Report to Congress
Transformative Research at the National Science Foundation
April 16, 2008

Summary

Supporting potentially transformative research (PTR) is central to the vision of the National Science Foundation (NSF). Congress, the National Science Board, and the scientific community all want to ensure the NSF's support for PTR remains strong. NSF has taken the following steps in support of PTR: conducted a proposer survey including questions on transformational research; modified the intellectual merit review criterion to call attention to potentially transformative concepts; established the NSF-wide Facilitating Transformative and Interdisciplinary Research (FacTIR) working group; established an operational definition of transformative research; and developed a plan to provide program officers and the scientific community with flexible funding mechanisms to support early stage, exploratory research and research requiring a rapid release of funds. FacTIR is developing recommendations on how PTR can be better solicited, reviewed, and tracked throughout the Foundation's many funding programs.

Introduction

This report was written in response to report language (H. Rept. 110-497) associated with the Consolidated Appropriations Act, 2008 (P.L. 110-161)[1]. This congressional interest mirrors that of the National Science Board (NSB) and the scientific community in general.[2,3] All wish to ensure the NSF's support for potentially transformative research (PTR) remains strong.

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[1] The report language (H. Rept. 110-497) associated with the Consolidated Appropriations Act, 2008 (P.L. 110-161) contained the following reporting requirements:

> *"Transformative research is considered to be both revolutionary and "cutting edge." While the Foundation currently conducts research that could be considered transformational, several reports including the National Science Board's (NSB) Enhancing Support of Transformative Research at the National Science Foundation notes that no funds are dedicated for this express purpose. The Appropriations Committees direct the Foundation to review current practices supporting the solicitation of, and the support of, transformational proposals. The Foundation shall provide a report regarding this review to the Committees on how this emerging area can be addressed, 90 days after enactment of this Act, and provide semi-annual reports with any updates thereafter. The initial report should include the Foundation's definition of transformative research."*

This report is in response to the 90-day reporting requirement. It provides the status of the Foundation's activities regarding the facilitation and support of transformative research. As required, semi-annual updates of relevant Foundation efforts will be provided in the future.

[2] NSB-07-32, http://www.nsf.gov/pubs/2007/nsb0732/nsb0732.pdf

[3] NRC. 2008. The role of theory in advancing 21st-century biology: catalyzing transformative research. National Academy Press. 196 pp.

Support for PTR is central to realizing the vision of the National Science Foundation (NSF). The NSF's FY 2006-2011 Strategic Plan articulates a vision of "*Advancing discovery, innovation and education beyond the frontiers of current knowledge, and empowering future generations in science and engineering.*"[4] This vision is to be realized, in part, by fostering "*research that will advance the frontiers of knowledge, emphasizing areas of greatest opportunity and potential benefit and establishing the nation as a global leader in fundamental and transformational science and engineering.*" To achieve this vision, the nation's scientists, engineers, and educators must view NSF as supportive of proposals that contain their very best and most innovative ideas, including those proposals that contain PTR.

To ensure NSF's support for PTR remains strong, Dr. Arden L. Bement, Jr., (NSF Director) established the NSF-wide Facilitating Transformative and Interdisciplinary (FacTIR) working group in December 2007 to provide recommendations on how the Foundation might improve its solicitation, review, and tracking of PTR. The first part of FacTIR's charge was to develop the framework and implementation plan for new flexible funding mechanisms (to replace the Small Grants for Exploratory Research funding mechanism) to support both early-stage, exploratory research and for research that requires the rapid release of funds. To date, the working group has held two Foundation-wide meetings to gather input from NSF's staff, developed a definition of transformative research, and developed recommendations for implementing the two new funding mechanisms (for early-stage, exploratory research and for research that requires the rapid release of funds).

Definition of Transformative Research

The NSB[5] defines transformative research as "research driven by ideas that have the potential to radically change our understanding of an important existing scientific or engineering concept or leading to the creation of a new paradigm or field of science or engineering. Such research also is characterized by its challenge to current understanding or its pathway to new frontiers." In order to make the NSB definition operational within the context of NSF's funding programs, the Foundation is currently using the following definition, which builds on the NSB definition, with added explanatory text and examples:

> *Transformative research involves ideas, discoveries, or tools that radically change our understanding of an important existing scientific or engineering concept or educational practice or leads to the creation of a new paradigm or field of science, engineering, or education. Such research challenges current understanding or provides pathways to new frontiers.*
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> *Transformative research results often do not fit within established models or theories and may initially be unexpected or difficult to interpret; their*

