

FY 2021 Budget Request to Congress



The *National Science Foundation Act of 1950 (Public Law 81-507)* sets forth our mission: ***“To promote the progress of science; to advance the national health, prosperity, and welfare; to secure the national defense...”***

On April 10, 2019, the first image of a black hole was released by the Event Horizon Telescope (EHT) team. This discovery was enabled by the significant investment from the National Science Foundation and the use of NSF funded telescopes and instrumentation including the Atacama Large Millimeter/submillimeter Array (ALMA), the Submillimeter Telescope operated by the Arizona Radio Observatory, the South Pole Telescope, and the Large Millimeter Telescope. After years of theoretical physics research and detector development, researchers coordinated eight telescopes on five continents to capture observations of a black hole 55 million light-years away by effectively forming an Earth-sized virtual telescope. This accomplishment, which was awarded the 2020 Breakthrough Prize in Fundamental Physics, was achieved after years of work involving international collaboration of over 300 researchers. This project emphasizes several unique aspects of the mission and work of NSF in its investment in projects that empower discoverers to ask the questions and develop the technologies that lead to the next big breakthroughs.

The success of EHT highlights several NSF programs that support the transformative research of high risk and potentially high reward. These programs include those that fund priority research areas, encourage partnerships and large-scale international collaboration, and empower early career scientists and students. As a data-driven discovery, the EHT project aligns with three of NSF’s Big Ideas. Future astrophysical discoveries will also benefit from new hardware and software advances generated by Harnessing the Data Revolution, particularly development of new data cyberinfrastructure for timely handling, processing, analyzing and modeling of multi-messenger astrophysical data. By exploring new ways to probe the cosmos, Windows on the Universe continues to enrich our view of the universe, and Mid-Scale Research Infrastructure offers a new funding mechanism that is responsive to ambitious projects like EHT requiring dynamic and flexible investment.

Since the agency’s founding in 1950, NSF has been the only federal agency dedicated to funding basic non-biomedical research across all areas of science and engineering. NSF has been on the forefront of the innovations that provide American prosperity and strength, and sustain the U.S. role as a global leader driving innovation in technological and scientific advancements. Additionally, NSF is committed to the development of a future-focused science and engineering workforce that draws on the talents of all Americans.

NSF’s FY 2021 Request supports investments in the Administration’s research and development priority area of Industries of the Future (IoTf). These investments will continue NSF’s focused support of the science, technology, innovation and workforce development to ensure that America remains at the forefront of scientific progress, national and economic security, and personal well-being, while continuing to serve as the standard-bearer for today’s emerging technologies and innovations. NSF will support IoTf through the research areas of advanced manufacturing, advanced wireless, artificial intelligence, biotechnology, and quantum information science. To achieve and complement NSF’s IoTf goals, NSF will make strategic investments across the agency to support the heart of NSF’s mission, basic research, while helping to usher in the next generation of science and technology with convergence research that spans and integrates all areas of science and realms of human knowledge.

Overview

In FY 2021, NSF will make strategic investments in basic research, the STEM workforce, and research infrastructure that will advance the Nation's global competitiveness economically and scientifically. Federal investment in basic research and the STEM workforce is vital to the Nation's continued global leadership. These investments will fuel our Nation's economy for decades to come, produce high-paying jobs for American workers, improve American prosperity including our quality of life, and enhance our national security.

Innovations in basic research are dependent upon strategic investments in scientific infrastructure and instrumentation. Facilities and research infrastructure have long been a NSF priority. NSF will continue efficient and effective management of all research infrastructure and large facilities. NSF's FY 2021 investments will continue to prioritize the health and balance of its facilities portfolio, leveraging NSF's substantial investment in facilities to further support the scientific output of the communities they serve.

In FY 2021, NSF will continue oversight of the construction of the following projects in the Major Research Equipment and Facilities Construction (MREFC) account: Antarctic Infrastructure Modernization for Science (AIMS) project, the High Luminosity-Large Hadron Collider Upgrade (HL-LHC), and the Vera C. Rubin Observatory (formerly Large Synoptic Survey Telescope). Continued investment in the construction of major research infrastructure allows the U.S. to maintain international leadership in science and engineering by developing new capabilities to address the most challenging scientific questions.

NSF will continue to build, strengthen, and expand strategic multisector partnerships in order to enhance the impact of NSF's investments. 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. This, in turn, accelerates discovery and translation of research to products and services, and enhances preparation of the future workforce to benefit society and grow the American economy. However, entering into and maintaining these partnerships requires significant time and intellectual capital, as well as strategic foresight.

Within the global science and engineering enterprise, unprecedented competition exists for highly skilled, technical workers who will lead tomorrow's innovations. Continued U.S. leadership and support for basic research is critically important for the Nation. The JASON report, "Fundamental Research Security", released in December 2019 provides an opportunity for NSF to assess the policy impacts and frame the problems within the area of science and security. In collaboration with other federal agencies, colleges and universities, and other stakeholders in the U.S. science and engineering enterprise, this effort will ensure that America continues to attract and retain the best science and engineering talent globally, and uphold values of ethics and research integrity in science and engineering.

NSF's FY 2021 Budget Request is \$7.74 billion, a \$675 million increase above the FY 2020 Request level, a 5.0 percent decrease from the FY 2019 Actual level, and a 6.5 percent decrease from the FY 2020 Enacted level.

Industries of the Future

NSF's FY 2021 Request aligns with the Administration's Research and Development priorities by making critical investments in the Industries of the Future (IotF). As the only federal agency dedicated to funding basic non-biomedical research across all areas of science and engineering, NSF has long supported the science and technological innovations that create new industries. NSF plans to invest \$868 million in artificial intelligence (+\$403 million above FY 2019 Actual) and more than double our support of quantum information science to \$226 million (+\$120 million above FY 2019 Actual) in FY 2021.¹ All IotF investments support cross-cutting, convergent, and interdependent fields of research that collectively offer enormous economic potential and are critical to the Nation's long-term economic and national security. NSF's FY 2021 Request will ensure NSF continues to invest in the breakthrough discoveries and workforce development needed to draw on the talents of all Americans, as well as sustain America's globally preeminent innovation ecosystem.

