Background Paper

Identifying, Reviewing, and Supporting Transformative Research at the National Science Foundation

A Background Paper for the NSB-Sponsored Workshop on
Transformative Research

August 12, 2005
Arlington, Virginia

Executive Summary

The National Science Board (NSB, the Board) is currently reviewing existing mechanisms and considering new policies that could enhance the ability of the National Science Foundation (NSF) to identify, nurture, evaluate, and fund innovative, "potentially transformative" research. For the purposes of this discussion, potentially transformative research is defined as research that has the capability to revolutionize existing fields, create new sub-fields, or cause paradigm shifts in thought.

In order to determine feasible ways in which NSF could alter its current practices, the Board is interested in examining the strategies employed within NSF and at other organizations in the scientific community, to identify and fund this type of research. In December 2004 the Board established a Task Force on Transformative Research. Over the next two years this Task Force will convene several workshops, each of which will examine different issues related to transformative research. The Task Force will produce a report at the end of this time that synthesizes the contributions from its deliberations, the workshops, and other sources, and presents policy recommendations for the Board to consider.

The purpose of the first NSB-sponsored workshop on transformative research, to be held on August 12, 2005, is to:

- explore how well current NSF procedures solicit, identify, and support potentially transformative research;
- identify barriers that interfere with the selection and funding of such research proposals; and identify specific suggestions for enhancing NSF's ability to attract, select and fun potentially transformative research in a time of constrained budgets.

The purpose of this paper is to: (1) provide a basic overview of the current funding and identification techniques used by NSF, in the context of how they support potentially transformative research; (2) present a synthesis of comments drawn from the reports of external Committees of Visitors (COV) and Advisory Committees (AC), which address how NSF identifies, reviews, supports "innovative" or "highrisk" research[1]; and (3) catalyze discussion at the August 12 workshop. The content for this paper has been drawn in part from the National Science Board Working Paper *Overview of Approaches for Identifying, Reviewing, and Supporting Transformative Research,* as well as from recent NSF COV and AC reports.

NSF currently has several initiatives that facilitate and support potentially transformative research. Part I of this paper provides an overview of these efforts, including NSF-wide initiatives such as the Small Grants for Exploratory Research (SGER), accomplishment based renewals, creativity extensions, and preliminary proposals; multidisciplinary, multi-directorate initiatives such as those encompassed by the five NSF priority areas; large-scale, center-based programs such as the Engineering Research Centers and Science and Technology Centers programs; and organizational structures that attempt to institutionalize cross-directorate or interdisciplinary programs such as the Emerging Frontiers Division in the BIO Directorate. Characteristics of each of these initiatives are discussed in the context of supporting potentially transformative research.

Part II of this paper synthesizes comments from NSF COV and AC reports, which in the course of reviewing the proposal decisions of program groups, address how well NSF identifies, reviews, and supports transformative, innovative or high-risk research. Common barriers discussed in these reports include: a lack of a clear and consistent definition; a lack of useful categories and metrics for categorizing

[1] Excerpts are from reports of NSF Committees of Visitors (COVs) completed since 2001 and the 2004 report of the Foundationwide Advisory Committee for Government Performance and Results Act Performance Assessment (AC/GPRA)

"high risk" or "innovative" research proposals; the conservatism of reviewers; and competing portfolio considerations and a constrained budget environment.

I. NSF Structures for Supporting Potentially Transformative Research

This section provides an overview of twelve current NSF initiatives, programs and mechanisms that may support potentially transformative research. For the purposes of this discussion, potentially transformative research is defined as research that has the capability to revolutionize existing fields, create new sub-fields, or cause paradigm shifts in thought.

NSF sources highlight structures at multiple levels for enabling and catalyzing potentially transformative research, including exploratory research (e.g., Small Grants for Exploratory Research [SGER]-type awards), high-priority research areas (e.g. Human and Social Dynamics), and organizational structures (e.g. Emerging Frontiers Division) to promote potentially-transformative research.[1,2,3]

There are other programs that do not explicitly focus on transformative research, but may yield such results. For example, Small Business Innovation Research (SBIR), Small Business Technology Transfer (STTR), and initiatives within the Directorate of Engineering's Division of Design, Manufacture, and Industrial Innovation (DMII), involve innovative university-industry collaborations and are often mentioned in NSF discussions of experimental or innovative research.[4,5,6] However, because this document is focused on basic research, analysis of the SBIR/STTR program is not included.

