in size, to much larger bodies several kilometers wide. Figure 1 shows the current known near-Earth asteroid (NEA)[2] population (green bars), the current estimate of total NEA population (red line), the completeness percentage of survey efforts (blue line), and the estimated damage from a NEA impact (background), all as a function of the estimated size of the NEA.[3]

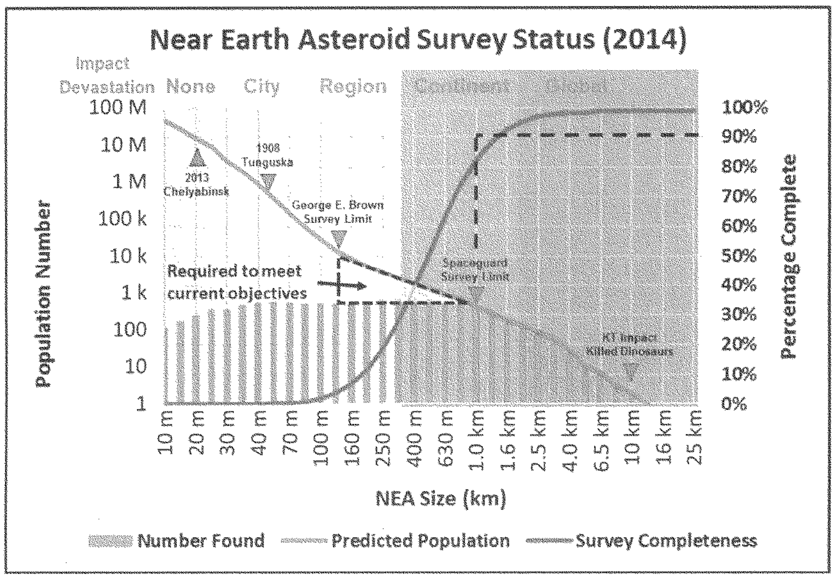

Figure 1: NEAs of various sizes: number detected to date and estimated total number.

Smaller asteroids fly by or enter Earth's atmosphere frequently. The greatest number are small enough to burn up in the atmosphere, and most go completely undetected. Recently released U.S. Department of Defense data show that between 1994 and 2013, 556 bolide (see Glossary) events were observed in the atmosphere; these correspond to asteroids ranging from 1 meter to 20 meters in size entering Earth's

[1] See the Glossary for definitions of key terms used in this document.

[2] This survey status does not include comets, hence the distinction between NEOs and NEAs in Figure 1. However, Earth approaching comets represent less than 1% of the NEO population, and their enhanced signature from expelled dust make them much easier to detect once they cross inside the orbit of Mars.

[3] Harris, Alan, and Asteroid Grand Challenge. "NEA Populations and Impact Frequency." *Population*, 10 (2014): 6.

atmosphere.

Even small NEOs can have significant destructive effects (see the background shading in Figure 1). For example, the airburst near Chelyabinsk, Russia on February 15, 2013 was caused by a small asteroid approximately 20 meters wide that had an energy equivalent of almost 500 kilotons of trinitrotoluene (TNT), or roughly 20-30 times greater than the energy released from the first atomic bombs. Current estimates of the NEO population predict that almost 10 million objects with a diameter greater than 20 meters exist but have not yet been detected.

Similarly, an object estimated to be approximately 40 meters wide exploded over Tunguska, Russia in 1908 with the equivalent of 5-10 megatons of TNT and leveled over 2,000 square kilometers of trees. If a similar airburst event were to occur over a major metropolitan area, millions of injuries and casualties could result. Current estimates of the NEO population predict that over 300,000 objects greater than 40 meters in size could be an impact hazard to the Earth and have not yet been detected.

The most recent Congressionally-directed asteroid survey requires that NASA find 90% of objects that are 140 meters in size or greater (see References). Such objects would strike Earth with a minimum energy equivalent of over 60 megatons of TNT, which is more energy than yielded by the most powerful nuclear weapon ever tested. After almost two decades of search, about 28% of the estimated population of asteroids 140 meters in size or larger have been discovered. The highlighted triangle in Figure 1, "Required to meet current objectives", illustrates estimates of the predicted population of objects >140m that are yet to be discovered.

Larger NEOs (>140 m), representing the potential to inflict serious damage to entire cities or regions, are also easier to detect and track, therefore more is known about this population than what is known about smaller objects. As Figure 1 shows, there are far fewer larger objects than smaller objects, so the probability of impact of a larger object is much lower compared to the probability of impact of a smaller object.

The exact effects from a NEO impact depend on, among other things, its composition, size, shape, porosity, and impact velocity. Small, rocky NEOs are likely to explode before hitting the ground, resulting in an airburst that could cause a wider radius of moderate damage compared to a similarly sized NEO composed of mostly metal that would strike the ground and cause localized devastation. However, larger, denser NEOs would require more energy to deflect, and have more kinetic energy overall upon impact. As more NEOs are detected, and the total population of NEOs is better characterized, assessing the overall hazard of a NEO impact will become more achievable.

Unlike other natural disasters (*e.g.*, hurricanes) and space weather events (*e.g.*, solar flares), NEO impacts are predictable many years in advance and, most importantly, potentially preventable when a survey of the population is complete. NEO impacts are a global hazard and could have major environmental, economic, and geopolitical consequences detrimental to the United States, even if the impact is beyond U.S. territory. Although currently a global leader in detecting and tracking NEOs, the United States will depend (in part) on international cooperation and coordination to help develop capabilities for characterization and future capabilities related to the development and implementation of deflection and disruption capabilities for NEOs.

When a NEO that is on course to impact Earth is identified, it is a global threat that requires the leadership of the United States to establish a coordinated global approach for detection, tracking, and characterization as well as for deflection and disruption operations, if necessary, and preparedness in the event of an impact. If prevention proves technically infeasible or is attempted and fails, the United States may also need to take a leadership role in helping the international community reduce the negative consequences of a NEO impact.

While it is highly unlikely that there will be a civilization-ending NEO impact over the next two centuries, the risk of smaller but still catastrophic NEO impacts is real, and there is currently no whole-of-government or international strategy to respond to such an event throughout all phases of a NEO impact scenario timeline (Figure 2). The *National Near-Earth Object Preparedness Strategy* (Strategy) and the forthcoming *National Near-Earth Object Preparedness Action Plan* (Action Plan) identify goals and activities to enhance the understanding of risk from, and national preparedness for, NEO impacts.

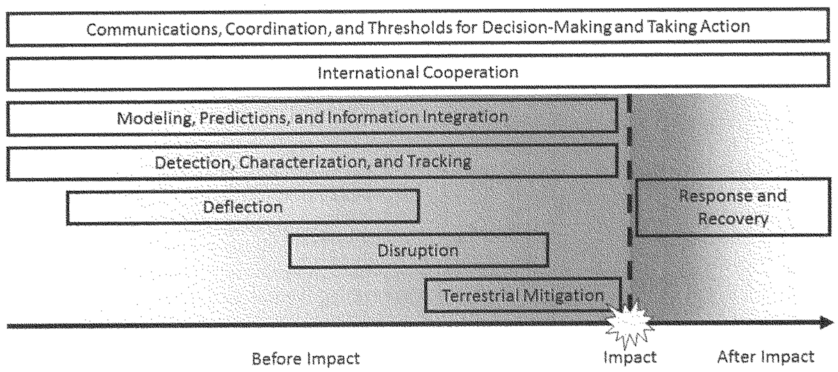

Figure 2: Illustrative timeline of the phases of operations in a NEO preparedness strategy.

This Strategy outlines objectives for enhancing the Nation's NEO preparedness in three key areas: hazard and threat assessment, decision-making, and response. Some Federal departments and agencies have already taken significant steps in these key areas. The goals outlined in this Strategy will leverage these efforts and existing policies, while promoting enhanced coordination and cooperation across the public and private sectors in the United States and abroad.

Authority for Creation of the National Near-Earth Object Preparedness Strategy

To address the mandates and challenges above, an Interagency Working Group (IWG) for Detecting and Mitigating the Impact of Earth-bound Near-Earth Objects (DAMIEN) was established in 2016 by action of the Committee on Homeland and National Security within the National Science and Technology Council (NSTC). The DAMIEN-IWG developed this Strategy and will develop the forthcoming Action Plan to enhance preparedness for the hazard of NEO impacts.

This Strategy will work to ensure that NEO impact preparedness is fully integrated with and builds upon several governmental frameworks already in place. These include: Presidential Policy Directive (PPD)-4, "National Space Policy" (June 28, 2010); PPD-8, "National Preparedness" (March 30, 2011); and PPD-21, "Critical Infrastructure Security and Resilience" (February 12, 2013); Section 321 of the NASA Authorization Act of 2005 and Section 804 of the NASA Authorization Act of 2008; and the Office of Science and Technology Policy's (OSTP) 2010 response to Congress (See References for the complete citations).

PPD-4 instructs NASA to "pursue capabilities, in cooperation with other departments, agencies, and commercial partners, to detect, track, catalog, and characterize NEOs to reduce the risk of harm to humans from an unexpected NEO impact on our planet and to identify potentially resource-rich planetary objects."

PPD-8 calls for an integrated, all-of-Nation, capabilities-based approach to preparedness for all hazards. It also calls for the creation of a series of National Planning Frameworks. Accordingly, the Department of Homeland Security (DHS) coordinated the development of the Strategic National Risk Assessment (SNRA). As of now, the SNRA does not include preparedness for the hazard of NEO impacts.

PPD-21 identifies three strategic imperatives to drive the Federal approach to strengthening critical infrastructure security and resilience at the core of this Strategy. The Directive identifies energy and communications systems as vital due to the enabling functions they provide across all critical infrastructure sectors. The Directive also instructs the Federal Government to engage with industry and international partners to strengthen the security and resilience of domestic and international critical infrastructures on which the Nation depends.

Section 321 of the NASA Authorization Act of 2005, labeled the George E. Brown, Jr. Near-Earth Object Survey Act, directs NASA to detect, track, and characterize 90% of all NEOs with a size of 140 meters or greater, to be completed by 2020 (see Figure 1 (yellow triangle) for an estimation of how many such objects remain to be discovered). This survey will take much longer to complete without significant upgrades to capabilities that aid in detecting and tracking NEOs.

Subsequently, Section 804 of the NASA Authorization Act of 2008 requires that the Director of OSTP: (1) develop a policy for notifying Federal agencies and relevant emergency response institutions of an impending NEO threat if near-term public safety is at risk; and (2) recommend a Federal agency or agencies to be responsible for: (A) protecting the United States from a NEO that is expected to impact Earth; and (B) implementing a deflection campaign in consultation with international bodies, should one be necessary. In October 2010, OSTP responded to Congress and laid out Administration plans to meet the requirements in the NASA authorization.