Artificial Intelligence (AI) research is advancing rapidly and holds the potential to transform American lives through improved educational opportunities, increased economic prosperity, and enhanced national and homeland security. NSF investments in AI span fundamental research in machine learning, computer vision, and natural language processing, along with the safety, security, robustness, and explainability of AI systems; translational research at the intersection of AI and various science and engineering domains as well as economic sectors such as agriculture, manufacturing, and personalized medicine; and education and learning, including growing human capital and institutional capacity to nurture a next generation of AI researchers and practitioners. NSF FY 2021 investments in AI will include support for a set of National AI Research and Development (R&D) Institutes, which will further AI through multi-disciplinary, multi-institution teams to focus on larger-scale, longer-term challenges in both foundational and translational AI.

Quantum Information Science (QIS) examines uniquely quantum phenomena that can be harnessed to advance information processing, transmission, measurement, and fundamental understanding in ways that classical approaches can only do much less efficiently, or not at all. NSF will increase support for QIS research and development, which strongly aligns with the Administration's National Strategic Overview for QIS and the National Quantum Initiative Act to consolidate and expand the U.S.' world-leading position in fundamental quantum research and deliver proof-of-concept devices, applications, tools, or systems with a demonstrable quantum advantage over their classical counterparts.

Advanced Manufacturing investments support the fundamental research needed to revitalize American manufacturing to grow the national prosperity and workforce, and to reshape our strategic industries. NSF research accelerates advances in manufacturing technologies with emphasis on multidisciplinary research that fundamentally alters and transforms manufacturing capabilities, methods and practices. Investments in advanced manufacturing include research on highly connected cyber-physical systems in smart processing and cyber manufacturing systems, and activities that develop new methods, processes, analyses, tools, or equipment for new and existing manufacturing products, supply chain components, and materials. NSF's investments will enable new functionalities that will increase the efficiency and sustainability of the production of the next generation of products and services. These developments will yield advantages such as reduced time to market, new performance attributes, improved small-batch production, cost savings, energy savings, and reduced environmental impact from the manufacturing of products. NSF FY 2021 investments includes support for Future Manufacturing research, which will enable a new generation of manufacturing industries that do not exist today, will be compatible with human needs, and will make U.S. manufacturing competitive far into the future

¹ NSF IotF investments have funding overlap and thus should not be summed.

Advanced Wireless Research, including the Spectrum Innovation Initiative will advance knowledge gaps and innovate in areas critical to future generations of wireless technologies and networks, such as wireless devices, circuits, protocols, and systems; mobile edge computing; distributed machine learning and inference on mobile devices; human-machine-network interactions; and dynamic spectrum allocation and sharing. This work will offer new insights capable of making wireless communication faster, smarter, more responsive, and more robust, and more secure – with profound implications for science and society. Research in advanced wireless includes the support for passive uses of the spectrum, including advanced receiver design and interference mitigation techniques for radio astronomy and atmospheric science. NSF’s leadership in wireless research has three intertwined components: supporting fundamental research enabling advanced wireless technologies; establishing advanced wireless research testing platforms, in collaboration with industry and other government agencies, to experiment on new approaches at scale; and catalyzing academic, industry, national scientific facility, and community leaders to work together to prototype innovative wireless approaches to address societal challenges.

Biotechnology investments support the data, research infrastructure, and innovation that enable an understanding of living organisms and their biologically-related processes at the level of the genetic code. Advanced biotechnology, including advanced sequencing, metabolic engineering, epigenetic modulation of gene expression, and gene editing, serve to both accelerate scientific discovery in biology and to enable the harnessing of biological systems for economic and societal benefit. Biotechnology is considered one of the key drivers of growth in the bioeconomy. NSF invests in biotechnology and related drivers of the U.S. bioeconomy through a multitude of programs in research, infrastructure, and education, including genomics, synthetic biology, bioinformatics, computational biology, engineering biology, tissue engineering, and the development of new types of biomaterials, bio-based microelectronics, and biomanufacturing. NSF’s educational investments in these areas are essential to support the biotechnology workforce needed to grow the U.S. bioeconomy. NSF investments in research on ethical, legal, and environmental consequences of synthetic biology and other biotechnologies also support the bioeconomy through understanding of product adoption and socially responsible use.

For more information about NSF’s investments in AI, QIS, and Advanced Manufacturing see the NSF-Wide Investments chapter.

Strategic Research Investments

In FY 2021, NSF will make investments that support the basic research that advances human knowledge and makes tomorrow's innovations possible. Additional investments will support research in the areas of microelectronics and semiconductors, spectrum innovation, coastlines and people, and strengthening American infrastructure. In FY 2021, NSF expects that over 90 percent of its annual budget will be used to fund research and education grants and research infrastructure in the science and education communities. New discoveries made possible through basic research investments will enable the Nation to overcome crucial scientific barriers for emerging technologies that will strengthen U.S. scientific leadership, economic prosperity, and national security.

Basic research forms the core of NSF's work and has led to discoveries and innovations that have been awarded Nobel Prizes, and changed humankind's conception of the known world. In FY 2021, NSF expects to invest \$5.02 billion, or 65 percent of NSF's total budget, in basic research. Basic research is responsible for advancing our knowledge of the universe, as well as innovations like high speed internet, nanotechnology, and advances in robotics that require understanding of the fundamental laws that govern the physical world. NSF funds basic research in all of the agency's directorates and continues to fund research that transcends a single discipline.

Research in **Semiconductors and Microelectronics** (\$84.16 million) is critical to future advances and security in several areas, including information technology, communications, sensing, smart electric grid, transportation, health, and advanced manufacturing. NSF will support research to address fundamental science and engineering questions on the concepts, materials, devices, circuits, and platforms necessary to sustain progress in semiconductor and microelectronic technologies. This investment will strengthen America's capabilities and capacity for revolutionary microelectronics design, architecture, and fabrication, as well as high-performance computing.

NSF's **Spectrum Innovation Initiative** (\$17.0 million) will catalyze spectrum research, which addresses key challenges related to an increasingly congested radio frequency environment and outdated approaches to spectrum allocation. NSF is uniquely positioned to lead this effort with its mission to both protect and innovate in scientific uses of the spectrum and in the development of new technology (e.g., advanced wireless). FY 2021 funding will support three cross-cutting initiatives: (1) a novel mechanism for piloting, testing, and rolling out the most innovative approaches to dynamic spectrum sharing in specialized geographic regions, "National Radio Dynamic Zones"; (2) collaborative, center-scale institutes for sustained R&D in the most challenging areas to bring together diverse science and engineering perspectives; and (3) education and public outreach funding for the much needed workforce development specifically related to spectrum research.