Many current NSF programs use the phrase "high-risk" or "transformative" in their program announcements. However, the use of "high risk" in a program solicitation may be a weak proxy for whether transformative research is being supported by these programs or Directorates. NSF Directorates differ in the terminology they use to describe transformative research, and they differ widely in the number and size of solicitations using "high-risk" language. The CISE and Engineering Directorates are most likely to use "high-risk" terminology to describe their programs, while the Biological Sciences and Mathematical and Physical Sciences Directorates are much less likely to use this language. This finding is a reflection of how solicitations are written rather than a reflection of the research each directorate performs. The second limitation is that budget data are imprecise – a more realistic ratio would be FY 2003 funding relative to Directorate budgets, but NSF's budget web page lists the funding of only a subset of programs.

Small Grants for Exploratory Research (SGER)

The SGER mechanism, available to all research programs since FY 1990, is specifically designed to provide relatively small amounts of funding for exploratory and time-sensitive research. Such research is characterized as preliminary work on untested and novel ideas; ventures into emerging research ideas; the application of new expertise or new approaches to "established" research topics; having extreme urgency with regard to availability of or access to data, facilities, or specialized equipment, including quickresponse research on natural disasters and similar unanticipated events, and efforts of similar character likely to catalyze rapid and innovative advances. Until FY 2003 new SGERs were limited to $100,000 for no more than two years, while now the ceiling has been raised to $200,000. However, NSF and nonNSF individuals indicated in interviews that SGERs still may not offer sufficient funding to catalyze potentially transformative research.

Program characteristics include: (i) Program Officers have the flexibility and freedom to quickly identify innovative research and fund it without external review; (ii) SGERs are short-term, allowing the awards to remain flexible and responsive to changing areas of scientific investigation; (iii) the proposals are short (a few pages) as is the turnaround time. These characteristics of SGERs have allowed NSF to be very timely. For example, after September 11th, the SGER program within the SBE Directorate was able to

fund grants on social psychology, perception and cognition, and the geographical dimension of terrorism within weeks of the attacks, and within the ENG Directorate, SGERs provided funds to assess structural damage at the World Trade Center.

NSF High-Priority, Multidisciplinary, Multi-directorate Initiatives

NSF currently runs five high-priority, multidisciplinary initiatives that are supported by various NSF Directorates. One of the five areas, Math and Science Partnerships (MSP), was not included in this review because while it is a highly innovative and multidisciplinary program, its focus is on education rather than on basic scientific research.

The *Information Technology Research (ITR)* program encourages, "innovative, high-payoff IT research and education" (FY 2004, is the fifth and last year that ITR will be an NSF priority area). The program has participation from all Directorates at NSF and the Office of Polar Programs (Office of the Director). Total funds expended in FY 2004 are $313 million.

The *Nanotechnology* priority area is an inter-agency effort that explores phenomena at molecular and atomic scales and new techniques to facilitate a broad range of applications. As a program, the Nanoscale Science and Engineering initiative is open, covering the entire spectrum of exploratory research as related to nanoscience. The current program solicitation provides funding in three ways: Nanoscale Exploratory Research (NER) – an SGER program within the larger solicitation; Nanoscale Interdisciplinary Research Teams (NIRT); and Nanoscale Science and Engineering Centers (NSEC). Proposals are reviewed by inter-agency and NSF-wide panels. FY 2004 funding for the Nanoscale program was $254 million.

The *Bio-complexity in the Environment (BE)* priority area is a multidisciplinary effort that draws on new scientific and technological capabilities to investigate the interactions among ecological, social and physical earth systems. This is a multi-year, agency-wide set of activities in environmental science, engineering and education, and includes funding of both focused initiatives and core programs that foster research on interdependencies among the elements of specific environmental systems, as well as the interactions among systems. Program funding for FY 2004 is $100 million.

The *Human and Social Dynamics (HSD)* priority area seeks to stimulate breakthroughs in knowledge about human action and development as well as organizational, cultural, and societal adaptation and change. The area, with participation from all NSF Directorates and the Office of Polar Programs (OPP), requires a comprehensive, multidisciplinary approach across science, engineering, and education, including the development of an infrastructure that can support such efforts. Program funding for FY 2004 is $24 million.

Common characteristics of these high-priority, multidisciplinary, multi-directorate initiatives for supporting transformative research include: (i) high levels of funding and a large number of awards; (ii) multi-disciplinarily; (iii) allocation of funds to each Directorate, rather than to specific programs; (iv) cross-Directorate management with rotating leadership on steering committees.