Implementation of the National Near-Earth Object Preparedness Strategy

The Action Plan, to be released subsequent to this Strategy, details the Federal activities that will be undertaken to implement this Strategy and achieve the seven high-level goals, and includes deliverables, timelines, and metrics to measure progress and success. This Strategy acknowledges the challenges associated with planning and preparing for events with low probability of occurrence but potential for catastrophic consequences, as well as high uncertainty on the correct course of action when a threat materializes. As a result, the activities identified herein should be prioritized accordingly. The Executive Office of the President will coordinate the development and execution of the Action Plan and will reevaluate and update the Strategy and Action Plan within three years of the date of publication respectively, or as needed.

Full implementation of this Strategy will require the action of a global network of governments, U.S. Government agencies, intergovernmental organizations, and non-governmental organizations including academia, the media, nonprofit organizations, and industry. Strong collaborations must be established among the Federal Government, other nations, industry, and academia to enhance NEO observing networks, conduct research, improve prediction models, plan and execute deflection and disruption missions, and supply the services necessary to protect life and property. These partnerships between the United States and the international community, industry, and academia will form the backbone of preparations for any threat of a NEO impact event.

Strategic Goals

This Strategy defines seven strategic goals to prepare the Nation for a variety of NEO impact scenarios. These goals aim to improve the Nation's warning of, options for preventing, planning for, recovery from, and international collaboration responding to, NEO impacts. These strategic goals address the entire range of possible NEO impact scenarios, from decades of warning to no warning at all. Various possible phases, as well as capabilities that encompass the entire timeline of how to respond to potential NEO impacts, are shown in Figure 2.

The seven high-level goals for Federal research, development, deployment, operations, coordination, and engagement are:

1. Enhance NEO Detection, Tracking, and Characterization Capabilities
2. Develop Methods for NEO Deflection and Disruption
3. Improve Modeling, Predictions, and Information Integration
4. Develop Emergency Procedures for NEO Impact Scenarios
5. Establish NEO Impact Response and Recovery Procedures
6. Leverage and Support International Cooperation
7. Establish Coordination and Communications Protocols and Thresholds for Taking Action

Enhance NEO Detection, Tracking, and Characterization Capabilities

Finding NEOs as early as possible is the first priority for planetary defense, in order to give adequate time to make decisions and implement courses of action. This fact must be stressed: the earlier a NEO threat is detected, the better the emergency response to the threat will be. However, accurately predicting their orbits and understanding their structure and composition are equally critical to assessing the NEO impact hazard and how to best respond to a NEO impact threat.

NASA is the global leader for ground- and space-based observations to detect, track, and characterize near-Earth asteroids and comets. Part of characterization is identifying and interpreting spectral signatures of near-earth objects, and the U.S. Geological Survey develops and maintains the spectral libraries necessary for this work. NASA and the Department of State collaborated with the United Nations to foster the International Asteroid Warning Network (IAWN), a voluntary organization of astronomers to encourage rapid reporting of asteroid observation data from observatories worldwide. NASA funds the Minor Planet Center (MPC), a clearinghouse for worldwide asteroid observations that identifies objects in potentially hazardous orbits, currently hosted by the Smithsonian Astrophysical Observatory. These, and other partnerships, have increased the global detection rate substantially over the last 10 years. Furthermore, attention to tracking smaller objects has increased with improved awareness of the negative consequences of impacts by smaller but far more populous NEOs. This has resulted in increased detection rates of these objects even though they are much harder to detect. Careful stewardship has enabled expansion of U.S. NEO observations through small investments in new technologies and analytic capabilities that have increased the fidelity and breadth of those observations. However, efforts to comply with congressional directives to complete the search for objects as small as 140 meters in size are several years behind schedule.

The following objectives would improve detection, tracking, and characterization capabilities:

- **Develop a capability roadmap to inform a strategy for both U.S. and foreign capabilities for detection, tracking, and characterization.** Development of a capability roadmap to inform investments by contributing nations will enable improvements to the overall global network. A roadmap will incorporate innovations in optical and infrared detection capabilities, improvements in ground-based radar capabilities, and improvements in automating and improving accuracy of analytical software. More costly, but just as important, is the development of improvements in on-board data processing and downlink for space-based observatories.

- **Improve observation capabilities for more complete and rapid observation of the entire population of NEOs.** To cite one example, several study reports have found that a space-based observatory, working in concert with observations from ground-based telescopes, may be the best approach to detecting, tracking, and characterizing the NEO population. This combination would more rapidly complete the survey of objects larger than 140 meters while greatly improving our understanding of the hazard from the 50-140 meter NEO population, and provide a voluminous dataset for both science and planetary defense.
- **Update existing observatories with capabilities to improve characterization assessments.** Efforts to deflect or disrupt a NEO could be made more effective if a basic understanding of the object's mass, composition, and structure is first obtained. For example, improvements in spectroscopy will enable faster estimates of gross composition. Ease of access to larger aperture telescopes when critical data are needed should be coordinated. Additionally, better planetary radar capabilities, such as increased power, radar frequency, or time available at major radio telescopes, are also critical to improving orbit determination, measuring size and understanding rotation states, and obtaining essential information about the object's surface structure. These data, when combined with advanced spectroscopic observations, can provide critical information to inform development of space-based technologies to prevent a NEO impact.

Develop Methods for NEO Deflection and Disruption

Several studies over the last two decades have pointed out that technologies exist that may be capable of preventing a NEO impact, and that true preparedness may need to include the ability to deflect (turn away) or disrupt (break into small pieces) a NEO headed towards Earth. The NEO population is quite diverse, a fact which presents significant unknowns when considering how to develop technologies capable of deflecting or disrupting the object. Observations, including optical and planetary radar (when objects are accessible for observation), over many years may improve our understanding of the composition, mass, and behavior of any particular object (see Goal 1, above), which in turn could improve design of deflection technologies. Disruption of the NEO may be required if there is little warning time or if the object is very large. Technologies to deflect the NEO away from Earth can be used, but to either disrupt or deflect a very large object, research and development of high-energy solutions is required.[4]

The following objectives would improve deflection and disruption capabilities:

- **Develop capabilities for fast-response focused reconnaissance and characterization.** The objective of Goal 1 is to provide timely, high-certainty, actionable warning that a NEO threat exists, but because of the diversity of NEOs an effective deflection or disruption mission may need more detailed information on the specific threat. One candidate concept for this objective would be a capability to rapidly launch, intercept, and conduct reconnaissance on a NEO, to

[4] Challenges associated with the transfer of space-related data, technologies, and equipment required for asteroid deflection and disruption, or other purposes discussed in this Strategy, would only be approved if consistent with U.S. export control laws and regulations as well as international obligations and commitments.

provide up-close imagery, composition, and mass measurements (*e.g.*, passive (visible, thermal, multi/hyperspectral) and active (radar, LIDAR, *etc.*) imaging techniques) in order to determine ways to enhance the effectiveness of any subsequent deflection or disruption missions.

- **Research deflection and disruption capabilities for NEOs of varying size, mass, composition, and impact warning times.** With enough warning time, a NEO impact can be prevented. To address most impact scenarios, prevention capabilities should include the ability to achieve timely effects and feedback, for example: to launch a deflector or disruptor that can rapidly reach the object; conduct rendezvous and proximity operations when needed; and deploy kinetic impactors or other technologies. Additionally, deploying an instrumented means to measure the deflection over time can provide assurance of mission success. Where practical, real world demonstration of the deflection or disruption technique to test effectiveness and reduce uncertainties should be pursued, particularly when this can be done as a part of a mission to an asteroid or comet with broader science and exploration objectives. An assessment of the technical, policy, and legal issues with regard to delivering and triggering a high-energy device to deflect or disrupt NEO impact threat objects will be required.
- **Research technologies required for deflection and disruption concepts.** Given the potential short time between first detection and potential NEO impact, precursor reconnaissance of the object may not be possible. To improve mission success, some key technologies to be developed include:
  - Rapid assessment capabilities for ground-based, orbital, and deep-space systems.
  - Fast orbit transfers to maximize momentum transfer for kinetic impactors or maximize distance from Earth at point of intercept for deflection missions. High-acceleration maneuvering, near the point of intercept, is critical for optimized intercept locations and course corrections immediately before intercept.
  - Algorithms and on-board artificial intelligence for short-notice disruption missions to self-assess the optimal time and location for interception or disruption.

Improve Modeling, Predictions, and Information Integration

The NEO population is diverse, and the effects of impact with Earth are not well understood. Additionally, efforts to catalog and track NEOs, and to model NEO impact effects, are a very recent undertaking. A successful national strategy for NEO preparedness will depend, in part, upon quantitative modeling and analysis capabilities to more accurately predict a NEO's orbital trajectory, including non-gravitational perturbations, to determine what effects different deflection and disruption techniques may have on the orbital trajectory. Furthermore, it will be necessary to estimate the potential damage from a NEO impact, including secondary effects like local environmental and climate disturbances and economic consequences, and communicate how these models and analyses integrate across a range of activities. Given the relative immaturity of our understanding of these objects, it is understood that rapid advances could be made with modest investments that leverage existing analytical capabilities.

Numerical modeling and leveraging state-of-the-art computational facilities and advanced simulation codes are of central importance in understanding prevention options and their consequences, predicting impact effects, and estimating uncertainties. Examples of modeling include the estimation of impact probabilities (or locations) of detected NEOs, evaluation of deflection and disruption technologies and techniques and how NEOs of varying sizes and compositions respond, and analysis of the risk to life and infrastructure by NEO impact effects in air, land, and water. The resultant information will be utilized throughout all phases of a response, including evaluation of the efficacy and risks of prevention, planning for emergency preparation and response, and estimation of casualty and property losses—essential information for decision-makers. The quality and sufficiency of modeling and analysis capabilities underpin all other efforts, permitting decision-makers to understand what could happen and to plan and act accordingly. Modeling also can be used to study alternative courses of action, advise training and preparation exercises, and inform cost-benefit decisions, among other roles.

The following objectives would enhance modeling and prediction capabilities and their integration across the Nation's effort:

- **Ensure that adequate modeling capabilities are developed for each topical need, especially for modeling NEO trajectories to reduce orbit uncertainties and impact effects.** In light of the core role of modeling and analysis, a comprehensive review should be conducted of modeling and analysis needs for planetary defense purposes to inform an assessment of current capabilities, including identifying strengths and gaps. A plan should be formed to establish capabilities where none exist or where the current capability is inadequate, as well as to maintain and improve existing capabilities, including identification of appropriate resources to support the activities.
- **Determine what outputs are required by whom.** When a potential NEO impact threat is detected, it will be important that all parties involved have, well in advance, a clear understanding of who requires what information, in order to reduce delays or confusion. Various agencies each have their own needs, while some information is required across the entire response effort. In addition to an *a priori* list of what each organization will need, training and preparation exercises provide an excellent means to uncover unexpected requests and interdependencies, and should be employed to search for omissions.
- **Establish an organizational construct to coordinate the development and dissemination of modeling results.** A national planetary defense response capability will need to rely on an as-yet-to-be-developed organization spread across a range of governmental and non-governmental organizations. In the case of a real event, many independent sources of information and analysis are expected to emerge, both foreign and domestic. A capability or process will be needed to rapidly sort through the many sources of data and determine which are most valid and useful to decision-makers. It is important to ensure rapid assessment and timely delivery of valid information among U.S. Government agencies, as well as to international and intergovernmental organizations and foreign capitals through diplomatic, scientific, and emergency management channels, and provide verified information, notifications, and warnings in order to manage public awareness.