FY 2021 investment of \$16.0 million in **Coastlines and People (CoPe)** will support interdisciplinary research through establishment of virtual centers or research "hubs" aimed at improving prediction of coastal natural hazards, and understanding of the complex interactions between coastal hazards, people, ecosystems and the built environment. Coastal research offers compelling lines of scientific inquiry with potential for great societal and economic benefit. Research Hubs will address scientific questions that cross multiple disciplines and scales (time and space). These hubs will engage and involve stakeholders and local communities; exploring science that informs pathways to sustainability in changing coastal environments.

FY 2021 investments to **Strengthen American Infrastructure** (\$6.0 million) will link experts on physical, computational, and material aspects of infrastructure design with scientists whose fundamental research

Overview

explains how humans will—and will not—use infrastructure that we build. This approach to infrastructure is a critical component to building better, smarter, and more cost-effective roads, electric grids, and hospitals. Improving infrastructure in these ways spurs private-sector innovation, grows the economy, and is essential to national competitiveness.

Additional Research Priorities

In FY 2021, NSF will continue to emphasize ongoing investments that engage scientists and engineers from all STEM fields in creating private-public partnerships, protect the Nation's cyber assets, and expand the reach of NSF funding.

Ongoing NSF-wide Investments

A **NSF Innovation Corps (I-Corps™)** investment of \$31.42 million in FY 2021 will prepare scientists and engineers to reduce the time and risk associated with translating promising ideas and technologies from the laboratory to the marketplace. I-Corps™ accelerates the economic and societal benefits of NSF-funded, basic research projects. In FY 2021, NSF will support I-Corps™ Teams and I-Corps™ Hubs to expand, utilize, and sustain a national innovation ecosystem that helps researchers and entrepreneurs effectively identify viable market opportunities and augments the development of technologies that benefit the Nation.

The **Secure and Trustworthy Cyberspace (SaTC)** investment, \$124.91 million in FY 2021, 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 future cybersecurity workforce. SaTC aligns NSF's cybersecurity investments with the national cybersecurity strategy.

Ongoing Targeted Priorities

NSF's FY 2021 Request of \$163.67 million for the **Established Program to Stimulate Competitive Research (EPSCoR)** will enhance the research competitiveness and strengthen the STEM capacity and capability of targeted jurisdictions

In FY 2021, the **Historically Black Colleges and Universities Excellence in Research (HBCU-EiR)** program (\$9.50 million) supports basic research projects that enable STEM and STEM education faculty to further develop research capacity at HBCUs and to conduct research.

Through innovative programs like the **Small Business Innovation Research (SBIR)** and the **Small Business Technology Transfer (STTR)**, NSF will continue to support the basic and early-stage applied research that provides the fundamental building blocks of technological advances. FY 2021 funding for SBIR/STTR, including operations, will total \$209.25 million.

Strategic Infrastructure and Instrumentation

In FY 2021, NSF is dedicated to the support of research infrastructure and instrumentation. The Nation's science and engineering activities rely on instrumentation that is geographically and technically accessible, cost effective, and managed well. To ensure that the infrastructure needs of the entire community are met, NSF supports activities that ensure instrumentation and infrastructure can be designed, developed, acquired, or constructed through programs with focused oversight and investments.

Instrumentation and Infrastructure

The Major Research Instrumentation (MRI) program is responsible for catalyzing new knowledge and discoveries by helping STEM professionals acquire or develop the instrumentation needed at their institutions. MRI grants support instrumentation in all NSF-supported research disciplines. MRI makes awards of up to \$4 million, for projects with total costs (including matching funding) as high as \$6 million.

In the American Innovation and Competitiveness Act (AICA) of 2017, Congress directed the agency to develop a strategy for supporting research infrastructure with a total project cost above the upper limit for the MRI program and below the MREFC threshold. NSF responded by introducing the Mid-scale Research Infrastructure (Mid-scale RI) program. This dedicated activity implements a high-priority, agency-wide mechanism that includes upgrades to major facilities as well as stand-alone projects.

In FY 2021, NSF will continue funding the Mid-scale Research Infrastructure (Mid-scale RI) program through two tracks. Mid-scale RI Track 1 will support the acquisition or development of instrumentation in the \$6 million to \$20 million range. Mid-scale RI Track 1 funding is provided through the Research and Related Activities account, and awards will fund projects similar to those supported in FY 2019 such as Event Horizon Telescope 2.0, next generation atmospheric research aircraft, and neutron spin-echo spectrometer. Mid-scale RI Track 2 will make awards in the \$20 million to \$100 million range, and is funded through the MREFC account. Mid-scale RI Track 2 includes support for upgrades to major facilities and stand-alone projects.

Facility Operations and Maintenance

NSF's FY 2021 Request for facilities operations and maintenance is \$867.42 million, all of which is provided through the R&RA account.

Major Research Equipment and Facilities Construction

Projects that require an investment of more than \$100 million are supported by NSF's Major Research Equipment and Facilities Construction account.

The FY 2021 Request includes funding to continue construction of three projects—AIMS, the two detector upgrades at the HL-LHC, and the Vera C. Rubin Observatory, formerly Large Synoptic Survey Telescope (LSST)—as well as Mid-scale RI Track 2. The total request to support these projects and associated oversight costs is \$229.75 million.

MREFC Account Funding, by Project

(Dollars in Millions)

	FY 2019 Actual	FY 2020 Enacted	FY 2021 Request
Antarctic Infrastructure Modernization for Science	\$103.70	\$97.89	\$90.00
Daniel K. Inouye Solar Telescope	19.59	-	-
High Luminosity-Large Hadron Collider Upgrade	-	33.00	33.00
Mid-Scale Research Infrastructure ¹	-	65.00	65.00
National Ecological Observatory Network	0.07	-	-
Regional Class Research Vessels	108.12	-	-
Vera C. Rubin Observatory	53.48	46.34	40.75
Major Facilities Administrative Reviews and Audits	0.32	1.00	1.00
Total	\$285.27	\$243.23	\$229.75

¹ Mid-scale Research Infrastructure funding in the FY 2019 Actual is reflected in the R&RA account within Integrative Activities. Mid-scale projects in this table have a total implementation cost between \$20 million and \$100 million.

