UNDERSTANDING THE BRAIN (UtB) $143,930,000
+$37,490,000 / 35.2%

Overview

Understanding the Brain (UtB) is a multi-year effort that continues the previously titled "Cognitive Science and Neuroscience" activity and that includes NSF's participation in the Administration's Brain Research through Advancing Innovative Neurotechnologies (BRAIN) Initiative.

For over three decades, NSF has supported fundamental brain research from molecules to cognition and behavior, and enabled technology development, through many disciplinary programs spread across the Foundation. In 2012, Congress encouraged NSF to create a cross-foundation activity in Cognitive Science and Neuroscience, and also encouraged the White House to form an Interagency Working Group on Neuroscience (IWGN) under the National Science and Technology Council, which is co-chaired by NSF. In FY 2013, the President announced the multi-agency BRAIN Initiative, with NSF as one of the lead participating agencies. The Understanding the Brain activity draws together and consolidates NSF's ongoing activities in Cognitive Science and Neuroscience and the BRAIN Initiative. With UtB, NSF aims to leverage its existing investments and foster greater collaboration among these research and technology disciplines to accelerate fundamental discoveries in neuroscience, cognitive science, and neuroengineering.

Understanding the brain is one of the grand scientific challenges at the intersection of the physical, life, behavioral, and engineering sciences. The National Research Council report, "*Research at the Intersection of the Physical and Life Sciences*" (2010), identified "Understanding the Brain" as one of the top five grand challenges for research that will significantly benefit society. The National Academy of Engineering has also recognized "*Reverse-Engineering the Brain*" as a Grand Challenge for Engineering (2008).

Many incremental advances in research and technology in recent decades are elucidating individual elements of the nervous system and brain and their relationships to specific behaviors and cognitive processes. However, 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 the brain interacts with its environment, and how the brain can recover from lost functionality.

The critical challenge to this comprehensive understanding is to integrate research and innovation across multiple scales of space and time, from molecular, physical (e.g., biophysical and biochemical), physiological, and genetic to cognitive, behavioral, and social, with the ultimate goals of establishing integrative, quantitative, and predictive theories of brain structure and function.

To address this challenge, NSF is making major investments in collaborative fundamental science, in innovative enabling technologies, and in workforce development to accelerate discovery and revolutionize our understanding of the brain. NSF is leveraging and substantially expanding its investments in high-risk/high-reward exploratory and transformational scientific and engineering research with emphasis on integration across scales and disciplines. Novel experimentation, multimodal data integration, and theoretical developments that span the molecular, biophysical, biochemical, systems, genetic, organismal, and social scales will elucidate the mechanisms linking dynamic brain activity to behavior and physiology of the whole organism in its environmental context. New conceptual and physical tools with the associated technologies will expand the limits of detection, refine the level of experimental manipulation, and improve computational capability, allowing a fuller characterization and analysis of temporal and spatial patterns of the activity of networks of neurons that drive behavior. Other

investments will aim to improve education through discoveries in the neural bases of learning, and enhance our understanding of how the brain adapts to changing environments.

NSF is uniquely positioned to advance research on understanding the brain by bringing together a wide range of scientific and engineering disciplines to reveal the fundamental principles underlying brain structure and function. The co-mingling of these disciplinary and interdisciplinary fields is expected to yield enhanced understanding of the brain, cognition, and behavior, through the development of new technologies and theories. NSF has been a catalyst for transformative breakthroughs in brain research and related technologies; for example, the fundamental research that led to the development of optogenetics, the CLARITY transparent brain preservation technique, brain-machine interface systems, and the first FDA-approved artificial retina began with NSF support. In addition, NSF's capacity for enabling integrative activities in neuroscience at a global scale is exemplified by NSF's long-term supporting role in the International Neuroinformatics Coordinating Facility (INCF).