Develop Emergency Procedures for NEO Impact Scenarios

In an ideal situation, an Earth-bound NEO can be deflected or disrupted well before it reaches Earth. Scenarios may occur in which a NEO impact cannot be prevented because there is not enough time between detection and impact to deflect or disrupt it. In the event that a NEO impact can be predicted, but cannot be prevented, a plan must be in place to prepare for the impact to avoid loss of life and mitigate damage to critical infrastructure as much as possible. The recently established NASA/FEMA-led Planetary Impact Emergency Response Working Group (PIERWG) has been coordinating efforts to integrate ways to address the risks and dangers of potential NEO impacts into national disaster response protocols to ensure the establishment of operational response capabilities unique to NEO impacts.

Adding NEO impacts to the Strategic National Risk Assessment (SNRA) will have the additional benefit of including the problem of this scenario in the national lists of priorities. No study has been conducted to determine whether NEO emergencies meet the statistical criteria for inclusion in the SNRA; however, while NEO events are rare, the consequences for failure to prepare or respond to a NEO event are extremely high. Inclusion in the SNRA will provide policy makers with the opportunity and motivation to include funding for future NEO emergency efforts. Under this structure, FEMA will have the requirement to at least consider preparing emergency response plans for these events. It is expected that existing plans for other hazards such as earthquakes or volcano eruptions, for which the U.S. Geological Survey has monitoring and warning responsibility, can be leveraged for a NEO-impact response plan. Coordination and training will be required to inform local, state, tribal, territorial, and regional emergency planners.

The following objectives would benefit establishment of effective national preparedness procedures:

- **Promote a collaborative national approach to defend against, mitigate, respond to, and recover from NEO impact events.** Response to a predicted NEO-impact event would require an approach that would be facilitated by multiple agencies, with potential participation by other governments and industry. Such an approach should also include:
  - Facilitating the exchange of information and best practices with national and international emergency management stakeholders to strengthen global capacity to mitigate, respond to, and recover from NEO impacts.
  - Assessing the potential implications of a NEO impact event on critical infrastructure and supply chain dependencies, both foreign and domestic.
  - Coordinating international partnership activities to support the objectives of preparedness and response exercises.
- **Develop coherent national and international communications strategies to facilitate NEO impact preparations.** Such communications strategies should include:
  - Developing and disseminating training materials to assist Federal, state, and local governments as well as foreign governments in understanding the threat, and to assist in preparedness and recovery planning.
  - Using national emergency alert and warning protocols currently in place (*i.e.*, orbital debris impact warnings) as much as possible while modifying existing protocols for other natural disasters where necessary.
  - Assisting in coordinating worldwide forecasts, alerts, and warnings using consistent nomenclature and non-technical terminology whenever possible.
  - Continuing to coordinate with the United Nations International Asteroid Warning Network to develop standard public awareness protocols and possible warning formats.

Establish NEO Impact Response and Recovery Procedures

The Department of Homeland Security, through its operational component FEMA, has coordinated the development of emergency response plans for all hazards via the Federal Interagency Operations Plans (FIOP) and Annexes. The FIOPs are the Federal Government's concept-of-operations documents that provide detailed explanations of how Federal agencies work together in crisis situations. The FIOPs are "all-hazards" documents and have separate annexes to cover specific hazards. This strategic goal seeks to identify all of the unique aspects of a NEO impact and ensure that our emergency responders and citizens are prepared to respond and provide the capability for national resilience in such an unusual scenario. While it is expected that a NEO impact emergency response could be similar to a hurricane response plan (including evacuations and other preparations in the event that there is warning before impact) or an earthquake response plan (in the event that there is no warning), NEO impact modeling and simulation will inform specific details. Whether a NEO impact occurs with or without warning, a NEO impact Annex to the FIOP should be in place to inform decision-makers of possible first steps and to provide the basis of planning for local emergency responders. The remediation of damage to critical infrastructure should be prioritized to expedite recovery across all sectors.

The following objectives would help to establish effective response and recovery procedures:

- **Establish national and international protocols to efficiently respond to a NEO impact, whether in deep ocean, coastal regions, or on land.** Different types of NEO impact scenarios have different national and international considerations, especially regarding the environmental consequences. Earthquakes and tsunamis could result from larger NEO impacts, creating consequences that spread far beyond the impact site, and the mechanisms for timely notifications and warnings should be developed and exercised as necessary to ensure proper public understanding and response to the emergency.
- **Facilitate international cooperation and planning to promote recovery from a NEO impact in a timely manner with minimal disruption to the status quo.** This includes assessments of critical infrastructure damage to effectively deliver foreign aid and recovery equipment to governments as needed.

Leverage and Support International Cooperation

The risk of a NEO impact is a global hazard best addressed well in advance of detecting the first potential impact through consultations, coordination, and cooperation with the international community directed towards improving detection, deflection, disruption, mitigation, and disaster relief. The United States' role would be to foster global collaboration and take advantage of mutual interests and international capabilities to improve preparedness for potential NEO impacts. If deflection or disruption proves technically infeasible, the United States may be best postured to take a leadership role in helping to reduce the severity of, and facilitate recovery from, the aftereffects of a NEO impact, even if the impact is outside U.S. territory.

The United States and other nations are sharing observations and research, disseminating data products and services, and collaborating on real-time predictions which could be used to avoid or reduce potential damage to critical technology and infrastructure. For example, the NASA Planetary Defense Coordination Office works with the International Asteroid Warning Network (IAWN), sponsored by the U.N Committee on the Peaceful Uses of Outer Space (UNCOPUOS). The Network is a voluntary collaboration among governments, institutions, observatories, and individuals that enables coordination among astronomers and enables a free and open data exchange. IAWN members, and other observatories, voluntarily submit data to the Smithsonian Astrophysical Observatory's Minor Planet Center, a NASA-funded clearinghouse for NEO detection data. It is expected that more nations will join the effort to work together to foster greater global collaboration, taking advantage of mutual interests and international capabilities to improve situational awareness, predictions, and preparedness for NEO events. However, addressing the challenges associated with asteroid deflection and disruption through the transfer of space-related data, technologies, and equipment, or other purposes discussed in this Strategy, would only be approved if consistent with U.S. export control laws and regulations as well as international obligations and commitments.

The following objectives would enhance leveraging and support of international cooperation:

- **Build international support for acknowledging and addressing the potential Earth impact of a large NEO as a global challenge.** While detection rates are increasing, it is estimated that less than 30% of NEOs large enough to cause regional damage have been identified. A prerequisite to enhanced international cooperation and high-level support for appropriate policies and coordination mechanisms among partner countries is increased awareness of the risks and dangers of NEOs to the entire planet.

- **Foster consultation, coordination, and cooperation channels and efforts for the planning for, mitigation of, and response to NEO impacts.** The United States should take a leadership role in consulting, coordinating, and cooperating through multilateral channels including, but not limited to, the U.N. General Assembly, the U.N. Security Council, UNCOPUOS, and intergovernmental organizations, as well as in bilateral channels. In particular, the United States should continue its leadership in IAWN and the U.N.-mandated Space Mission Planning Advisory Group (SMPAG). The United States should also explore the necessity for additional consultative and coordination mechanisms at the bilateral government-to-government and intergovernmental level to discuss and share information related to detection, tracking, and characterization, prevention planning and options, as well as mitigation and recovery plans in order to supplement/complement existing mechanisms.
- **Increase engagement and cooperation with the international community on observation infrastructure, data sharing, numerical modeling, and scientific research.** The Federal Government should explore opportunities to work with the international community to enhance research, observations, models, and forecasting tools that will improve NEO detection, characterization, and trajectory forecasting. This will be done in compliance with U.S. export control laws and regulations as well as international obligations and commitments.
- **Strengthen international coordination and cooperation on NEO data and analyses.** Providing high-quality NEO data products and analyses worldwide requires international consensus and cooperation. Toward this end, the United States should:
  - Seek international agreement on common terminology, measurements, and scales of magnitude.
  - Continue to promote and coordinate sharing and dissemination of NEO observations, model outputs, and forecasts.
  - Establish coordination procedures across NEO research, forecasting, and detection centers (*e.g.*, Minor Planet Center and the Jet Propulsion Laboratory's Center for NEO Studies).
- **Promote a collaborative international approach to preparedness for NEO events.** A NEO impact can have global consequences regardless of impact location. Towards this end, the United States should:
  - Foster the development of international standards for NEO events requiring potential prevention, mitigation, emergency response, and recovery efforts to aid in decision-making.
  - Foster the development of international communication standards to ensure NEO events are effectively and responsibly communicated to the international community across diverse cultures via diplomatic, scientific, and media channels.
  - Conduct tabletop and physical exercises with global partners regarding preparedness for prevention, mitigation, response, and recovery efforts.

Establish Coordination and Communications Protocols and Thresholds for Taking Action

Developing the process and procedures, including protocols and thresholds, to be used in decision-making and communications—especially during a crisis with inherently high uncertainty—is necessary for timely and effective implementation of prevention and mitigation measures. It is possible that there may be little to no warning of an impending NEO impact, therefore pre-planning and conducting simulations and exercises of emergency decision-making and communication across all—but especially time-critical and stressful—NEO impact scenarios are critical to prevention, mitigation, emergency response, and recovery. Coordination across all areas of government is necessary.

The following objectives would assist creation of a comprehensive framework for determining the proper course of action across every phase of a NEO impact threat scenario:

- **Coordinate communication within the U.S. Government, as well as with other governments, the media, and the public regarding NEO threats.** Governments, scientists, observatories, and institutions will have the shared responsibility to make announcements using only verified and validated data if a potentially hazardous object is detected. The combination of public access to data, and its rigorous analysis by the worldwide network, will help to minimize the promulgation of false predictions.
    - NASA, per direction from the National Space Policy (PPD-4), has the responsibility to assess and report threats as they are detected. The NASA Planetary Defense Coordination Office (PDCO) was specifically created to confirm data and analysis on potential impact threats are properly verified and validated and to ensure credible, rapid, and concise information transmission to the Executive Office of the President and other Federal agencies. PIERWG, co-chaired by NASA and FEMA, was created to ensure coordinated Federal response for terrestrial preparedness to the announcement. The PDCO also has the responsibility to draft announcements for providing information to the media and the public. FEMA will have a responsibility of communicating emergency response plans and notifications to the public. It is expected that a significant amount of basic education about this particular type of hazard will need to be provided, in addition to developing means of communicating uncertainties regarding the risks of a NEO impact and its aftereffects.
    - NASA should develop plans for notifying the U.S. Congress as appropriate for the magnitude of a projected NEO impact threat. Interagency teams should provide briefings to the appropriate Committees and Subcommittees prior to, or concurrent with, diplomatic notifications.
    - The Department of State, in coordination with other U.S. departments and agencies, should develop plans for notifying foreign governments and international and intergovernmental organizations as appropriate for the magnitude of the projected NEO Earth impact threat. The Department of State, after receiving the information from NASA, and in coordination with other government agencies, will notify leadership of nations across the world of the impending risk and danger of an Earth-impacting NEO in an appropriate timeframe. As an example, the notification should include known characterization of the NEO, the date of its expected impact with Earth and projected impact location, plans (if any) for deflection or disruption, and preparedness plans including those for mitigation, emergency response, and recovery, including offers of U.S. assistance.
- **Develop a set of thresholds to aid U.S. decisions for whether to implement deflection or disruption missions for projected NEO Earth impacts on U.S. territory and outside of U.S. territory.** UNCOPUOS has endorsed the establishment of SMPAG for space agencies to lay the groundwork for an international response to a predicted NEO impact. Once technologies are developed and the capability exists to deflect or disrupt an incoming NEO, thresholds will aid the United States, in consultation and coordination with its global partners, in determining whether

an impact can be, or should be, prevented. The United States must nevertheless retain the decision-making authority and ability to act by itself to defend its national interests from NEO threats, especially when time is limited or the international consensus is lacking or not attainable.