Center-based Initiatives

NSF has created large-scale, center-based programs to encourage interdepartmental synergies within academic institutions and between universities and industry. This collaborative mechanism is intended to spawn new ideas and research methods while promoting innovative, potentially transformational basic research. Centers-based research is an important priority for NSF – in FY 2005 the request for Centersbased programs was $460 million, 10% of the total Research and Related Activities budget request. NSF currently has over 15 centers programs.

Characteristics of these Centers include: (i) programs are large-scale and long-term; (ii) Centers are interdisciplinary in focus; (iii) Centers typically take up to two years to select (iii) multi-disciplinary review panels are assembled with the task to identify potentially transformative problems, and thus, potentially transformative research; (iv) these Centers are agile, with a limited hierarchy.

NSF interviewees indicated that it is initially difficult to get people from different disciplines to work together and to understand each other's language – it may take several years before the different groups really begin to work together as a team. Additionally, NSF interviewees often felt that there is a high burden on NSF staff to manage a Centers program and on the university-based faculty and administrators who oversee the individual Centers.

Organizational Loci of Multidisciplinary, Crosscutting, Potentially Transformative Research

There exist a small number of NSF *organizational* structures that attempt to institutionalize crossdirectorate or interdisciplinary programs and support potentially transformative research. A subset of offices that work with individual directorates and cross-directorates to organize and run programs is presented below.

The *Office of Integrative Activities (OIA)* in the Office of the Director is responsible for overseeing and coordinating cross-Foundational activities. Among its activities, OIA works across organizational boundaries to promote understanding of and support for new directions stemming from strategic planning undertaken by the NSF leadership, and works in partnership with Directorates, major offices, and other parties to develop and promote a performance-based approach to NSF's management of its investment portfolio.

The *Office of Multidisciplinary Activities (OMA)* in the Directorate for Mathematical and Physical Sciences is charged with facilitating and supporting opportunities that cross traditional disciplinary boundaries. OMA works in partnership with the five MPS Divisions to respond more effectively, particularly to proposals that, because of their subject, scope, or multi-investigator or multidisciplinary nature, do not readily fit the existing MPS program structure. OMA provides a focal point in the Directorate for partnerships (e.g., with other agencies, industry, national laboratories, State and local governments, international organizations), seeds crosscutting research in areas of particular promise, and supports innovative experiments in education that could lead to new paradigms in graduate and undergraduate education in the mathematical and physical sciences, particularly in multidisciplinary settings.

The *Emerging Frontiers (EF) Division* in the BIO Directorate attempts to catalyze and support multidisciplinary research and networking activities that arise from advances in disciplinary research. Administration of EF is a collaborative effort among BIO's Division Directors and Program Directors. The Emerging Frontiers Division heads several programs within the BIO Directorate that are aimed at potentially-transformative research areas, including the Frontiers in Integrative Biological Research program (which encourages investigators to identify major under-studied or unanswered questions in biology and to use innovative approaches to address them by integrating the scientific concepts and research tools from across disciplines) and the Research Coordination Networks program (which creates networks of biological scientists working on common problems). The Emerging Frontiers Division also spearheads the BIO Directorate's efforts in NSF's five cross-cutting themes.

Such programs serve as *organizational* loci for supporting potentially transformative research in that they present a centralized organization to support interdisciplinary and cross-directorate programs. However, the current organizational loci do not have a principal core to fund transformational research.

Other NSF Means for Supporting Potentially Transformative Research

There are three additional means by which NSF helps support potentially transformative research.

NSF program officers have the ability to recommend *accomplishment based renewals* to existing grants. This funding can support the pursuit of ideas stemming from previously-funded research. The *accomplishment based renewal* process imposes a minimal burden on applicants and provide additional funding to promising research. In FY 2000, there were 39 requests for accomplishment based renewals, 27 of which were awarded.

A *creativity extension* is an extension of funding for up to two years for certain research grants. The objective of such extensions is to offer the most creative investigators an extended opportunity to attack "high-risk" opportunities in the same general research area, but not necessarily covered by the original/current proposal. Special Creativity Extensions are initiated by the NSF Program Officer based on progress during the first two years of a three-year grant. In FY 2000, there were 43 creativity extensions made to existing NSF grants.

Some programs try to manage proposal pressure by requiring submission of *preliminary proposals.* The process can help researchers target their proposals to the appropriate entities, reduce the burden imposed on applicants, and also allow researchers to make modifications to a proposal before it is submitted, so that the chances of success are improved. Normally, preliminary proposals require only enough information to make fair and reasonable decisions regarding encouragement/discouragement of a full proposal. However, they may also discourage the submission of full proposals for high-risk research.