[4] NSF 06-48, http://www.nsf.gov/pubs/2006/nsf0648/nsf0648.jsp
[5] NSB-07-32, http://www.nsf.gov/nsb/documents/2007/tr_report.pdf

transformative nature and utility might not be recognized until years later. Characteristics of transformative research are that it:

a. *Challenges conventional wisdom,*
b. *Leads to unexpected insights that enable new techniques or methodologies, or*
c. *Redefines the boundaries of science, engineering, or education.*

The following are examples of transformative research sorted by these transformative characteristics:

- The continental drift model—at first controversial and then proved right 50 years later based on new analytical methods and sampling of the ocean floor. (a)
- The discovery of metallic glasses, at first an obscure theoretical possibility that eventually made possible the operation of today's integrated circuits. (a)
- The idea that polar sheets could serve as neutrino detectors, originally tested in Greenland through an NSF SGER award. (a, b)
- The discovery of the widespread exchange of genetic information in the environment, both among microbes and between microbes and higher organisms, which alters evolutionary changes such as in the development of disease resistance and revises our fundamental understanding of The Tree of Life. (a, b).
- Research into large-scale, hypertext web searches that eventually led to the creation of Google. (b)
- The use of magnetic resonance imaging as a tool for monitoring brain function, which greatly expanded the limits of behavioral research. (b)
- The cross-disciplinary coordination of investigations into cognitive simulation and pedagogical techniques that resulted in today's highly effective cognitive tutors. (b)
- The development of the Force Concept Inventory in Physics, which set a direction for improvement in education based on measurement of students' deep understanding of scientific concepts. (b, c)
- Research on Very Large Scale Integrated circuit design methodology that not only led to the microelectronic revolution's cell-phones, personal data assistants, and supercomputers, but also provided the intellectual framework of abstraction that pervades most of today's computer science. (c)
- The careful refinement of distance measures in the Universe, intended to fine-tune cosmological parameters, which instead gave rise to radically new physics, and the concept of dark energy. (c)

Identification and Support of Potentially Transformative Research

The ability to identify proposals during the review stage that **will** result in transformative results before the research is conducted and before the scientific community can

assimilate the findings into evolving theory is challenging and, in most cases, impossible. However, the Foundation can and does identify proposals that contain **potentially** transformative research ideas or concepts. For example, PTR proposals may request support for dramatically new ways of conceptualizing and addressing major scientific or technological challenges. Other PTR proposals may request support for key incremental or threshold advances (e.g., new methods or analytical techniques) that, if successful, could put a discipline on a new scientific trajectory, provide tools that allow unprecedented insights, or radically accelerate the rate of data collection. Alternatively, some proposals may generate serendipitous transformative results that would have been almost impossible to predict prior to the conduct of the research (e.g., research on small RNAs, ribonucleic acids, and the unanticipated discovery of their now known to be pervasive role in gene regulation).

While acknowledging that there is no practical way to determine *a priori* which research proposals will ultimately yield transformative results, the Foundation must ensure its funding programs and review practices pay special attention to those PTR proposals that reviewers find highly innovative or high risk/high reward.[6] Due to the highly innovative or risky nature of the proposed research, it may have a high degree of uncertainty in achieving expected outcomes due to the use of novel or complex methods, technical difficulty, or interdisciplinary scope. In addition to scientific or technical issues that may increase the uncertainty associated with supporting a PTR proposal, other factors, such as scientific bias, lack of appropriate reviewer expertise, or constrained funding, also may have a significant impact on whether a PTR proposal receives funding.

NSF has a long history of supporting PTR as evidenced by the fact that the Foundation has supported the work of 178 Nobel Laureates since its establishment in 1950.[7] By any measure, the Foundation has and continues to support research at the leading edge of science, engineering, and education. The real challenge for the Foundation is to seek new ways to be even more inviting to PTR proposals, determine whether there are any unintended barriers to supporting such work, and facilitate the process for identifying and selecting the best PTR proposals for funding.