- **Develop decision flowcharts for NEO threat scenarios incorporating benchmarks and decision thresholds.** Prior to any NEO crisis, flowcharts should be created which integrate decision-making thresholds to help guide non-expert decision-makers to make the best decisions under uncertainty. These flowcharts should cover a wide range of variables to a NEO impact scenario such as size, composition, impact probability or location, and time before impact. These flowcharts will also help identify additional research and development gaps.
- **Develop protocols for international interactions regarding NEO impacts outside of U.S. territory.** Prior to any NEO crisis, decision-making and communications protocols should be created to guide the transmission of notifications and warnings through multilateral and bilateral diplomatic, scientific, and emergency management channels, as well as through the media. Through consultations, coordination, and cooperation the United States would work closely with the international community to address the risks and dangers of any potential NEO threats.

Conclusion

As with other low-probability, high-consequence hazards, potential NEO impacts pose a significant and complex challenge. This Strategy is a step in addressing the myriad challenges of managing and reducing the risks posed by both large and small NEOs. The seven high-level goals and associated objectives outlined in this Strategy support a collaborative and Federally-coordinated approach to developing effective policies, practices, and procedures for decreasing the Nation's vulnerabilities associated with the NEO impact hazard.

DEFENDING PLANET EARTH
NEAR-EARTH-OBJECT SURVEYS AND HAZARD MITIGATION STRATEGIES

Committee to Review Near-Earth-Object Surveys and Hazard Mitigation Strategies

Space Studies Board

Aeronautics and Space Engineering Board

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Preface

The Consolidated Appropriations Act, 2008,[1] required NASA to ask the National Research Council (NRC) to conduct a study of near-Earth object (NEO) surveys and hazard mitigation strategies. Near-Earth objects orbit the Sun and approach or cross Earth's orbit. In a June 2, 2008, letter, James L. Green, director, Planetary Science Division, NASA, and Craig Foltz, acting director, Astronomical Sciences Division, National Science Foundation (NSF), wrote to Lennard Fisk, then chair of the Space Studies Board, requesting that the Space Studies Board, in cooperation with the Aeronautics and Space Engineering Board, conduct a two-part study to address issues in the detection of potentially hazardous NEOs and approaches to mitigating identified hazards (see Appendix B). The ad hoc Committee to Review Near-Earth Object Surveys and Hazard Mitigation Strategies consisted of the Steering Committee, the Survey/Detection Panel, and the Mitigation Panel.

The statement of task required the committee to include an assessment of the costs of various alternatives, using independent cost estimating. Options that blend the use of different facilities (ground- and space-based) or involve international cooperation were considered. Each study phase resulted in a report to be delivered on the schedule provided below. Key questions addressed during each phase of the study are the following:

Task 1: NEO Surveys

What is the optimal approach to completing the NEO census called for in the George E. Brown, Jr. Near-Earth Object Survey section of the 2005 NASA Authorization Act[2] to detect,[3] track, catalogue, and characterize the physical characteristics of at least 90 percent of potentially hazardous NEOs larger than 140 meters in diameter by the end of year 2020? Specific issues to be considered include, but are not limited to, the following:

- What observational, data-reduction, and data-analysis resources are necessary to achieve the Congressional mandate of detecting, tracking, and cataloguing the NEO population of interest?

[1]Consolidated Appropriations Act, 2008 (Public Law 110-161), Division B—Commerce, Justice, Science, and Related Agencies Appropriations Act, 2008, December 26, 2007.

[2]National Aeronautics and Space Administration Authorization Act of 2005 (Public Law 109-155), January 4, 2005, Section 321, George E. Brown, Jr. Near-Earth Object Survey Act.

[3]The committee notes that the statement of task includes the term "detect," which includes spotting asteroids that have previously been discovered. The committee therefore uses the more appropriate term "discover" to refer to the locating of previously unknown objects.

- What physical characteristics of individual objects above and beyond the determination of accurate orbits should be obtained during the survey to support mitigation efforts?
- What role could be played by the National Science Foundation's Arecibo Observatory in characterizing these objects?
- What are possible roles of other ground- and space-based facilities in addressing survey goals, e.g., potential contributions of the Large Synoptic Survey Telescope (LSST) and the Panoramic Survey Telescope and Rapid Response System (Pan STARRS)?

Task 2: NEO Hazard Mitigation

What is the optimal approach to developing a deflection[4] capability, including options with a significant international component? Issues to be considered include, but are not limited to, the following:

- What mitigation strategy should be followed if a potentially hazardous NEO is identified?
- What are the relative merits and costs of various deflection scenarios that have been proposed?

NASA and NSF requested an initial report for the first task no later than September 30, 2009. The committee delivered its interim report,[5] containing only findings but no recommendations, in early August 2009.

As indicated in Task 1 above, Congress charged the committee to recommend ways to discover and (partially) characterize 90 percent of NEOs exceeding 140 meters in diameter by the year 2020 (smaller objects are not discarded, once found). However, during its first meeting, the committee was explicitly asked by congressional staff to consider whether or not the congressionally established discovery goals should be modified.

[4]The committee interprets "deflection" to mean "orbit change."

[5]National Research Council, 2009, *Near-Earth Object Surveys and Hazard Mitigation Strategies: Interim Report*, The National Academies Press, Washington, D.C.

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Summary

The United States spends about $4 million annually searching for near-Earth objects (NEOs), according to NASA.[1] The goal is to detect those that may collide with Earth. The funding helps to operate several observatories that scan the sky searching for NEOs, but, as explained below, it is insufficient to detect the majority of NEOs that may present a tangible threat to humanity. A smaller amount of funding (significantly less than $1 million per year) supports the study of ways to protect Earth from such a potential collision ("mitigation").

Congress established two mandates for the search for NEOs by NASA. The first, in 1998 and now referred to as the Spaceguard Survey, called for the agency to discover 90 percent of NEOs with a diameter of 1 kilometer or greater within 10 years. An object of this limiting size is considered by many experts to be the minimum that could produce global devastation if it struck Earth. NASA is close to achieving this goal and should reach it within a few years. However, as the recent (2009) discovery of an approximately 2- to 3-kilometer-diameter NEO demonstrates, there are still large objects to be detected.

The second mandate, established in 2005, known as the George E. Brown, Jr. Near-Earth Object Survey Act,[2] called for NASA to detect 90 percent of NEOs 140 meters in diameter or greater by 2020. As the National Research Council's (NRC's) Committee to Review Near-Earth Object Surveys and Hazard Mitigation Strategies noted in its August 2009 interim report (NRC, 2009):

> **Finding: Congress has mandated that NASA discover 90 percent of all near-Earth objects 140 meters in diameter or greater by 2020. The administration has not requested and Congress has not appropriated new funds to meet this objective. Only limited facilities are currently involved in this survey/discovery effort, funded by NASA's existing budget.**

[1] "NEO" denotes "near-Earth object," which has a precise technical meaning but can be usefully thought of as an asteroid or comet whose orbit approaches Earth's orbit to within about one-third the average distance of Earth from the Sun. These objects are considered to be the only ones potentially capable of striking Earth, at least for the next century, except for comets that can enter the inner solar system from the outer system through the "slingshot" gravitational action of Jupiter.

[2] National Aeronautics and Space Administration Authorization Act of 2005 (Public Law 109-155), January 4, 2005, Section 321, George E. Brown, Jr. Near-Earth Object Survey Act.

Finding: The current near-Earth object surveys cannot meet the goals of the 2005 George E. Brown, Jr. Near-Earth Object Survey Act directing NASA to discover 90 percent of all near-Earth objects 140 meters in diameter or greater by 2020.

THE SURVEY AND DETECTION OF NEAR-EARTH OBJECTS

The charge from Congress to the NRC committee was stated as two tasks (see the Preface for the full statement of task). The first asks for the "optimal approach" to completing the George E. Brown, Jr. Near-Earth Object Survey. The second asks for the same approach to developing a capability to avert an NEO-Earth collision and for options that include "a significant international component."

The committee concluded that there is no way to define "optimal" in this context in a universally acceptable manner: there are too many variables involved that can be both chosen and weighted in too many plausible ways. Recognizing this fact, the committee first took a broad look at all aspects of the hazards to Earth posed by NEOs and then decided on responses to the charge. The body of this report contains extensive discussions of these many issues. This summary concentrates on responses to the charge and at the end provides a few comments on some of the other main conclusions drawn from the report.

Regarding the first task of its charge, the committee concluded that it is infeasible to complete the NEO census mandated in 2005 on the required time scale (2020), in part because for the past 5 years the administration has requested no funds, and the Congress has appropriated none, for this purpose. The committee concludes that there are two primary options for completing the survey:

Finding: The selected approach to completing the George E. Brown, Jr. Near-Earth Object Survey will depend on nonscientific factors:

- **If the completion of the survey as close as possible to the original 2020 deadline is considered more important, a space mission conducted in concert with observations using a suitable ground-based telescope and selected by peer-reviewed competition is the better approach. This combination could complete the survey well before 2030, perhaps as early as 2022 if funding were appropriated quickly.**
- **If cost conservation is deemed more important, the use of a large ground-based telescope is the better approach. Under this option, the survey could not be completed by the original 2020 deadline, but it could be completed before 2030. To achieve the intended cost-effectiveness, the funding to construct the telescope must come largely as funding from non-NEO programs.**

Multiple factors will drive the decision on how to approach completion of this survey. These factors include, but are not limited to, the perceived urgency for completing the survey as close as possible to the original 2020 deadline, the availability of funds to complete the survey, and the acceptability of the risk associated with the construction and operation of various ground- and space-based options.