NSF's cross-foundation activity has brought the relevant but disparate scientific communities together, and has resulted in the funding of novel collaborative efforts and innovative research and technology awards. In FY 2013, NSF released a cross-foundation Dear Colleague Letter "Accelerating Integrative Research in Neuroscience and Cognitive Science (AIR-NCS)" and funded nine new Integrated NSF Support Promoting Interdisciplinary Research and Education (INSPIRE) awards and one new Research Coordination Network (RCN) as a result. In FY 2013 and FY 2014, NSF sponsored a series of workshops across the participating science and engineering directorates to provide input on research priorities and engage in preparatory collaborative activities. NSF used the resulting reports, white papers, and research articles to develop this multi-year roadmap of investment priorities and to devise targeted calls for research proposals. For example, in FY 2014 the Directorate for Biological Sciences (BIO) published a Dear Colleague Letter (DCL) for Early-concept Grant for Exploratory Research (EAGER) proposals for "catching circuits in action" projects to apply innovative neurotechnologies to study neural circuits responsible for cognition and behavior. This resulted in 36 highly interdisciplinary awards focused on elucidating the functional roles of neural circuits, funded by multiple NSF directorates. These awardees were invited to a joint meeting with the first cohort of NIH BRAIN Initiative awardees following the annual meeting of the Society for Neuroscience in Washington D.C. as part of the President's BRAIN Initiative.

Total Funding for UtB

(Dollars in Millions)

	FY 2014 Actual	FY 2015 Estimate	FY 2016 Request
Understanding the Brain (UtB)	**$92.62**	**$106.44**	**$143.93**
BRAIN Initiative	*22.62*	*48.48*	*71.56*

Goal

The overall goal of UtB is *to enable scientific understanding of the full complexity of the brain in action and in context*. This multi-year goal is being pursued across the four ongoing priority areas:

1. Develop innovative neurotechnologies to monitor and analyze brain activity, as well as new tools, experimental approaches, theories, and models to integrate neuroscience information across scales and scientific disciplines.

   This priority area is aligned with the objectives of the Administration's BRAIN Initiative. These objectives are focused on development of innovative technologies, tools and instrumentation, computational infrastructure, theory, and models that will accelerate the integration of knowledge

across experimental scales from atomic to behavioral; across multiple science, engineering, and computational disciplines; and across species and lifespans. Expected outcomes include the development of new neurotechnologies, predictive models, and theories of brain and nervous system function that can guide follow-on experimental research and foster further technical and theoretical achievements.

2. Identify the fundamental relationships among neural activity, cognition, and behavior.

   This priority area aims to foster increased understanding of the causal relationships between neuronal activity in the brain, cognitive processes, and behavior. Advancements in this area require increased collaboration among the neuroscience, cognitive science, and behavioral and social science disciplines; adoption of innovative technologies and methods to monitor and manipulate brain activity, such as the recent development of optogenetics; and the utilization of cyber-infrastructure platforms and computational tools for performing multi-scale analysis of neuroscientific and behavioral data. NSF-planned investments are designed to provide an agile means for research teams to form around specific behavioral paradigms and adapt and/or develop technologies and models. Expected outcomes include an increase in the number of such teams working together on specific neural-behavioral paradigms utilizing advanced methods and models.

3. Transform our understanding of how the brain responds and adapts to changing environments and recovers from lost functionality.

   This priority area aims to expand support for exploring the links among the environment, behavior, and brain function, as well as the enhancing and restorative neurotechnologies that can be brought to bear in these areas. NSF research investments will catalyze the formation of new teams to elucidate basic brain mechanisms and their relationships to social and physical environments, cognition and behavior, and related neuroengineering. The expected outcome is measurable progress in developing specific mappings between brain functional/structural changes, changes in behavior and cognition, and changes in psychosocial, external physical, and technological environments; and acceptance of those mappings more widely in the community via citation and use/re-use.

4. Train a new generation of scientists, engineers, and educators for a transdisciplinary, globally competitive workforce in neuroscience and neuroengineering.

   This priority area focuses on development of a scientific workforce for understanding the brain that is better prepared for interdisciplinary and global collaboration, data analysis and sharing, and adoption of new and innovative technologies, tools, and models. In order to transform the workforce, the activities funded under priority areas 1-3 will require special training and professional development for multi-disciplinary research and international collaboration. The expected outcome will be a future workforce fully engaged in and facile with technologies and data science to understand the brain in action and in context.

Results of NSF's cross-foundational and interagency activities have the potential to accelerate scientific discovery and innovation, promote advances in technology, improve the competitiveness of the scientific workforce, and enhance the lives of Americans through improved educational, economic, health, and social institutions. Improved understanding of the brain will promote brain health; enable engineered solutions that enhance, replace, or compensate for lost function; improve the effectiveness of formal and informal educational approaches; and lead to brain-inspired smarter technologies for improved quality of life. Basic research in these areas will also offer novel insights into how cognitive abilities develop and can be maintained and improved throughout the lifespan.