NSF-Funded Nobel Prize Winners

Physics	Chemistry	Medicine	Economics	Total
55	44	41	38	178

Promoting Potentially Transformative Research

PTR can originate, be supported, and conducted under multiple program and funding scenarios. These include 1) unsolicited proposals that are submitted to the Foundation,

[6] Here, high risk is associated with a high degree of technical difficulty or novelty, not other forms or risk (e.g., scientific expertise, financial, and institutional) that may be associated with a proposal.
[7] NSF Fact Sheet; NSF-funded Nobel Prize winners in science through 2007; http://www.nsf.gov/news/news_summ.jsp?cntn_id=100683

2) targeted solicitations either within a single directorate or among directorates or agencies (see Box), or 3) special funding mechanisms designed to support exploratory or exceptionally creative research. In addition, NSF sponsors workshops and other studies that explore the scientific, engineering, and education frontier. While the total annual level of funding for PTR proposals supported by the Foundation is difficult to determine, funding for targeted solicitations that support a large number of PTR proposals was estimated at over $250 million in FY 2007.

Examples of Current Targeted Programs that Support Potentially Transformative Research

- Frontiers in Integrative Biological Research (BIO)
- Emerging Models and Technologies (CISE)
- Emerging Frontiers in Research and Innovation (ENG)
- Frontiers in Physics (MPS)
- Office of Multidisciplinary Activities (MPS)
- Science and Technology Centers (NSF)
- Cyber-enabled Discovery and Innovation (NSF)

NSF uses funding mechanisms, such as the Small Grants for Exploratory Research (SGER), creativity extensions, and accomplishment-based renewals, to supplement or encourage potentially transformative ideas. These are mechanisms NSF uses to allow program officers with a keen knowledge of the portfolio of research supported by their program to identify and fund PTR proposals without an extensive external merit review process. The following table contains funding levels for each of these funding mechanisms.

	FY 2005	FY 2006	FY 2007
SGER	$27.0 M	$40.0 M	$34.8 M
Creativity Extensions	$5.6 M	$4.7 M	$5.4 M
Accomplishment Based Renewals	$16.3 M	$17.9 M	$ 21.4M
Total	$48.9 M	$62.6 M	$61.6 M

Support by fiscal year for Small Grants for Exploratory Research (SGER), Creativity Extensions, and Accomplishment Based Renewals. A significant percentage of SGER awards supported "urgent" proposals that are not necessarily PTR proposals.

Small Grants for Exploratory Research[8] (SGER) are designed to provide program officers and the scientific community with a flexible funding mechanism to support the following types of research:

- Preliminary work on untested and innovative ideas
- Ventures into emerging and potentially transformative research areas
- Application of new expertise or approaches to established topics
- Work having a severe urgency with regard to availability of data, equipment or unanticipated events
- Efforts likely to catalyze rapid and innovative advances

The SGER funding mechanism has streamlined submission and review requirements. Up to 5% of program funds can be spent on SGER awards. While widely supported within the Foundation, data indicate that the SGER funding mechanism is not implemented consistently across the Foundation and is not being used to the extent possible.[9] As a result, the Foundation is working on developing a replacement for the SGER funding mechanism to clearly reflect the intentions of the SGER mechanism and to promote greater use by program officers and the scientific community.

Creativity Extensions are extensions of funding for up to two years for certain research grants.[10] The objective of such extensions is to offer the most creative investigators an extended opportunity to address "high-risk" research opportunities in the same general area, but not necessarily covered by the original/current proposal.

Accomplishment Based Renewals allow proposers to substitute the normally required Project Description with up to six reprints of publications resulting from research (NSF supported or closely related to work supported by NSF) for the past 3-5 years.[11] In addition, a brief (4 page) research plan is included for the proposed future research. Such a funding mechanism enables program officers to recommend support, after appropriate review, for scientists and engineers based on their recent achievements and prospects for continued success.

Community Perception

In spite of the many existing programs and funding mechanisms that support PTR proposals, the perception remains among many that NSF should be even more supportive of PTR proposals. For example, the NSB[2] states "...it is the Board's conclusion that NSF's messages and mechanisms (as currently structured) will not counteract the external perception by many that NSF is not as welcoming as it should be to such [transformative] research."

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[8] NSF Grant Proposal Guide, Chapter II, Section D.1.
[9] SRI Study of Small Grants for Exploratory Research, Draft Interim Report, 2008.
[10] NSF Award and Administration Guide, Chapter I, Section D.3.d.
[11] NSF Grant Proposal Guide, Chapter V. Section B.