Of the ground-based options, the Large Synoptic Survey Telescope (LSST) and the Panoramic Survey Telescope and Rapid Response System, mentioned in the statement of task, and the additional options submitted to the committee in response to its public request for suggestions during the beginning of this study, the most capable appears to be the LSST. The LSST is to be constructed in Chile and has several science missions as well as the capability of observing NEOs. Although the primary mirror for the LSST has been cast and is being polished, the telescope has not been fully funded and is pending prioritization in the astronomy and astrophysics decadal survey of the NRC that is currently underway.

Unless unexpected technical problems interfere, a space-based option should provide the fastest means to complete the survey. However, unlike ground-based telescopes, space options carry a modest launch risk and a more limited lifetime: ground-based telescopes have far longer useful lifetimes and could be employed for continued NEO surveys and for new science projects. (Ground-based telescopes generally have an annual operating cost that is approximately 10 percent of their design and construction costs.)

The committee notes that objects smaller than 140 meters in diameter are also capable of causing significant damage to Earth. The best-known case from recent history is the 1908 impact of an object at Tunguska in the Siberian wilderness that devastated more than 2,000 square kilometers of forest. It has been estimated that the size of this object was on the order of approximately 70 meters in diameter, but recent research indicates that it could have been substantially smaller (30 to 50 meters in diameter), with much of the damage that it caused being due to shock waves from the explosion of the object in Earth's atmosphere. (See, e.g., Chyba et al., 1993; Boslough and Crawford, 1997, 2008.) The committee strongly stresses that this new conclusion is preliminary and must be independently validated. Since smaller objects are more numerous than larger ones, however, this new result, if correct, implies an increase in the frequency of such events to approximately once in three centuries.

All told, the committee was struck by the many uncertainties that suffuse the subject of NEOs, including one other related example: Do airbursts from impactors in this size range over an ocean cause tsunamis that can severely damage a coastline? This uncertainty and others have led the committee to the following recommendation:

Recommendation: Because recent studies of meteor airbursts have suggested that near-Earth objects as small as 30 to 50 meters in diameter could be highly destructive, surveys should attempt to detect as many 30- to 50-meter-diameter objects as possible. This search for smaller-diameter objects should not be allowed to interfere with the survey for objects 140 meters in diameter or greater.

In all cases, the data-reduction and data-analysis resources necessary to achieve the congressional mandate would be covered by the survey projects themselves and by a continuation of the current funding of the Smithsonian Astrophysical Observatory's Minor Planet Center, as discussed in the report.

CHARACTERIZATION AND THE ARECIBO AND GOLDSTONE OBSERVATORIES

Obtaining the orbits and the physical properties of NEOs is known as characterization and is primarily needed to inform planning for any active defense of Earth. Such defense would be carried out through a suitable attack on any object predicted with near certainty to otherwise collide with Earth and cause significant damage. The apparently huge variation in the physical properties of NEOs seems to render infeasible the development of a comprehensive inventory through in situ investigations by suitably instrumented spacecraft: the costs would be truly astronomical. A spacecraft reconnaissance mission might make good sense to conduct on an object that, without human intervention, would hit Earth with near certainty. Such a mission would be feasible provided there was sufficient warning time for the results to suitably inform the development of an attack mission to cause the object to miss colliding with Earth.

In addition to spacecraft reconnaissance missions as needed, the committee concluded that vigorous, ground-based characterization at modest cost is important for the NEO task. Modest funding could support optical observations of already-known and newly discovered asteroids and comets to obtain some types of information on this broad range of objects, such as their reflectivity as a function of color, to help infer their surface properties and mineralogy, and their rotation properties. In addition, the complementary radar systems at the Arecibo Observatory in Puerto Rico and the Goldstone Solar System Radar in California are powerful facilities for characterization within their reach in the solar system, a maximum of about one-tenth of the Earth-Sun distance. Arecibo—which has a maximum sensitivity about 20-fold higher than Goldstone's but does not have nearly as good sky coverage as Goldstone—can, for example, model the three-dimensional shapes of (generally very odd-shaped) asteroids and estimate their surface characteristics, as well as determine whether an asteroid has a (smaller) satellite or satellites around it, all important to know for planning active defense. Also, from a few relatively closely spaced (in time) observations, radar can accurately determine the orbits of NEOs, which has the advantage of being able to calm public fears quickly (or possibly, in some cases, to show that they are warranted).

Finding: The Arecibo and Goldstone radar systems play a unique role in the characterization of NEOs, providing unmatched accuracy in orbit determination and offering insight into size, shape, surface structure, and other properties for objects within their latitude coverage and detection range.

Recommendation: Immediate action is required to ensure the continued operation of the Arecibo Observatory at a level sufficient to maintain and staff the radar facility. Additionally, NASA and the National Science Foundation should support a vigorous program of radar observations of NEOs at Arecibo, and NASA should support such a program at Goldstone for orbit determination and the characterization of physical properties.

For both Arecibo and Goldstone, continued funding is far from assured, not only for the radar systems but for the entire facilities. The incremental annual funding required to maintain and operate the radar systems, even at their present relatively low levels of operation, is about $2 million at each facility (see Chapter 4). The annual funding for Arecibo is approximately $12 million. Goldstone is one of the three deep-space communications facilities of the Deep Space Network, and its overall funding includes additional equipment for space communications.

MITIGATION

"Mitigation" refers to all means of defending Earth and its inhabitants from the effects of an impending impact by an NEO. Four main types of defense are discussed in this report. The choice of which one(s) to use depends primarily on the warning time available and on the mass and speed of the impactor. The types of mitigation are these:

1. *Civil defense.* This option may be the only one feasible for warning times shorter than perhaps a year or two, and depending on the state of readiness for applying an active defense, civil defense may be the only choice for even longer times.
2. *"Slow-push" or "slow-pull" methods.* For these options the orbit of the target object would be changed so that it avoided collision with Earth. The most effective way to change the orbit, given a constraint on the energy that would be available, is to change the velocity of the object, either in or opposite to the direction in which it is moving (direct deflection—that is, moving the object sideways—is *much* less efficient). These options take considerable time, on the order of decades, to be effective, and even then they would be useful only for objects whose diameters are no larger than 100 meters or so.
3. *Kinetic impactors.* In these mitigation scenarios, the target's orbit would be changed by the sending of one or more spacecraft with very massive payload(s) to impact directly on the target at high speed in its direction, or opposite to its direction, of motion. The effectiveness of this option depends not only on the mass of the target but also on any net enhancement resulting from material being thrown out of the target, in the direction opposite to that of the payload, upon impact.
4. *Nuclear explosions.* For nontechnical reasons, this would likely be a last resort, but it is also the most powerful technique and could take several different forms, as discussed in the report. The nuclear option would be usable for objects up to a few kilometers in diameter.

For larger NEOs (more than a few kilometers in diameter), which would be on the scale that would inflict serious global damage and, perhaps, mass extinctions, there is at present no feasible defense. Luckily such events are exceedingly rare, the last known being about 65 million years ago.

Of the foregoing options, only kinetic impact has been demonstrated (by way of the very successful Deep Impact spacecraft that collided with comet Tempel-1 in July 2006). The other options have not advanced past the conceptual stage. Even Deep Impact, a 10-kilometer-per-second impact on a 6-kilometer-diameter body, was on a scale far lower than would be required for Earth defense for an NEO on the order of 100 meters in diameter, and it impacted on a relatively large—and therefore easier to hit—object.

Although the committee was charged in its statement of task with determining the "optimal approach to developing a deflection capability," it concluded that work in this area is relatively new and immature. The committee therefore concluded that the "optimal approach" starts with a research program.

FURTHER RESEARCH

Struck by the significant unknowns in many aspects of NEO hazards that could yield to Earth-based research, the committee recommends the following:

Recommendation: The United States should initiate a peer-reviewed, targeted research program in the area of impact hazard and mitigation of NEOs. Because this is a policy-driven, applied program, it should not be in competition with basic scientific research programs or funded from them. This research program should encompass three principal task areas: surveys, characterization, and mitigation. The scope should include analysis, simulation, and laboratory experiments. This research program does not include mitigation space experiments or tests that are treated elsewhere in this report.

NATIONAL AND INTERNATIONAL COOPERATION

Responding effectively to hazards posed by NEOs requires the joint efforts of diverse institutions and individuals, with organization playing a key role. Because NEOs are a global threat, efforts to deal with them could involve international cooperation from the outset. (However, this is one area in which one nation, acting alone, could address such a global threat.) The report discusses possible means to organize, both nationally and internationally, responses to the hazards posed by NEOs. Arrangements at present are largely ad hoc and informal here and abroad, and they involve both government and private entities.

The committee discussed ways to organize the national community to deal with the hazards of NEOs and also recommends an approach to international cooperation:

Recommendation: The United States should take the lead in organizing and empowering a suitable international entity to participate in developing a detailed plan for dealing with the NEO hazard.

One major concern with such an organization, especially in the area of preparing for disasters, is the maintenance of attention and morale, given the expected exceptionally long intervals between harmful events. Countering the tendency to complacency would be a continuing challenge. This problem would be mitigated if, for example, the civil defense aspects were combined in the National Response Framework with those for other natural hazards.

RECENT NEAR-EARTH-OBJECT-RELATED EVENTS

The U.S. Department of Defense, which operates sensors in Earth orbit capable of detecting the high-altitude explosion of small NEOs, has in the past shared this information with the NEO science community. The committee concluded that this data sharing is important for understanding issues such as the population size of small NEOs and the hazard that they pose. This sharing is also important for validating airburst simulations, characterizing the physical properties of small NEOs (such as their strength), and assisting in the recovery of meteorites.

Recommendation: Data from NEO airburst events observed by the U.S. Department of Defense satellites should be made available to the scientific community to allow it to improve understanding of the NEO hazards to Earth.

In 2008, Congress passed the Consolidated Appropriations Act[3] calling for the Office of Science and Technology Policy to determine by October 2010 which agency should be responsible for conducting the NEO survey and detection and mitigation program. Several agencies are possible candidates for such a role.

During its deliberations the committee learned of several efforts outside the United States to develop spacecraft to search for categories of NEOs. In particular, Canada's Near-Earth-Object Surveillance Satellite, or NEOSSat,

[3]Consolidated Appropriations Act, 2008 (Public Law 110-161), Division B—Commerce, Justice, Science, and Related Agencies Appropriations Act, 2008, December 26, 2007.

and Germany's AsteroidFinder are interesting and capable small-scale missions that will detect a small percentage of specific types of NEOs, those primarily inside Earth's orbit. These spacecraft will not accomplish the goals of the George E. Brown, Jr. Near-Earth Object Survey Act of 2005. However, they highlight the fact that other countries are beginning to consider the NEO issue seriously. Such efforts also represent an opportunity for future international cooperation and coordination in the search for potentially hazardous NEOs. In addition, the committee was impressed with the European Space Agency's early development of the Don Quijote spacecraft mission, which would consist of an observing spacecraft and a kinetic impactor. This mission, though not funded, would have value for testing a mitigation technique and could still be an opportunity for international cooperation in this area.