Approach

Multiple divisions of nearly all NSF science and engineering directorates will participate in the proposed activities. During the last two years, a high-level Steering Committee for Understanding the Brain and two programmatic-level working groups were established by NSF senior management under formal charge to ensure cross-directorate coordination of the proposed activities, including those related to NSF's participation in the BRAIN Initiative. In FY 2015, NSF has streamlined these three groups into a single Understanding the Brain Coordinating Group (UtBCG) to improve communication and efficiency related to support for the BRAIN Initiative, neuroscience, and cognitive science research across the Foundation. The UtBCG is charged with ensuring implementation of the programmatic roadmap as well as interfacing with other federal entities and coordinating the formation of an interagency working group to discuss the creation of a National Brain Observatory as specified in the explanatory statement that accompanied the Consolidated and Further Continuing Appropriations Act of 2015 (P.L. 113-235). As NSF has a long history of funding important neuroscience and cognitive science research through specific core programs, many of these ongoing activities in the core programs will not be under direct purview of the UtBCG.

Through existing mechanisms including workshops, DCLs, RCNs, and targeted solicitations and special mechanisms such as EAGERs and Ideas Labs, NSF will bring together the diverse relevant scientific communities in biology, chemistry, behavior, cognitive science, social science, computer science, engineering, physics, psychology, mathematics, and statistics to identify scientific priorities and needed research infrastructure, establish cross-disciplinary standards, integrate data and methods, and catalyze the development of conceptual and theoretical frameworks.

Many science and engineering research communities that are involved in brain-related research and technology development are expected to continue to participate and benefit from these activities. Interagency collaborations through existing programs such as Collaborative Research in Computational NeuroScience (CRCNS), and international collaborations such as those with the U.S. - Israel Binational Science Foundation are engaged.

Investment Framework

UtB Funding by Directorate

(Dollars in Millions)

Directorate/Office	FY 2014 Actual	FY 2015 Estimate	FY 2016 Request
Biological Sciences	$33.60	$37.77	$43.40
Computer and Information Science and Engineering	11.58	16.50	28.58
Education and Human Resources	5.17	5.00	11.00
Engineering	8.63	10.99	16.75
Mathematical and Physical Sciences	13.08	14.18	18.70
Social, Behavioral, and Economic Sciences	20.56	22.00	25.00
Office of International Science and Engineering	-	-	0.50
Total	**$92.62**	**$106.44**	**$143.93**

Totals may not add due to rounding.

FY 2014 – FY 2015

In FY 2014, NSF invested $22.62 million in the BRAIN Initiative to catalyze fundamental research and new collaborations across neuroscience, neuroengineering, and cognitive science. An additional $70.0 million, through core research activities, focused on accelerating fundamental research and associated development of new technologies for neuroscience and neuroengineering, bringing the total for UtB to

$92.62 million. Participating directorates funded approximately $10 million in new EAGER awards for innovative approaches and neurotechnologies to understand the brain, following a response to a call for letters of interest that was much greater and wider than anticipated (575 responses received, spanning all relevant science and engineering disciplines). Over the past year, NSF has also continued to engage leaders across all scientific and engineering disciplines through a series of cross-disciplinary workshops that have identified a number of key gaps in scientific understanding of the brain and needed technologies. This input guides NSF's investment strategies for FY 2015 and FY 2016. Such activities will also provide insight into future requests.

In FY 2015, NSF increases its investment to $106.44 million for the UtB activity, with $48.48 million of these funds devoted to projects related to the BRAIN Initiative. These investments will drive integration of research at multiple scales of analysis and accelerate the development of new theoretical, experimental, and analytical approaches, including computational and data-enabled modeling and new neural engineering and technology research and development. Funding will also enable transformative scientific progress toward understanding of the functional dynamics of the brain and complex neural systems, and their interactions with changing physical, technological, and social environments throughout the lifespan.

To understand the full complexity of the brain, it will be crucial to increase collaborations among relevant scientific communities, which have traditionally focused on discipline-specific experimental questions. Consequently, FY 2015 investments will also fund new interdisciplinary and transdisciplinary team formation and workforce development through the development of up to two solicitations and two Ideas Labs sponsored by unique combinations of our disciplinary directorates. One such solicitation, integrative Strategies for Understanding Neural and Cognitive Systems (NSF-NCS), has already been issued by SBE, CISE, ENG, and EHR. It invites bold, potentially transformative, scientifically interdisciplinary proposals around two research themes: Neuroengineering and Brain-Inspired Concepts and Designs; and Individuality and Variation. Funding will also support increases in interagency collaboration, coordination, and communication through the BRAIN Initiative and the efforts of the Interagency Working Group on Neuroscience.