The **AIMS** (\$90.0 million) construction project funding request will support the third year of the multi-year funding profile. Antarctica makes up nearly nine percent of the continental mass of Earth's surface. NSF manages all U.S. activities as a single, integrated program, making Antarctic research possible for scientists supported by NSF and other U.S. agencies. Funding for the AIMS infrastructure improvement project will protect U.S. interests on the continent. It will continue modernization of major facilities at the aging McMurdo Station, much of which was recommended by the U.S. Antarctic Program Blue Ribbon Panel in 2012, so that anticipated science support needs are met for the next three to five decades. When completed, AIMS will enable faster, more streamlined and cost-effective logistical and science support by co-locating or consolidating warehousing, skilled trades work, and field science support where field projects are prepared for movement into the field, into four buildings. AIMS will also provide necessary utilities to support these facilities.

The **LHC** (\$33.0 million) is the world's largest and highest energy particle accelerator. Located near Geneva, Switzerland and operated by the European Organization for Nuclear Research (CERN), the LHC can accelerate and collide counter-propagating bunches of protons at a total energy of 14 tera-electron volts. A Toroidal LHC ApparatuS (ATLAS) and Compact Muon Solenoid (CMS) are two general purpose detectors used by researchers to observe these collisions and analyze their characteristics. Together, CMS and ATLAS represent the United States contribution to the LHC facility. In FY 2021, NSF funding together with our Department of Energy partner will support year two of the five-year project for the **HL-LHC Upgrade**. This investment will upgrade components of the of the ATLAS and CMS detectors, enabling them to function at much higher collision rates following an upgrade to the LHC to increase its luminosity.

The **Vera C. Rubin Observatory** (\$40.75 million) will be an 8-meter-class wide-field optical telescope capable of carrying out surveys of the entire southern 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. FY 2021 will be year eight of its nine-year construction funding profile.

The **Mid-Scale Research Infrastructure** (\$65.0 million) project has a dedicated funding line in the MREFC account for Track 2 awards. Individual projects will be selected through dedicated program solicitations and NSF's merit review process. Although funding will be allocated from the MREFC account, managing directorates will be responsible for award oversight.

Big Ideas and Convergence Accelerator

In 2021, NSF will continue to invest in its Big Ideas and the Convergence Accelerator, which support bold inquiries into the frontiers of science and engineering. These efforts endeavor to break down the silos of conventional scientific research funded by NSF to embrace the cross-disciplinary and dynamic nature of the science of the future. The Big Ideas represent unique opportunities for the U.S. to define and push the frontiers of global science and engineering leadership and to invest in fundamental research. This research will advance the Nation's economic competitiveness, security, and prestige on the global stage. For more information, see the NSF-Wide Investments chapter.

About the Big Ideas

Six of the Big Ideas are research ideas, which will build on the foundation of NSF-funded research over the last 70 years. The Research Big Ideas are complemented by Enabling Big Ideas, which are areas in which research endeavors to improve the way in which science is done, from impacting the workforce to developing the infrastructure that will drive the discoveries and aid the discoverers of tomorrow's science.

Research Big Ideas:

- **Harnessing the Data Revolution for 21st-Century Science and Engineering (HDR)** (\$45.0 million): 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 (FW-HTF)** (\$45.0 million): 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.
- **The Quantum Leap (QL): Leading the Next Quantum Revolution** (\$50.0 million): 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.
- **Navigating the New Arctic (NNA)** (\$30.0 million): Establishing an observing network of mobile and fixed platforms and tools, including cyber tools, across the Arctic to document and understand the Arctic's rapid biological, physical, chemical, and social changes, in partnership with other agencies, countries, and native populations.
- **Understanding the Rules of Life (URoL): Predicting Phenotype** (\$30.0 million): Elucidating the sets of rules that predict an organism's observable characteristics. Advances in understanding life at the fundamental level of the genome will enable re-engineering of cells, organisms, and ecosystems, and innovative biochemicals and biomaterials that sustain a vibrant bioeconomy and strengthen society.
- **Windows on the Universe (WoU): The Era of Multi-messenger Astrophysics** (\$30.0 million): 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.

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Enabling Big Ideas:

- **NSF INCLUDES** (\$18.92 million): Transforming education and career pathways to help broaden participation in science and engineering and build a diverse, highly skilled American workforce.
- **Growing Convergence Research at NSF (GCR)** (\$15.20 million): Merging ideas, approaches, tools, and technologies from widely diverse fields of science and engineering to stimulate discovery and innovation.
- **Mid-scale Research Infrastructure** (\$97.67 million): Developing an agile process for funding experimental research capabilities in the mid-scale range, spanning the midscale gap in research infrastructure. This is a “sweet spot” for science and engineering that has been challenging to fund through traditional NSF programs.

About the Convergence Accelerator

The Convergence Accelerator (CA) is an organizational framework that stands separately from the NSF research directorates, with its own budget, staff, and initiatives. Each CA research track will be a time-limited entity focused on specific research topics and themes. Therefore, CA research tracks will evolve over time and will be informed by external stakeholder input. The CA will reward high-risk, innovative thinking by multidisciplinary teams of researchers who want to accelerate discovery and innovation. The CA is a way of achieving rapid lab-to-market or research outcomes. The FY 2021 CA funding is \$70.0 million, or \$28.61 million above the FY 2019 Actual. NSF anticipates external partners will begin contributing financially to the effort in FY 2021.

Education and STEM Workforce

NSF's education and STEM workforce investments are primarily housed in the Directorate for Education and Human Resources, but represent agency-wide investments in the education of tomorrow's scientists, engineers, and educators. NSF is committed to building and leveraging a diverse, highly skilled American workforce for the 21st century economy. This workforce must be capable of adapting to the increasingly technical nature of work across all sectors, which will require a greater emphasis on STEM education and literacy. NSF works to prioritize programs that will provide experiential learning opportunities, as well as programs that prioritize computer science education and reskilling. NSF's extensive broadening participation portfolio impacts minority serving institutions and rural communities. Priority STEM education activities to prepare America's future workforce in FY 2021 are:

The **Advanced Technological Education (ATE)** (\$70.97 million) program focuses on the education of technicians for the high-technology fields that drive our Nation's economy. The program involves partnerships between academic institutions and industry to promote improvement in the education of science and engineering technicians at the undergraduate and secondary institution school levels. The ATE program supports curriculum development; professional development of college faculty and secondary school teachers; career pathways; and other activities.

The **NSF Research Traineeship (NRT)** (\$61.87 million) program encourages the development and implementation of bold, new, and potentially transformative and scalable models for STEM graduate education training. The program is dedicated to effective training of STEM graduate students in high priority interdisciplinary or convergent research areas through innovative professional development activities that will educate the next generation of scientist. In FY2021, NRT will expand to include a special focus on traineeships in artificial intelligence and artificial intelligence engineering.