Finally, the committee points out a current estimate of the long-term average annual human fatality rate from impactors: slightly under 100 (Harris, 2009). At first blush, one is inclined to dismiss this rate as trivial in the general scheme of things. However, one must also consider the extreme damage that could be inflicted by a single impact; this presents the classic problem of the conflict between "extremely important" and "extremely rare." The committee considers work on this problem as insurance, with the premiums devoted wholly toward preventing the tragedy. The question then is: What is a reasonable expenditure on annual premiums? The committee offers a few possibilities for what could perhaps be accomplished at three different levels of funding (see Chapter 8); it is, however, the political leadership of the country that determines the amount to be spent on scanning the skies for potential hazards and preparing our defenses.

REFERENCES

Boslough, M., and D. Crawford. 2008. Low-altitude airbursts and the impact threat. International Journal of Impact Engineering 35:1441-1448.

Boslough, M.B.E., and D.A. Crawford. 1997. Shoemaker-Levy 9 and plume-forming collisions on Earth. Near-Earth Objects, the United Nations International Conference: Proceedings of the International Conference held April 24-26, 1995, in New York, N.Y. (J.L. Remo, ed.). Annals of the New York Academy of Sciences 822:236-282.

Chyba, C.F., P.J. Thomas, and K.J. Zahnle. 1993. The 1908 Tunguska explosion—Atmospheric disruption of a stony asteroid. Nature 361:40-44.

Harris, A.W., Space Science Institute. 2009. The NEO population, impact risk, progress of current surveys, and prospects for future surveys, presentation to the Survey/Detection Panel of the NRC Committee to Review Near-Earth Object Surveys and Hazard Mitigation Strategies, January 28-30, 2009.

NRC (National Research Council). 2009. *Near-Earth Object Surveys and Hazard Mitigation Strategies: Interim Report.* The National Academies Press, Washington, D.C., available at http://www.nap.edu/catalog.php?record_id=12738, pp. 1-2.

YOUTH VIOLENCE: WHAT WE NEED TO KNOW

Report of the Subcommittee on Youth Violence of the Advisory Committee to the Social, Behavioral and Economic Sciences Directorate, National Science Foundation

February 1 and 2, 2013

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Report of the Subcommittee on Youth Violence of the Advisory Committee to the Social, Behavioral and Economic Sciences Directorate, National Science Foundation[1]

INTRODUCTION

Rampage shootings in schools differ in dramatic ways from "street violence" commonly associated with urban areas. School rampages typically occur in stable, close knit, low crime and very small rural towns and less often in exurbs. The shooter generally is a white adolescent male, with no recorded history of disciplinary problems, and no documented history of medical treatment for mental disorders. The shooter is often at the high end of the intelligence and academic achievement spectrum, but lacking in the badges of athletic ability and other social attributes that are highly valued by peers.

Urban "street shooters," by contrast, are found in densely populated areas with high crime levels, low levels of social trust, and are rarely high academic performers. High poverty neighborhoods, often plagued by illicit drug and gun markets, are particularly at risk for youth violence. Although rampage shootings are rare, they are devastating because of the randomness of the victims. Urban bloodshed, which often unfolds between known antagonists, is far more ubiquitous and hence exacts a terrible toll on families and communities destabilized by persistent violence.

When gun violence of either kind occurs, it is only natural for citizens and policymakers to seek to identify "the cause." Although tragic events like the Newtown shooting are caused by multiple risk factors, three main factors have been discussed—access to guns, exposure to violent media, and mental health. We have a body of reliable evidence and a stable of theories to explain youth violence that have emerged from decades of research, including research supported by the National Science Foundation, the National Institutes of Health, the National Research Council, and other federal agencies.

Particularly important within this corpus is research documenting risk factors for aggressive and violent behavior, especially poor parenting practices, households under economic stress, rejection from adolescent peer groups, deteriorating mental health, and intensive exposure to the fantasy world of online games that glorify violence and desensitize the viewer to its consequences. Particularly damaging is the fusion of masculinity and violence in popular culture that is consumed by adolescents in all corners of the country. The interplay, or additive nature, of these risk factors is important to consider because no single risk factor provides us with a comprehensive understanding.

Adolescents in low crime communities who believe themselves to be "social losers" see a solution in enacting dangerous, anti-social behavior because they will be able to replace a damaged identity with a new and more satisfying one: the notorious, dangerous, hyper-masculine anti-hero. Adolescents in high crime communities absorb the "code of the streets," which requires individuals and groups to project – and sometimes to enact – a tough, violence-prone image in order to ward off threats they encounter in ordinary interaction.

Though we know a great deal about the etiology of youth violence, the changing online and gaming landscape, state level variation in access to weapons, and evolving nature of family structure, among other changes, require a forward looking research agenda to examine these changes and new challenges. Our understanding of the social relations within schools that can help youth to avoid violence as they contend with peer conflict, to develop social trust that governs levels of interpersonal conflict, and to come forward in the presence of threats, is underdeveloped. Advances in the study of large-scale datasets offer the possibility of learning about youth culture and "cyberbullying" from publically available social media that have become important forms of youth-to-youth communication. Additionally, while civil liberties implications will require further study, the potential for online intervention exists, which may prevent both cyberbullying and violent behavior.

In the sections that follow, we focus on key areas for future research. These suggestions are supported by the research summarized in Appendix A, where the contributing members of this advisory panel have described "what we know."

[1] Co-Chair: Brad J. Bushman (The Ohio State University & VU University, Amsterdam, the Netherlands); Co-Chair: Katherine Newman (Johns Hopkins University); Participants: Sandra Calvert (Georgetown University), Geraldine Downey (Columbia University), Mark Dredze (Johns Hopkins University), Michael Gottfredson (University of Oregon), Nina G. Jablonski (Pennsylvania State University), Ann Masten (University of Minnesota), Calvin Morrill (University of California, Berkeley), Daniel B. Neill (Carnegie Mellon University), Daniel Romer (University of Pennsylvania), Daniel Webster (Johns Hopkins University)

YOUTH VIOLENCE AND EXPOSURE TO MEDIA VIOLENCE

Public debate on the link between violent media and aggressive and violent behavior can be contentious, especially in the wake of a shooting rampage. Anders Breivik, who murdered 69 youth in Norway, claims he used the video game "Modern Warfare 2" as a military simulator to help him practice shooting people. Similarly, Eric Harris and Dylan Klebold, who murdered 13 fellow students in Colorado, claimed they used the violent video game "Doom" to practice their shooting rampage. Violent video games have also been implicated in other school shootings (e.g., Bethel, Alaska; Paducah, Ky.; Jonesboro, Ark.).

It is not possible to know whether playing violent games *caused* Breivik, Harris and Klebold (or any other killer) to shoot their victims. However, a comprehensive review of more than 381 effects from studies involving more than 130,000 participants around the world shows that violent video games increases aggressive thoughts, angry feelings, physiological arousal (e.g., heart rate, blood pressure), and aggressive behavior. Violent games also decrease helping behavior and feelings of empathy for others. A meta-analysis of 26 studies involving 13,661 participants found that violent media exposure is also significantly linked to violent behavior (e.g. punching, beating, choking others), although the effects are smaller than for aggressive behavior. Yet, additional research is still needed to address some important questions about media impacts, particularly given the rapid evolution of the technology that is flooding young consumers with ever more realistic depictions of violent behavior on screen.

At-risk Individuals: Some individuals are more at risk for the effects of violent media than are others. We know very little about the differential impact of violent media on certain subpopulations.

- Are youth with certain mental illnesses more or less sensitive to violent media?
- Are males with extremely traditionally masculine gender roles particularly at risk for violent media effects?
- Very young children may be especially at risk for negative outcomes after violent media exposure. How much and what kinds of violent media do young children (< 8 years) consume and how does that exposure impact their development?
- How does playing newer kinds of aggressive games on apps influence children's aggressive thoughts and behaviors?
- The relationship between gaming and depression among adolescents is poorly understood. Are youth becoming depressed because their engagement in gaming is removing them from social interaction and intensifying the feeling of isolation? Or are youth who are already socially isolated more attracted to gaming to begin with? Do virtual relations "crowd out" actual social bonds?

Fantasy-reality Distinctions and Transfer to Real-life Settings: The distinction between fantasy and reality is blurry for very young children. Older youth could be susceptible to such problems as well.

- What kinds of relationships do youth form with onscreen characters? Do youth perceive these fantasy figures as friends, role models (heroes and anti-heroes), or as embodying themselves? Do these different kinds of relationships with media characters differentially affect the likelihood of aggressive outcomes after media exposure?
- The relationship between fantasy behavior (shooting on screen) and aggressive behavior is well understood. In what circumstances, though, does this fantasy behavior transfer to violent, criminal behavior among youth? For example, what is the relationship between violent media consumption and access to or ownership of guns? Are the people who have lethal weapons also those who are fantasizing about their use through online worlds?
- Violent media are becoming progressively more immersive as the technology advances (e.g., high definition, 3-D, surround sound, larger screens, virtual reality). Do more realistic media interfaces make it more difficult for youth to distinguish between fantasy and reality and make it more likely that they will act on what they do or see in media experiences?
- How does the consumption of violent media impact the formation and sustenance of trust? Do children and youth who play aggressive games come to see the world as "mean and scary?" Or are those who are

already distrustful disproportionately attracted to violent media? Or is this relationship bi-directional?

Group Processes: Youth often play aggressive games in groups, sometimes in the same setting. Little is known about how intergroup processes in online and offline settings versus solitary play influence aggressive outcomes.

- How does the impact of violent media differ when online games are played in groups (where the players are "working" side by side), as distributed allies (where players are in teams but not co-located), or as dyads versus playing alone?
- How does competition and collaboration between game players influence aggressive outcomes? Do solitary players team up with other online players, potentially creating allies and friends, or do they compete against them, making them more likely to be perceived as enemies?
- Does group versus solitary interaction around violent media amplify the problems that may be experienced by individuals who suffer from mental illnesses?

Environmental Factors: The media environments of children and youth have increasing amounts of aggressive content delivered by numerous platforms.

- How much aggressive content is in current television programs, films, video games, apps, and music?
- Do consumption patterns of violent media vary by geography (rural, suburban, urban), socioeconomic status (SES), gender, ethnicity, or household composition?
- Youth violence is decreasing while violent video consumption is increasing. Are youth who live in risky environments actually more protected from actual violence because they are indoors consuming media and therefore out of harm's way?
- Rating systems have not kept up with the increasingly violent content of popular media (e.g., PG-13 films contain as much violence today as R-rated films in the past). Ratings systems vary across media platforms and have included age and/or content markers. Because there are not standard ratings across platforms (e.g., R for movies; TV-MA for TV, T for Teen in video games), they are difficult for parents to understand. We need to evaluate the potential benefits of a universal rating system for all media (TV, films, video games, music, apps), with symbols that are more transparent. The PEGI (Pan European Game Information) system, for example, has five age-based ratings (3+, 7+, 12+, 16+, 18+) and six well-recognized symbols for potentially objectionable material (violence, sex, drugs, discrimination, fear, gambling).