FY 2016 Request

In FY 2016, NSF proposes an increase in investments of $37.49 million (for a total of $143.93 million) for the UtB activity. Within the total, $71.56 million will support activities related to the BRAIN Initiative. NSF will continue the focus initiated in FY 2015 by continuing to employ investment strategies designed to enable the transformational research, engineering, infrastructure development, and training required to accomplish the overall multi-year goal across the priority areas identified earlier:

- **Integrative and transdisciplinary team-based brain research.** NSF will seek proposals from interdisciplinary teams of researchers poised to promptly address targeted issues, such as innovative experimentation in realistic and complex environments; neurotechnology development; computational modeling and simulation; and quantitative theory development. Such teams will also contribute to defining requirements for cyberinfrastructure and analytic tools required to address the expected data surge from these experimental, modeling, and theoretical efforts. One major objective of these investments is to establish truly transdisciplinary team-based brain research: integrated collaborative research environments that rise above existing disciplines. NSF will use an array of existing funding mechanisms, potentially including traditional grants, special solicitations, RCNs, centers, EAGERs, and INSPIRE awards.
- **Data science, infrastructure, and tool development for understanding the brain.** NSF will provide new opportunities for building infrastructure and analytic capabilities for data integration and interpretation across scales and disciplines, with the objectives of transforming data to knowledge for advances in cognitive science, neuroscience, neuroengineering, and research and education. Proposals will also be sought to address outcome goals of establishing policies and community practices for data management, open access, data sharing, and methods for exploiting large-scale

neuroscience and behavioral data. A major NSF objective will be to encourage stronger connections with other NSF-funded communities that are dealing with similar Big Data issues and multi-modal data integration, such as those focused on earth, ocean and climate observing, high energy physics, astronomy, and related large-scale computing. NSF will fund planning workshops and other community engagement activities to identify and clarify specific needs for infrastructure and analytic tools.

- **Specialized training and professional development in multi-disciplinary and international research and large-scale data management and analysis.** To develop a scientific workforce that is better prepared for interdisciplinary and global collaboration in understanding the brain, NSF will provide opportunities for training and professional development of supported personnel (students, postdoctoral scholars, and principal investigators) in areas of multi-disciplinary research and international collaboration. Opportunities for multi-disciplinary training will require mentoring and professional activity in collaboration and co-located collaborations with experts from intellectually distinct disciplines. Supporting this effort, the NSF Research Traineeship program (NRT) will feature Understanding the Brain as one of its emphasis areas. For international training, opportunities must be provided for students and professionals to train and/or collaborate abroad for a defined period of time. Award supplements will be tracked separately for evaluation purposes.

Evaluation Framework

A range of impacts and endpoints are anticipated from NSF's UtB activities. Advanced technological, experimental, analytical, and theoretical innovations will expand the scope and scale of fundamental investigations across scientific and engineering disciplines to advance the understanding of the brain in action and in context and promote the translation of discoveries to societal benefits. The cross-disciplinary collaboration focus will accelerate establishment of policies and community practices for data management, open access, data sharing, and methods for handling and analyzing large-scale neuroscience and behavioral data. Finally, NSF workforce investments will increase the human capital and infrastructure needed to serve multi-scale, multi-level interdisciplinary neuroscience and cognitive science.

The UtBCG will oversee evaluation of the progress on scientific and programmatic activities. Assays of success of each priority area will be compared against the expected outcomes described above, using measures including:

- Priority Area 1: level of deployment and adoption of innovative technologies by the scientific community via reuse and citations;
- Priority Area 2: increases in the number of transdisciplinary teams funded to work and publish in this area;
- Priority Area 3: acceptance by the research community of new mappings between brain functional/structural changes and identified changes in psychosocial, external physical, and technological environments; and
- Priority Area 4: number of participants, and demographics of collaborations in publications before and after the investment period.

The progress of the implementation of this investment is being monitored and reviewed quarterly as part of a performance goal in FY 2015. For more information about monitoring key program investments, see the FY 2014 Annual Performance Report in the Performance chapter.