In 2007 NSF conducted a proposer survey, which included questions concerning NSF and transformative research.[12] The survey results showed that 56% of respondents believed to a great or moderate extent that NSF welcomes transformative research, and 42% believed to a great or moderate extent that NSF tended to fund such research. In addition, 45% of respondents would submit transformative proposals to NSF. Interestingly, respondents who served as reviewers tended to believe transformative research was not prevalent among the proposals they had reviewed, but the majority of these reviewers felt that NSF welcomed these proposals. The same respondents reported that they had recommended transformative research proposals for funding within the past 3 years. Survey data also indicated that approximately 65% of the respondents believed they had submitted proposals to NSF for transformative research within a three year period. These data are in contrast to the finding that 61% of the respondents thought that less than 10% of the proposals they have reviewed over a three year period constituted transformative research.[13] Such data may represent an inherent difficulty in a proposer's ability to communicate clearly to a reviewer those aspects of his or her proposal that are potentially transformative.

The Foundation needs to understand what lies behind this perception and develop strategies to address it. This will require an analysis of NSF's current practices and programs to institute corrective measures where appropriate. While the 2007 proposer survey data indicate a relatively positive attitude concerning NSF's support of transformative research, the Foundation needs to determine where it can do better. Taking such corrective action will be necessary to fulfill the National Science Board's 2020 vision for "a prosperous America that is powered by innovations flowing from the latest transformative scientific ideas with a workforce among the most scientifically and technically competent on the planet."[14] Building on an already strong base of scientific, engineering, and education excellence, actions described in this report and those that will be proposed in the coming months will help ensure this vision is realized.

Modification of Intellectual Merit Review Criterion

On September 24, 2007, the NSF Director issued Important Notice No. 130 on transformative research.[15] Important notices are sent to presidents of universities and colleges and heads of other NSF awardee organizations. This notice indicated that effective October 1, 2007, the NSF Grant Proposal Guide, as well as new funding opportunities issued after that date, will incorporate the following revised Intellectual Merit Criterion (new wording is underlined):

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[12] IPAMM Final Report, August 1, 2007, NSF, http://www.nsf.gov/news/newsmedia/IPAMM_Report_Final.pdf

[13] Booz, Allen, Hamilton 2007 NSF Proposer Survey, 2007

[14] NSB-05-142, http://www.nsf.gov/nsb/documents/2005/nsb05142/nsb05142.pdf

[15] NSF Important Notice No. 130, Transformative Research, September 24, 2007, http://www.nsf.gov/pubs/2007/in130/in130.jsp

What is the intellectual merit of the proposed activity?

How important is the proposed activity to advancing knowledge and understanding within its own field or across different fields? How well qualified is the proposer (individual or team) to conduct the project? (If appropriate, the reviewer will comment on the quality of prior work.) To what extend does the proposed activity suggest and explore creative, original, or potentially transformative concepts? How well conceived and organized is the proposed activity? Is there sufficient access to resources?

All proposals received after January 5, 2008 are being reviewed using this revised criterion. Program officers are instructing reviewers to pay special attention to those proposals that may include PTR.

Recommendations on New Funding Mechanisms

While acknowledging the need to develop a comprehensive set of recommendations and best practices on how to better facilitate the Foundation's support of PTR, the Foundation is taking an important early step by developing new funding mechanisms modeled on the successful aspects of the SGER.

Grants for EArly-concept Grants for Exploratory Research (EAGER) and Rapid Response Research (RAPID)

Two separate funding mechanisms are planned to replace the current SGER. This is intended to raise the visibility of these unique funding mechanisms, reduce confusion about the SGER program (i.e., making clear how and when such funding mechanisms can be used), and provide the scientific community with guidance in submitting proposals.

EAGER awards would support exploratory work in its *early* stages on untested, but potentially transformative, research ideas or approaches. This work may be considered especially "high risk, high reward" in the sense that it, for example, involves radically different approaches, applies new expertise, or engages novel disciplinary or interdisciplinary perspectives.

RAPID awards would support projects requiring a *rapid release* of funds and thus an expedited merit review process. While not specifically targeting PTR, this new funding mechanism would replace the part of SGER that covers projects "having a severe urgency with regard to availability of, or access to data, facilities or specialized equipment, including quick-response research on natural or anthropogenic disasters and similar unanticipated events."

The detailed implementation plan for these two funding mechanisms is under development and review by the Foundation. Issues such as grant size and duration, merit

review, format, funding, and relationship with existing Foundation programs will be determined.

Next Steps

By the end of this Calendar Year:

- FacTIR will provide the Director and Deputy Director with recommendations on the Foundation's support of PTR proposals.

- EAGER and RAPID funding mechanisms will be fully developed and ready for implementation.

- Training modules will be in place for NSF program officers to highlight the importance of supporting PTR proposals, with best practices identified for their use.

- Tracking mechanisms will be in place to monitor the success of the Foundation's efforts to better facilitate the support of PTR proposals.