II. Barriers to Identifying, Reviewing, and Supporting Potentially Transformative Research

Four important barriers to identifying, reviewing and supporting potentially transformative research at NSF were identified in various AC and COV reports: the lack of a clear and consistent definition of such terms as “high-risk” and “innovative”; the lack of useful categories and metrics for “high risk” or “innovative” research proposals; the tendency of reviewers to be conservative; and competing portfolio considerations and a constrained budget environment.

Lack of a Clear and Consistent Definition

A longstanding underlying problem in dealing with the topic of transformative research has been how to define and label the type of research under discussion. The use of the term “transformative” is a relatively recent development in the NSF context. Historically, NSF discussions and activities have typically characterized such research as “high-risk” and/or “innovative.” However, neither of those terms is rigorously defined and, for the most part, their application is “in the eye of” the individual reviewers and program officers.

Consistent application of a more precise term and its clear definition would ease the conceptual difficulties experienced by reviewers, program staff, and external committees, thereby promoting the efficiency of the proposal review system as well as its effectiveness. A recent critique of the general COV report template that was undertaken for the Engineering Directorate shows that there is disagreement both within and across COVs about what the terms “high risk” and “innovative” mean and to what extent they overlap. [7] This ambiguity causes frustration on the part of the COV members, leads them to spend precious time trying to develop their own definitions (sometimes with little success), and results in responses that are not comparable across COVs.

On this point, the AC/GPRA noted in reviewing a range of COV reports that: ". . . the term 'high risk' with regard to research is still not clearly defined. It was not always clear to the Committee what characteristics NSF staff making the designation of 'high risk' were using to indicate specific projects in the portfolio . . . In our view . . . a high risk project is one that attempts something of a different size and scope than has been tried previously [or] because it tries to do something with potentially large benefits for society that others have tried to do and failed." [8]

An aspect of the definitional problem is a tendency shown in some COV reports to lump together the terms high-risk, innovative, and multidisciplinary. Some COV members interpret multidisciplinary work to be risky and innovative by definition. In this regard the AC/GPRA "believes that it would be useful to separate the characterization of NSF-supported research into that which is 'innovative,' that which is 'high risk" (bold), and that which is multidisciplinary . . . These criteria are not mutually exclusive and all have intrinsic value in a broad and balanced portfolio."

That clearer definitions would be useful is also found in one COV's comments that ". . . future evaluation efforts at all levels will be enhanced by better definitions of these terms and by specific responses in progress reports."[9] Another COV "felt that the appropriate term should have been high risk, with high impact potential. It was also felt that maybe this kind of proposal should be evaluated by a different system."[10]

Lack of Useful Metrics

In some cases, COVs felt that any assessment on their part of high risk and innovative proposals would be too subjective, since NSF does not generally characterize proposals in that manner.

In replying to a COV, one Directorate recognized that "It is certainly true that an unambiguous definition of what is meant by "high risk" is difficult to come up with. . . . the real difficulty is in providing the COV members lists of proposals that are high risk . . .The NSF databases that hold information about proposals do not, unfortunately, provide any way of identifying [such] projects."[11]

One COV stated: "Given these imperfect measurements of high risk in projects, we concluded that the program funds an appropriate number of high-risk proposals and has implemented changes to ensure support to innovative proposals by new researchers. However, clearly a better metric is needed to answer this question if it is to be answered precisely." [12] Another noted, "It may be useful to develop a risk metric (e.g. new PI, new kind of experiment or instrument) . . . "[13]

Several COVs tended to interpret the term "high-risk" as applicable only, or mostly, to SGER proposals. For example: ". . . the Division Director has recommended that each [program director] should fund not less than 3 SGER awards. This will more than double [the Division's] investments in innovative research awards while being mindful of the 5% cap on the non-competitive award total for the Division."[14]

At times program staff and reviewers seemed to consider inexperienced Principal Investigators (PIs) to be high risks, even when their proposals otherwise had substantial merit. One COV observed that "In a number of cases . . . well-established researchers were selected for funding while similarly ranked proposals by new or unknown investigators were denied, because the panel or the [program officer] 'trusted' the PI to resolve the proposal shortcomings because the PI had a demonstrated track record . . When such decisions are made, the programs may want to consider allocating some resources for similarly ranked high-risk (i.e., less known PI's) proposals." Another COV declared, "CAREER proposals are submitted by new investigators with no proven track record. Therefore, these proposals are in a high-risk category."[15]

Reviewer Conservatism

The idea that reviewers tend to be too critical in their analysis of proposals, or too conservative in supporting innovative ideas, was a theme present in many COV reports. When the AC/GPRA summarized their review of 2004 COVs they stated their belief that ". . . the merit review process actually filters out these types of high risk projects and they are likely only to be funded when a NSF program manager takes the bold steps to support one of these efforts despite reviews that might be unfavorable (i.e., because of the somewhat conservative nature of the merit review process) . . ."