The **CyberCorps®: Scholarship for Service (SFS)** (\$52.13 million) program supports cybersecurity education 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.

Computer Science for All (CSforAll): Researcher and Research Practitioner Partnerships (\$18.97 million) will 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. 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 **Graduate Research Fellowship Program (GRFP)** (\$275.28 million) 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 2021, GRFP will continue to align fellowship awards with NSF and Administration research priorities, including IotF research areas of artificial intelligence and quantum information science.

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The **Hispanic-Serving Institutions Program (HSI)** (\$14.19 million) seeks to enhance the quality of undergraduate STEM education at HSIs and to increase retention and graduation rates of undergraduate students pursuing degrees in STEM fields at HSIs. The HSI Program seeks to build capacity at HSIs that typically do not receive high levels of NSF grant funding.

The **Historically Black Colleges and Universities Undergraduate Program (HBCU-UP)** (\$31.22 million) is committed to enhancing the quality of undergraduate STEM education and research at HBCUs to broaden participation in the nation's STEM workforce. HBCU-UP provides awards to develop, implement, and study evidence-based innovative models and approaches for improving the preparation and success of HBCU undergraduate students so that they may pursue STEM graduate programs and/or careers.

The **Improving Undergraduate STEM Education (IUSE)** (\$88.21 million) initiative 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. Directorates across NSF invest in this program to support the development of a workforce that will be able to handle the real-world challenges of a STEM career.

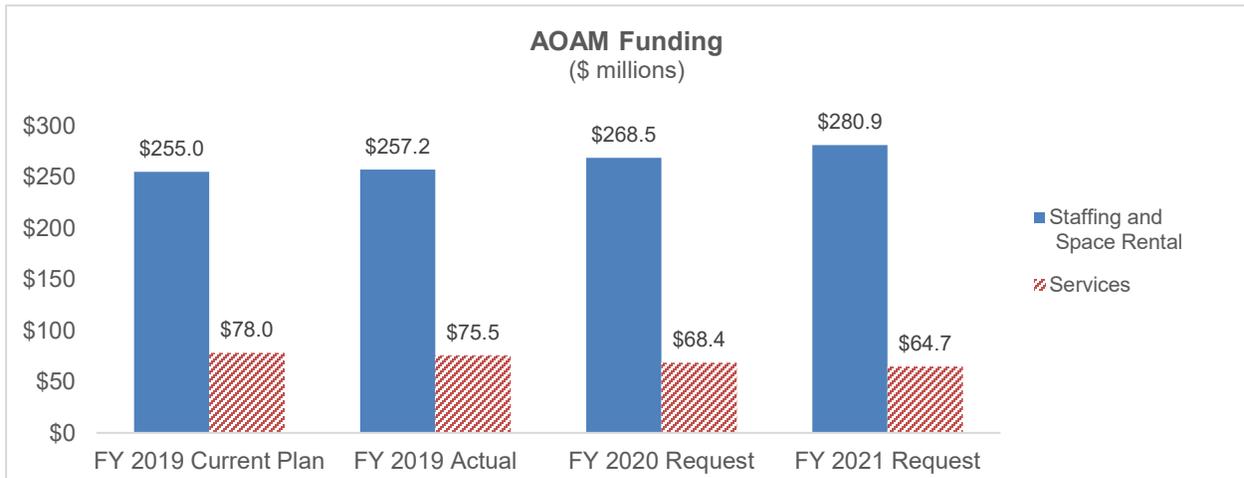
The **Tribal Colleges and Universities Program (TCUP)** (\$12.49 million) provides awards to Tribal Colleges and Universities, Alaska Native-serving institutions, and Native Hawaiian-serving institutions to promote high quality STEM education, research, and outreach.

Agency Operations and Award Management

In FY 2021, funding provides a total of \$345.64 million, an increase of \$12.95 million or 3.9 percent above the FY 2019 Actual for the Agency Operations and Award Management (AOAM) account. NSF continues to operate as a lean agency with AOAM costs representing 4.5 percent of NSF total FY 2021 budget.

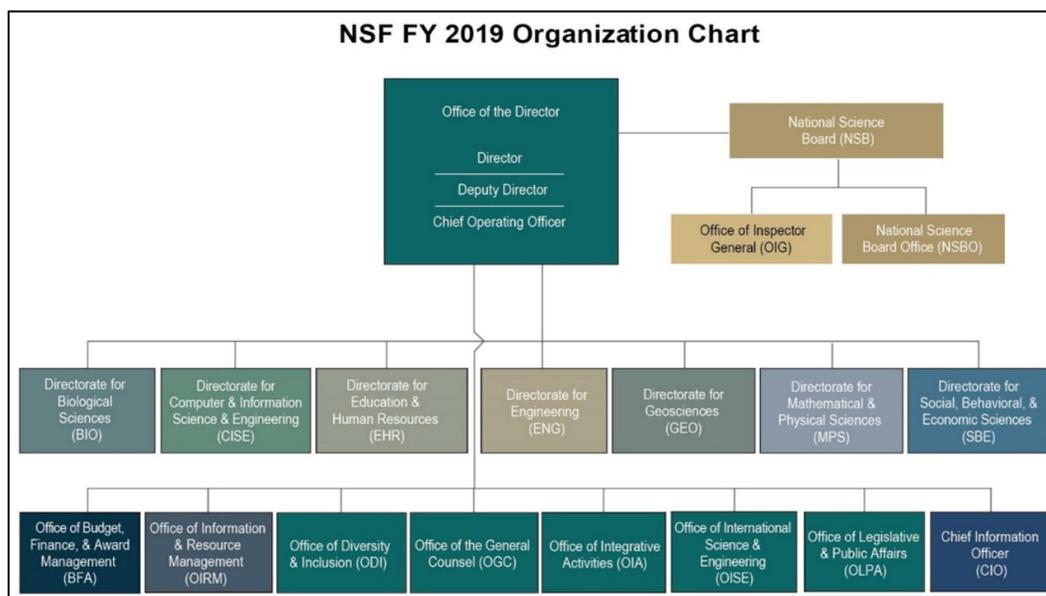
Investments in the AOAM account provide the fundamental framework through which the Foundation’s science and engineering research and education programs are administered. AOAM funds the essential services NSF needs to operate, and investments in the AOAM account continue to be an NSF priority. The AOAM account enables NSF to support innovations and workforce development essential to improving agency operations and advancing American leadership in science and technology.