Biological Factors: Researchers are beginning to explore the addictive nature of video games, but more research is needed.

- Do video games tap into biological reward systems (like other addicting substances such as drugs and alcohol)? Does group-shared fun while playing video games enhance reward effects? Self-control is important in other addictions. What role does self-control play in the use of video games?
- What is the difference between engagement, which can increase learning, and addiction?
- How do violent media impact brain development and function?

SOCIAL REJECTION AND PEER HIERARCHIES

Most youth who engage in lethal violence have a history of social rejection but are highly concerned about acceptance. However, rejection occurs in various forms and from various sources, and this may have important implications for understanding whether and under what circumstances rejection triggers violence versus other responses.

There is some suggestion that **rampage shooters** have a history of rejection from relatively small and cohesive peer networks that they have sought entry into often through behaviors that peers perceive as socially inept. Urban youth violence often occurs in response to perceived disrespect among **poor urban youth,** whose efforts to assert status within schools and on the street may take the form of highly aggressive behavior. These young men are at particular risk for school failure and dropout as a consequence of exclusionary disciplinary practices enacted to in response to their transgressive behavior. Disengagement from school promotes entry to networks outside of school, including gangs, that may encourage the use of violence to settle disputes.

In schools, how youth define and respond to behavior with peers and adults they find troubling needs to be studied holistically, incorporating violent behavior as a subset of potential responses and assessing how adults (including security guards) help to promote, as well as impede, nonviolent resolution of conflicts. Particularly important in these dynamics are peer/reputational hierarchies, the quality of interpersonal and group relations (e.g. strong as compared with weak ties) in different face-to-face and online spaces, and sex differences in regard to peer conflict. There needs to be more known about how these factors vary demographically across schools and broader contexts (e.g., urban compared with rural settings).

There is significant literature on school climates and cultures of social trust as undergirding, protective factors against violence and conflict. Much of this literature is based on self-reported beliefs and behaviors, but we know less about how trust is actually established and sustained over time, contributing to constructive conflict management that can stem the tide of aggression or violence.

Especially important in these processes may be the quality of adult-youth interaction and the facilitative impact of effective leadership. We need to know more about how security and exclusionary disciplinary regimes relate to social trust and adult-youth interaction, particularly with respect to peer hierarchies and youth conflict practices. Also important is greater knowledge about how off-campus, third parties (e.g., alumni, community members) can facilitate or inhibit the production of social trust in schools.

We know relatively little about how youth seek out help and support from adults when dealing with troubling situations either face-to-face or online. To study these dynamics, we need to expand our methodological toolkit to include comparative studies (across institutional types, from different countries, etc.), and multi-method studies that incorporate fieldwork, surveys, focus groups, and experimental designs.

- Across urban and rural contexts, it will be important to understand how heightened sensitivity to rejection develops and is sustained in youth. How do families, peers, schools, and societal stereotypes foster or moderate sensitivity to rejection? What goals do the use of violence, and especially lethal gun violence, serve among those who use it or plan to use it in response to rejection? Does violence provide a sense of escape from feelings of powerlessness?
- How do individual child characteristics, notably self-regulatory competency, moderate reactions to rejection and promote more adaptive responses to social threat?
- Adolescence is a time of rapid brain development. Understanding the neural basis of social threat and reactions to it is important and needs to be studied, potentially via functional and structural brain imaging.
- Understanding rejection by peers and adults in important settings such as schools—the form it takes in daily life: where, when and why and by whom—and how it interacts with the sensitivity to rejection of the target is important.
- Among marginalized youth, what kinds of relationships might reduce risk of extreme reactions to rejection, promote help seeking, and interrupt plans for revenge that might involve lethal violence? How do youth learn to seek help?
- Is evidence of sensitivity to rejection a useful indicator of heightened risk for extreme behavior, given that it is implicated in many types of disorders and has links with suicidal risk as well as to violence?
- How do youth handle peer conflict across different contexts? What social and institutional conditions (strong and weak ties) facilitate nonviolent as compared to violent responses?
- How is social trust produced in schools and what effects do different security regimes have on it?
- A number of rampage shooters have been college students or dropouts. Understanding what contributes to risk of lethal violence among college age students is important because they have aged out of adolescent peer groups and may be even more difficult to identify as a result.

COMPARATIVE CRIMINOLOGY

More research is required to discover the similarities and differences between rampage shootings or mass killings and other, more common forms of violent crimes and delinquencies. How the characteristics of the incidents themselves and the backgrounds and characteristics of the individuals involved differ from other types of aggressive, violent and weapon-involved crimes would be useful (e.g., the extent of planning, the relationship between levels of self-control or self-regulation and violence, the solitary or group nature of the offending, and the time, place, and method of occurrence).

The connection between self-destructive behavior and ideation and rampage shootings needs more study. Many rampage shootings seem characterized by both suicidal and homicidal ideation. What are the precursors of such ideation and how do these forms of ideation translate into action? How does this form of both suicidal and homicidal ideation differ from either form alone?

The news media cover rampage shootings heavily, but very little is known about the effects of such coverage on adolescents and young adults. Does such coverage increase thoughts of imitation, as it seems to in suicide? Is it more likely to influence thoughts of imitation among youth who already have thoughts of suicide and homicide? There is evidence that school shootings encourage (mainly false) reports of school bombings, but do some youth use such events as a way to achieve notoriety, as has been suggested in sensational coverage of suicides?

Given the established relationship between age and violence (with the peak age falling at late adolescence or early adulthood), there is a need to know more about:

- the relationship between suicide and homicide, and the intersection between the two;
- whether there are differential effects of self-control or self-regulation for the development of suicidal and homicidal ideation; and
- how school and other social institutions can create enhanced social efficacy and bonding effects for students, and how differences in school climate can reduce levels of crime and violence, particularly during adolescence.

FAMILY INFLUENCES ON VIOLENT BEHAVIOR

There is a large body of research suggesting that families are involved in different ways in the development and prevention of antisocial and violent behavior. Evidence also indicates that numerous aspects of family influence on children are malleable through intervention. Yet there are many gaps in knowledge about the roles of families in violent behavior that could inform policy and interventions to reduce risks for youth violence and promote resilience among high-risk children.

Research is needed on the role of early environments, both prenatal and post-natal, for neurobehavioral development related to risk, vulnerability and the protective factors strongly associated with the later development of violence in children. These include the effects of physiological stress on the development of executive functions and stress-regulation systems, and the effects of parenting on brain development and socialization of behaviors that predict violence. Research is also needed on the best intervention strategies for reducing stress in pregnant mothers and helping families prepare their children for kindergarten and gain access to high-quality child care and early learning experiences for children.

Monitoring by parents is implicated in violence development and prevention. Research is needed on the best strategies and developmental timing for parents to promote positive child uses of media, safe behavior around firearms, and healthy connections to pro-social peers, activities, and mentors. Because parents may not appreciate their influence on older youth, research is needed on educating parents about staying involved with their adolescent children.

Large, new studies planned on child development, such as the National Children's Study, should be urged to include survey items and methods that will inform these questions. Important data on the following questions can also be gleaned from existing longitudinal datasets.

- How do prenatal or early post-natal exposures to stress or trauma and environmental toxins alter the risk for violence later in development?
- Do interventions that improve self-control skills reduce youth violence? What are the most cost-effective strategies and timing for these interventions?
- What are the most effective interventions for educating parents about effective and age-appropriate ways to monitor child behavior, including their media use, peer interactions, and school involvement?
- High-risk families (e.g., unstable, homeless, with incarcerated parents or violence in the home) contribute disproportionately to violence in inner-city neighborhoods. What interventions make a difference in interrupting this cycle?
- Is the foster care system a "violence feeder system" in that young people who age out are particularly vulnerable to crime, domestic violence, and homelessness? What can be done to address the special needs of children in foster care?
- What kind of mental health and community resources are needed for families concerned about a child who demonstrates signs of preoccupation with violence, violent media, or violent behavior?
- Do large-scale interventions that aim to increase academic achievement (e.g., Race to the Top) also mitigate youth violence?

DATA MINING FOR PREDICTION AND INTERDICTION OF SHOOTINGS

Online data sources may have multiple potential uses for understanding, predicting, and preventing violence. These include but are not limited to (a) tracking population-level demographic and geographic trends in risk behaviors, (b) geographic "hot spot" prediction for urban violence, (c) "risk stratification" to identify–with appropriate safeguards–those who are signaling violent intentions and who would benefit from early intervention, (d) facilitating the reporting of planned or potential attacks by others (e.g., friends and classmates) with knowledge of impending events, and (e) understanding bullying behavior and its role in influencing violence. Each of these potential applications should be explored further to analyze its potential impact (benefits and risks) and feasibility of implementation. To be successful, research in any of these domains must address the potential biases and limitations of these online data sources. Clearly, it will also be necessary to address and mitigate serious risks to privacy.

Many of the methodological tools needed for these analyses (such as anomalous pattern detection, predictive modeling, sentiment analysis, and social network analysis) have already been developed in the fields of machine learning, data mining, computational linguistics and statistics. These existing tools should be integrated into systems which can address the challenges listed above.

Additionally, an interdisciplinary approach is needed to understand and address the gaps between the current methodological state of the art and what methods are actually needed to fully address these problems. For example, we may need more work on "deeper" natural language analysis to identify the intent of online text (e.g., distinguishing an actionable threat from other negative sentiments) and to infer user characteristics (e.g., location, age group, gender, mental illness). Similarly, we may need to develop better algorithms for learning and inference using complex data (with many types of information, multiple network and relational structures, multilingual data, etc.) and for detecting relevant, anomalous patterns in such data.

The focus should be on developing tools that can be broadly used, and framing methodological questions (e.g., early event detection and prediction) that generalize across multiple domains. The solutions to such problems would then advance the science, for example, of language understanding, massive data analysis, and pattern discovery, as well as potentially preventing or reducing youth violence. Open questions for further research include:

- Can Twitter and other online data sources (e.g., gaming forums) be used to track the demographic and geographic trends in consumption of violent media and correlate these with other indicators (e.g., use of violent language), accounting for demographic and other biases in these data sources?
- Can new data sources (e.g., online data such as Twitter or specialized systems to monitor, identify, and

track graffiti) be integrated with currently used law enforcement and 911 call data to enhance the timeliness and accuracy of prediction ("where" and "when" street shootings are likely to occur, as well as predicting "who" may be the perpetrators and victims–e.g., which gangs are likely to be involved)?