The \$7.4 billion in research funding that NSF will support in FY 2021 is made possible by the federal staff that enable the research and steward the taxpayer investment. The AOAM account provides the funding necessary to support NSF the institution, which is largely the cost of NSF personnel and NSF headquarter location in Alexandria, VA. These fixed costs increase year over year and are partially offset by reductions to the mission-support services necessary to operate the agency and support the NSF workforce. In FY 2021, AOAM will also fund NSF’s efforts to implement the policy requirements mandated by law, such as the American Innovation and Competitiveness Act (AICA), Digital Accountability and Transparency Act of 2014 (DATA Act), Foundations for Evidence-Based Policymaking Act of 2018 (Evidence Act).



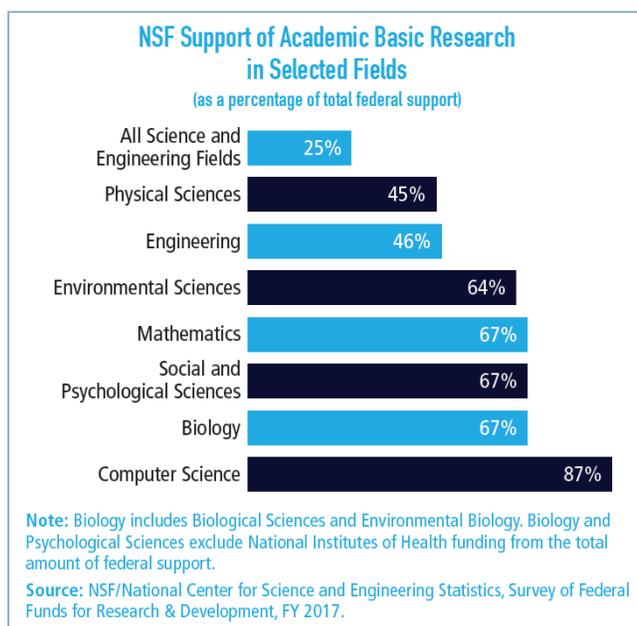
Organization and Role in the Federal Research Enterprise

NSF’s comprehensive and flexible support of meritorious projects enables the Foundation to identify and foster both fundamental and transformative discoveries and broader impacts within and among fields of inquiry. NSF has the latitude to support emerging fields, high-risk ideas, interdisciplinary collaborations, and research that pushes—and creates—the very frontiers of knowledge. In these ways, NSF’s discoveries inspire the American public—and the world.



NSF’s organization represents the major science and engineering fields, including biological sciences; computer and information science and engineering; engineering; geosciences; mathematical and physical sciences; and social, behavioral, and economic sciences. NSF also carries out specific responsibilities for education and human resources, integrative activities, and international science and engineering. The 25-member National Science Board approves the overall policies of the Foundation.

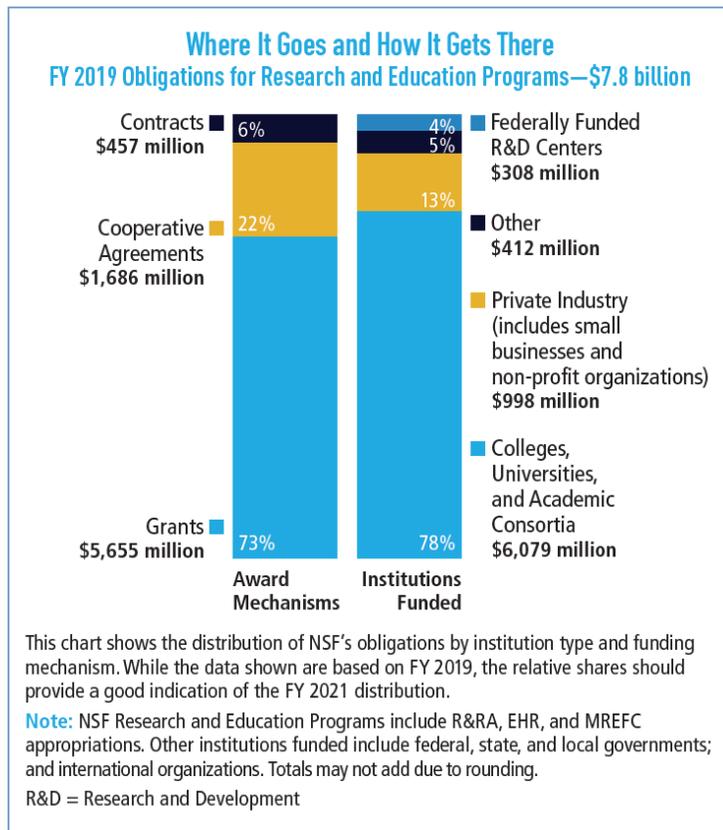
NSF’s annual budget represents approximately 25 percent of the total federal budget for basic research conducted at U.S. colleges and universities. In many science and engineering fields, NSF is the primary source of federal academic support.



NSF by the Numbers

NSF by the Numbers: In FY 2021, NSF expects to evaluate approximately 43,500 proposals through a competitive merit review process and make approximately 10,700 new competitive awards, 8,100 of which will be new research grants and the remainder of which will be contracts and cooperative agreements. This process involves approximately 192,000 proposal reviews, engaging on the order of 29,000 members of the science and engineering community participating as panelists and proposal reviewers. In a given year, NSF awards reach over 1,800 colleges, universities, and other public and private institutions in 50 states, the District of Columbia, and U.S. territories. In FY 2021, NSF support is expected to reach approximately 299,900 researchers, postdoctoral fellows, trainees, teachers, and students.

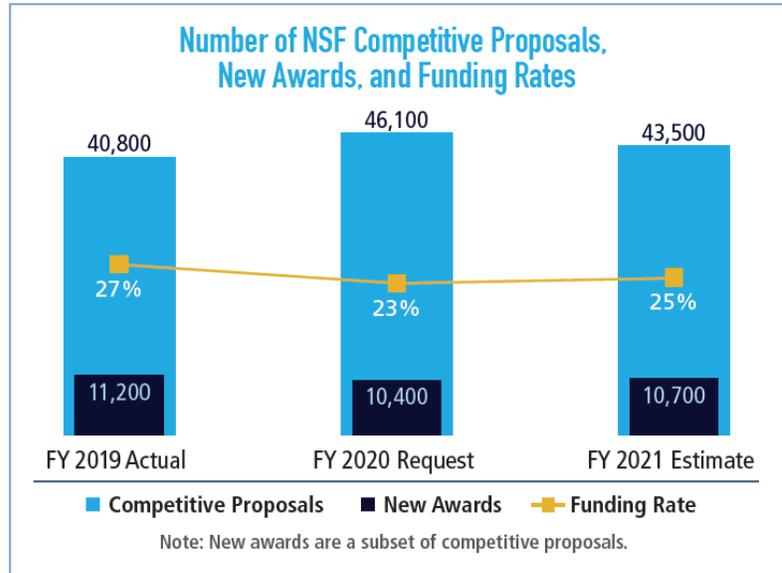
The chart on the right shows the distribution of NSF’s obligations by institution type and funding mechanism. While the data are based on FY 2019, it is expected that the relative shares in FY 2021 will be similar. As shown on the graph, 95 percent of NSF’s FY 2019 projects were funded using grants or cooperative agreements. NSF grants are either standard or continuing awards. That is, the award is made during one fiscal year for the full amount of the award or made over several years in increments. Cooperative agreements are used when the project requires substantial agency involvement during the project performance period (e.g., research centers, major multi-user research facilities). Contracts are used to acquire products, services, and studies (e.g., program evaluations) required primarily for NSF or other government use.



Most NSF awards are to academic institutions. As shown in the chart, 78 percent of support for research and education programs (\$6,079 million) was to colleges (including two-year and community colleges), universities, and academic consortia. Private industry, including small businesses, accounted for 13 percent (\$998 million), and support to Federally Funded Research and Development Centers (FFRDCs) accounted for four percent (\$308 million). Other recipients included federal, state, and local governments; nonprofit organizations; and international organizations. A small number of awards fund research in collaboration with other countries, which adds value to the U.S. scientific enterprise and maintains U.S. leadership in the global scientific enterprise.

Overview

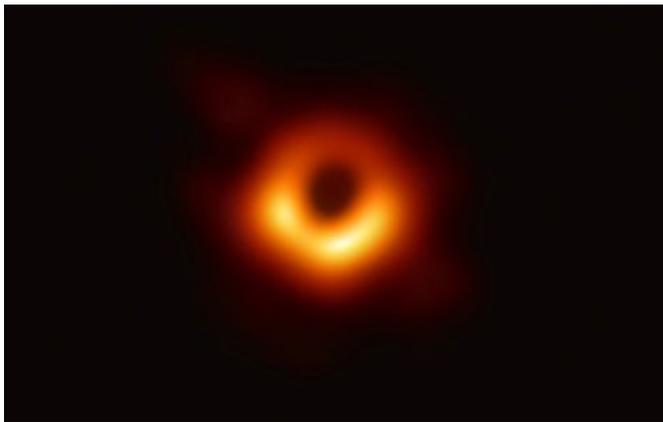
The chart on the left presents a high-level, agency-wide estimate of funding rates, or proposal “success,” as a comparison of the number of competitive proposals, new awards, and funding rate between FY 2019, FY 2020, and FY 2021. In FY 2021, NSF expects to make approximately 10,700 new awards, which corresponds to a funding rate of about 25 percent.



Highlights

For 70 years, NSF has invested in fundamental research and education to fulfill its mission of promoting the progress of science and engineering. In doing so, NSF-supported research has connected the discovery and advancement of knowledge with the potential societal, economic, and educational benefits that are critical for continued U.S. prosperity. Below are a few examples of the important advances that NSF funding enables.

Astronomers capture first image of a black hole



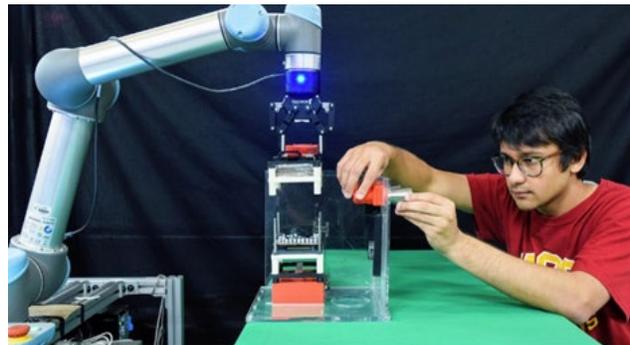
Using the EHT, scientists obtained an image of the black hole at the center of galaxy M87, outlined by emission from hot gas swirling around it under the influence of strong gravity near its event horizon. *Credit: Event Horizon Telescope Collaboration et al.*

The Event Horizon Telescope (EHT) was designed to see the unseeable. Black holes exert such strong gravitational forces that even light can't escape them. It took EHT, a planet-scale array of eight ground-based radio telescopes linked through international collaboration, to gather the first direct visual evidence of a supermassive black hole and its shadow, 55 million light-years from Earth. EHT uses very-long-baseline interferometry (VLBI), which synchronizes telescope facilities around the world to form one huge, Earth-size telescope. Decades of NSF investments in VLBI and radio astronomy technologies led to the creation of EHT and the black-hole image. In 2019, EHT's members received the Breakthrough Prize in

Fundamental Physics, an annual recognition of scientific achievements. Their next goals include imaging the supermassive black hole at the center of the Milky Way and capturing video of a black hole.

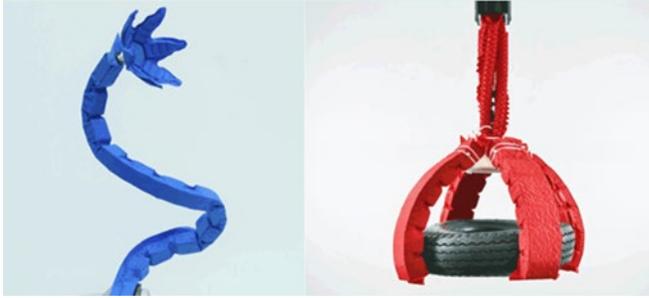
Working with industry to strengthen the STEM workforce

Across the U.S., industries increasingly depend on rapidly changing technology, creating pressure for employers to find workers with STEM skills and knowledge. To empower the workers of today to hold the jobs of tomorrow, a unique public-private partnership will develop online learning platforms and study the effectiveness of courseware to see what connects with learners of different ages and skill levels. Using a \$10 million gift from The Boeing Company, NSF funded five separate projects exploring approaches that will allow schools, companies, nonprofits and others to create new learning experiences to build a stronger, more STEM-educated workforce.