- Can we identify "risk factors" for individual mass shooters which are both (a) predictive and (b) can be reliably extracted from online data, such as latent user attributes (location, age, gender), socioeconomics (poverty), family (divorce, single parents), access to guns, expressions of violent sentiments, intentions, and plans, signs of certain mental illnesses, attitudes toward violence, social relationships (marginality, social rejection, encouragement by peer groups), etc.? Can administrative data be integrated with online data for more accurate risk predictions?
- Can we accurately model both the probability that these risk factors are present given noisy, unstructured online data, and estimate the overall risk of violent action given these factors? Given that these are very rare events and that the data are both limited and noisy, it is likely that an appropriate role of such monitoring would be to enable subpopulation-level early interventions among high-risk groups (e.g., availability of mental health counseling).
- Is there a role for monitoring online data in early warning and rapid response to mass shootings, similar to its role in disaster response more generally, to inform law enforcement and potential victims?
- Can we understand and develop a framework to inform and encourage best practices of online interventions at various stages leading up to a potential mass shooting (teachers providing online, positive influences; availability of mental health counseling; mitigating negative impacts of social rejection; facilitating reporting of potential threats and at-risk individuals in need of help)?
- Can online data from occurrences of "cyberbullying" be captured and analyzed to understand the causes, processes, and impacts of bullying behavior more generally? What are the similarities and differences between online and offline bullying behavior (e.g., online anonymity and greater spread of embarrassing information), and how do these change the impacts on victims of bullying?
- What are the risks of mining online data to individual privacy and how can these risks be mitigated or eliminated? For example, when are aggregated counts and de-identified data sufficient to study violent behavior? On the other hand, under what conditions is it acceptable to use online data to intervene at the individual level (which may not be possible without identifying at-risk individuals)? How are these privacy challenges affected by (a) data from children, (b) the role of parents and schools, and (c) public perceptions (e.g., it may not be considered acceptable to mine certain data even if those data are publicly available)?

GUN POLICY AND YOUTH

More than 80 percent of homicides involving victims or perpetrators ages 15-24 were committed with firearms, as were virtually all mass killings committed by youthful perpetrators. Due to developmental and social conditions mentioned elsewhere, it is critical to reduce access to firearms to youth, especially those with a history of delinquency, crime involvement, and certain mental illnesses.

The vast majority of youthful handgun offenders acquired their handguns from "street or black market" sources or from friends or family. But little is known about how the underground gun market functions for youth. Whereas social networks may be key to gun acquisition for urban youth in disadvantaged neighborhoods, youth who use guns to commit suicide or carry out rampage shootings typically access guns from parents or close family members. Thus, the following are key questions that should be addressed:

- What is the relationship between minimum age or youth-focused firearm restrictions (e.g., safe storage) and youth-perpetrated violence? Is the effectiveness of these laws dependent upon other gun regulations designed to deter the diversion of guns to prohibited persons (e.g., universal background checks, licensing provisions)?
- How do penalties and illegal gun suppression tactics by police affect illegal gun carrying and use by youth? More studies of gun law effects on youth violence are needed in which intervention and comparison jurisdictions have similar levels and trends in youth gun violence before they experiment with new gun poli-

cies. We need studies of this kind to establish causal inference in the effectiveness of policies.

- How do factors such as price, trust in gun sellers, gun characteristics (new/used), and perceived risks of prosecution affect youth illegal acquisition by youth of firearms? How easily do youth adapt to interdiction strategies (e.g., access sources outside of state if state gun laws reduce gun diversions)?
- Do youth steal guns opportunistically or target homes, stores, or individuals for gun theft? How important are stolen guns to the underground gun market where youth acquire guns? How commonly do youth discard guns, lose them to theft, sell them, or have them confiscated by parents, police, or school authorities?
- How do youth access ammunition?
- How much do community members know about how youth are illegally acquiring guns, stashing, and carrying guns? How willing would community members be to share this information on an anonymous basis with police?
- To what degree and under what conditions do youth share guns? What are the perceived norms and risks associated with gun sharing?
- Can violence interruption and conflict mediation by street outreach workers used to combat urban youth violence incorporate efforts to disarm or keep guns from youth engaged in the conflict?
- Similarly, can friends attempt to keep guns from youth planning rampage shootings?
- What is the potential for new technologies (personalized guns) to interrupt violent behavior among youth? How will consumers react to the introduction of these new technologies?

CONCLUSION

It is estimated that the social cost of gun violence is roughly $174 billion a year.[2] Beyond this enormous financial toll, we recognize the devastating emotional impact of lost lives, neighborhood destabilization, and fear of attack. For children in particular, exposure to violence erodes confidence in social institutions and the society they live in. These costs alone justify the dedication of our federal research agencies and the scientific community to understanding the problem of youth violence.

Researchers are ready to speak to the concerns of citizens and policymakers, building on many decades of work that informs the suggestions in this report. To do so, collaboration will be necessary across directorates of the National Science Foundation, since the basic scientific research spans a wide range of disciplines from psychology to cognitive science to computer science, from sociology to communications, from neurobiology to neuroscience, and across the age span from pre-natal environments to adolescence. Moreover, the multiple federal research agencies that apply basic science insights and develop policy responses will need to integrate and coordinate their efforts.

Further discussion will be needed to identify immediate and pressing questions that can be assessed rapidly as well as the long-term research problems. No single factor stands alone as an explanation for the violence patterns described here and hence it will take a collective effort to solve them.

[2] Firearm injuries cost $174 billion in the United States in 2010 and the government's firearm injury bill alone exceeded $12 billion. The costs include medical and mental health care costs, criminal justice costs, wage losses, and the value of pain, suffering and lost quality of life. http://www.childrenssafetynetwork.org/cost-gun-violence

Responses by Dr. Maria T. Zuber

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

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

Dr. Maria T. Zuber, Chair, National Science Board

Questions submitted by Ranking Member Eddie Bernice Johnson, House Committee on Science, Space, and Technology

1. In response to Congressional direction in the American Innovation and Competitiveness Act, NSF released a request for information on the demand for mid-scale research infrastructure funding opportunities last year. The FY 2019 budget proposal requests $60 million for Mid-Scale Research Infrastructure and includes it as one of the Foundation's ten Big Ideas. How will the NSB monitor implementation of the mid-scale program?

   Answer: The National Science Board (Board, NSB) has worked closely with NSF senior management on mid-scale research infrastructure since issuing its Congressionally-mandated 2011 report. The current Big Idea and Budget Request grew out of briefings to, and discussions with, the Board on ways to close the "mid-scale gap." This gap was a recurrent issue cited in NSB's *Annual Portfolio Review of Facilities* and in portfolio discussions with the MPS, GEO, and CISE directorates. NSB is pleased that NSF has put resources toward the Midscale Big Idea in the FY 19 Request.

   NSB will receive regular briefings on NSF's implementation of the Mid-Scale Big Idea, monitor its success, and consult with NSF to adjust the program, as needed. Three of NSB's standing committees are well positioned to participate in this effort. Once this program is in place, I anticipate that the Board's Committee on Awards and Facilities will approve mid-scale awards that exceed the threshold set by the Board's Delegation of Award Authority (currently approximately $10 million per year) and provide strategic guidance and lifecycle oversight. The Board's Committee on Oversight will oversee processes for implementing the mid-scale program, including risk management. NSB's Committee on Strategy will consult with the Director to assess the mid-scale program, to chart a long-term vision for a NSF commitment at the mid-scale level, and to ensure that this vision is reflected in FY 2020 and future budget requests. As part of its oversight, NSB will ensure that the new program has processes in place to identify and fund the most promising opportunities in the "mid-scale gap," enable convergent research, monitor full lifecycle planning for new facilities, and manage non-scientific risks appropriately.

   At the same time that NSF will be preparing to implement the Midscale Big Idea, in response to a report mandated in the *Consolidated Appropriations Act, 2018,* NSB will be looking at midscale infrastructure needs and NSF's structures to meet those needs. The Act charges the NSB to explore ways to bridge the gap between MRI- and MREFC-scale projects and to look at possible use of the MREFC account to fund activities in this space. The Board sees this report as a crucial step toward developing an enduring and sustainable mid-scale infrastructure program for NSF. This effort will require close understanding of ongoing NSF mid-scale activities and thoughtful consideration of the budgetary tradeoffs that will be necessary to devote additional resources to mid-scale infrastructure.

Appendix II

Additional Material for the Record

STATEMENT SUBMITTED BY REPRESENTATIVE DANIEL LIPINSKI

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

House Committee on Science, Space, and Technology
"An Overview of the National Science Foundation Budget Proposal for Fiscal Year 2019"
March 15, 2018

Thank you, Chairman Smith and Ranking Member Johnson, for holding this important hearing on the National Science Foundation's Fiscal Year 2019 Budget Proposal, and thanks to our witnesses, Dr. Córdova and Dr. Zuber, for being here this morning.

Authorizing and overseeing NSF is one of the most important responsibilities of our committee and one that I take very seriously. NSF is the second-largest federal funder of basic research in the U.S., and its impact on our education system, economy, national security, and global competitiveness is immense.

This year's NSF budget leaves much to be desired. While I am pleased to see a small increase in the Research and Related Activities Account, the main source of grants to universities and research institutions, I have concerns about how those funds are allocated among the six research directorates. I am also concerned about the fact that the total budget request, close to $7.5 billion, is the same as the appropriated level in Fiscal Year 2017, which is significantly lower than the Foundation's peak appropriation of $7.7 billion in 2010. The result of flat funding is a slow decline in purchasing power that leaves NSF unable to fund many of its top-rated proposals and forced to make difficult decisions about critical research facilities.

While most research directorates received flat funding in the FY19 request, the Social, Behavioral, and Economic Sciences directorate, or SBE, was targeted for an effective cut of 11%. As anyone who watches this committee knows, especially Chairman Smith, I have been an extremely forceful and outspoken advocate for SBE research funding. So it should come as no surprise that I strongly oppose this cut. According to a 2017 National Academies report on the value of SBE to the nation, *"Nearly every major challenge the United States faces—from alleviating unemployment to protecting itself from terrorism—requires understanding the causes and consequences of people's behavior."* Underfunding this research could have dire consequences.

Undervaluing the Social, Behavioral, and Economic Sciences also has the potential to undermine the effectiveness of at least one of the Ten Big Ideas. The "Future of Work at the Human-Technology Frontier" Idea was developed within the SBE directorate and will depend heavily on the social sciences for its success. However, primary responsibility for this Idea was given to the Engineering Directorate. With Engineering running the program and with reduced funding levels for SBE, we reinforce the false notion that social and behavioral questions are less important in this area of inquiry.

I would like to make another point about the Ten Big Ideas. While I support interdisciplinary and convergent research, and I support allocating funding to such initiatives, which this budget does for the first time, I do not support doing so at the expense of funding core disciplinary research. Convergence initiatives have the potential to amplify the impact of research in the core disciplines. But if we scale back directorate funding, we risk eroding the disciplinary expertise that must come together to make convergence research successful.

At a time when we have allowed NSF's purchasing power to decline with years of flat funding, and when we have significant additional budgetary authority available, now is a critical time to increase the NSF budget. At a bare minimum, we should be making inflationary increases to all research directorates, and should not force funds for the Ten Big Ideas to come at the expense of disciplinary research.

Our federal R&D expenditures as a percentage of GDP are at their lowest point since at least the 1950s and we have fallen well behind our global peers, currently ranking 10th globally. If we continue to underfund federal research agencies, we risk letting our scientific enterprise atrophy, doing irreparable harm to our global competitiveness and our future economic success.

Thank you and I yield back.

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