The partnership with Boeing will accelerate training in critical skill areas and increase diversity in STEM fields. *Credit: A. Kabir*

Robots with a softer touch



Origami-inspired artificial muscles can lift up to 1,000 times their own weight. *Credit: Shuguang Li, Wyss Institute at Harvard University*

Soft robotics have the potential to revolutionize the way we live, creating machines robust enough to work in healthcare or manufacturing, yet safe to use around people. But for years, their increased dexterity and flexibility came at a cost: reduced strength. NSF-funded researchers found a way around that, though. Using origami as their inspiration, they have created artificial muscles that allow soft robots to lift objects that are up to 1,000 times their own weight—using only air or water pressure. Each artificial muscle consists of an inner “skeleton” surrounded by air or fluid and sealed inside a “skin.” The shape and composition of the skeleton determines the muscle’s movement. Adaptable, scalable, and presenting comparably little damage if they break, these soft robots could help humans do everything from gently lifting the injured out of hospital beds to assembling cars.

Frontera: Fastest academic supercomputer in the world

Scientific challenges increasingly demand more computing power. The U.S. science and engineering community gained a major resource in 2019 when the Texas Advanced Computing Center (TACC) launched Frontera, the most powerful supercomputer on any academic campus and the fifth fastest system in the world. Supported by NSF, Frontera serves as a tool that will enable discoveries by researchers from across the country. Within weeks of coming online, the system had already enabled research in areas ranging from black hole physics to drug design, leveraging data analytics and artificial intelligence capabilities. It has already performed simulations of neutron stars merging and helped train neural networks to predict the characteristics of new drug compounds. Frontera is expected to have a major effect on fields including natural hazards modeling, genomics, astrophysics, and materials sciences.



Frontera is the most powerful supercomputer on any academic campus and the fifth fastest system in the world. *Credit: TACC*

An entire year trapped in the ice



The German RV Polarstern, which is serving as the base for the MOSAiC expedition, during an Arctic expedition. *Credit: M. Hoppmann*

In most cases, having your vessel frozen to an iceberg in the Arctic would be a worst-case scenario. For a group of international researchers who set sail in 2019, it was the launchpad for the largest polar expedition in the world. Hundreds of researchers, including NSF-supported scientists from the U.S., boarded the German research vessel Polarstern for the MOSAiC (Multidisciplinary drifting Observatory for the Study of Arctic Climate) expedition, a year-long operation that required lengthy logistical preparation by NSF staff and their international partners. Researchers worked to set up an observational network monitoring air, land, and sea that stretched over the sea ice as far as 30 miles away from the research vessel. MOSAiC aims to produce breakthroughs in understanding the Arctic climate system.

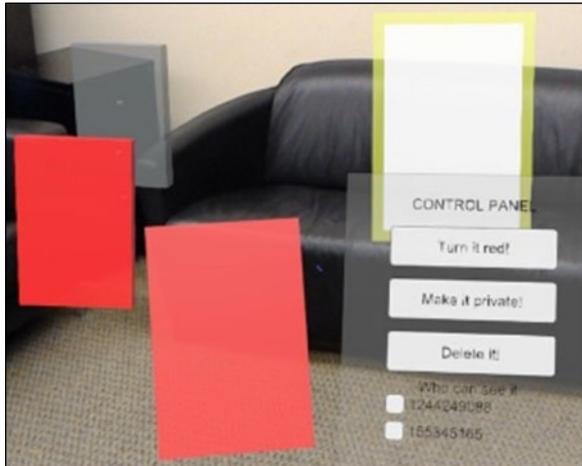
World’s largest outdoor shake table

Earthquakes don’t just shake the ground horizontally. They heave it vertically and twist it in ways that can tear buildings apart. Now, thanks to a \$16.5 million award from NSF, the world’s largest outdoor earthquake simulator, located at the University of California (UC) San Diego, does too. The upgrade will enable this “shake table” to more realistically recreate the ground motions of an earthquake. It will allow engineers to test structures from multi-story buildings to bridge columns and wind turbines to find out how resilient they are to earthquake conditions. The enhanced shake table would teach researchers new lessons even if they just repeated the more than 30 tests conducted since 2004. The engineers working on the upgrade already have a plan for the first structure they’ll test with it – a 10-story building made from cross laminated timber.



A graduate student inspects a six-story steel-framed building that is about to be tested on a shake table. *Credit: UC San Diego*

New tools to minimize risks in shared, augmented reality environments

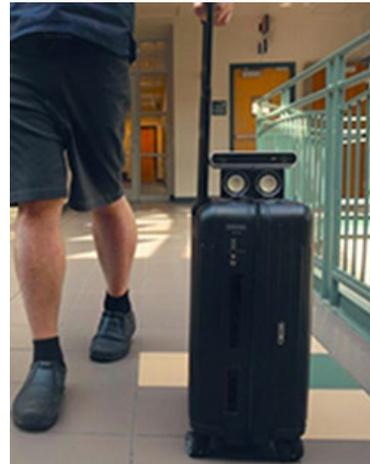


The team tested ShareAR with three case study apps. One of the apps is Doc Edit (above), which lets users create virtual notes or lists they can share or keep private; the semi-transparent gray box in the top left corner represents a “ghost object,” or a document that another user wishes to remain private. *Credit: Ruth et al., USENIX Security Symposium*

Augmented reality (AR) has, thus far, largely been deployed in the context of individuals playing popular video games that allow them to use smart phones or other devices to see virtual objects in the physical world around them. But soon this technology may find applications where groups are using it for learning, commerce or industry—which makes it all the more important to figure out how to safeguard AR from hackers and others who would hijack it or breach the privacy of users. NSF-supported researchers are laying the groundwork for a safe AR universe. Their new toolkit, known as ShareAR, lets app developers build in AR features without sacrificing their users’ privacy and security. ShareAR is the first of its kind as it takes into account the unique security issues associated with augmented reality, such as the idea that attackers could add malicious or inappropriate items into the virtual environments.

Collision-detecting suitcase

For the visually impaired, unfamiliar environments can prove difficult to navigate. A team of NSF-supported researchers are working to make at least one of those environments safer, with a smart suitcase that warns blind users of impending collisions, along with a wayfinding smartphone app for safe and independent navigation through airport terminals. The rolling suitcase sounds alarms when users are headed for a collision with a pedestrian, and the navigation app provides turn-by-turn audio instructions to users on how to reach a departure gate—or a restroom or a restaurant. The app, known as NavCong, employs airports’ Bluetooth beacons, for navigation waypoints.



Researchers have developed a smart suitcase that helps blind travelers navigate crowded airports. *Credit: Carnegie Mellon University*