One COV declared its "sense . . .that truly high-risk, potentially high gain projects probably would not receive a positive panel review because in general, panelists tend to be conservative in their judgments . . . [our] suggestion was to have a solicitation for a limited number of particularly creative proposals that would be funded at an attractive level over a time span sufficient to permit more than exploratory work."[16]

Several COVs acknowledged that strong action on the part of program managers could overcome systematic conservatism. For example, one COV stated that "The subset of [proposals] we randomly reviewed uniformly illustrated the acumen of the program officers as they repeatedly intervened, often quite imaginatively, to ensure that creative or novel, yet risky, ideas/proposers were given a chance to succeed. Typically these high-risk proposals were identified by favorable reviews on the basic scientific ideas, but low numeric ratings due to a reviewer's skepticism regarding the feasibility of the project, or the lack of a track record by an investigator."[17] Another observed that ". . . innovation is fostered by the feedback mechanism between the PIs and the [Program Officers] that results in improved proposals"[18]

On the other hand, COVs occasionally compliment a program about its handling of high risk proposals. For example, one COV stated: "It was clear from the jackets that scientific risk was not a negative factor in proposal review and that presenting a scientifically risky idea did not disadvantage proposals with respect to funding. . . Although reviewers are not asked to assess the innovativeness of proposals, in about 10% of cases innovativeness was so significant that reviewers noted it. There was no obvious discrimination against proposals called 'innovative'." [19]

Competing Portfolio Considerations and a Constrained Budget Environment

Any consideration of changes to the review system must take into account its many objectives and the dynamics among them. The system as a whole is experiencing greatly increased proposal pressure, with little increase in staff resources. In FY 2004, NSF took action on 43,582 competitively reviewed research and education proposals, an increase of 9 percent over FY 2003 and 25 percent over FY 2002. [20] The overall funding rate of 24 percent was the lowest in 15 years, and down from 33 percent in FY 2000. The number of program officers increased slightly from 380 in 2003 to 385 in 2004.

As the FY 2004 Merit Review report points out, "NSF program officers produce and manage a portfolio of awards that must be balanced among many issues and objectives. For example, in addition to support for high-risk proposals with potential for significant advances, in making their recommendations program officers must consider issues such as:

> Potential impact on human resources and infrastructure;
> Balance of different approaches to significant research questions; NSF core strategies, such as the integration of research and education; Special program objectives and initiatives;
> Balance of the overall portfolio, considering other available funding sources; and,
> Geographic distribution."

Additional policy considerations not specifically listed include the goals of increasing average award size and duration and broadening participation of underrepresented groups in science and engineering.

Difficult budgetary constraints coupled with a rapid growth in the number of submitted proposals to NSF, have increased pressure to fund only those proposals that receive excellent ratings from all reviewers while more risky or controversial research proposals might be passed over.[21] For example, one COV stated "[T]he intense competition also means that every proposal is under intense scrutiny for any lapses or shortcomings that could lead to eliminating it from consideration. Innovation and risk may go hand in hand to some extent. Innovation generally requires novel ideas, methodologies, and approaches that are untried and inherently riskier than simply applying known methods to different areas. This may tend to self-select proposals that are less radical and demonstrate a greater certainty of success."[22]

Another addressed the issue by saying " . . . there was some evidence that high-risk proposals suffer from expectations by members of panel reviews that the proposed methodology and outputs should (must) be known prior to grant award. Therefore, panelists may be unwilling to fund "risky" proposals during periods of tightening budgets."[23]

With regard to budgeting for transformative research, the AC/GPRA concludes "No obvious formula exists to guide NSF as to the fraction of the portfolio that should be 'high risk' (or 'bold'). However, we can say without hesitation that it is vital that the overall portfolio contain an appropriate amount of 'bold' research and that the definition of such research must be clear and widely understood by NSF's key stakeholders. We also recognize that there is always a tension in finding and funding such research relative to other priorities and, where possible, we suggest that NSF should do more. However, we also offer a caution: the need to show 'results' and, indeed, this GPRA process, should not make the finding and funding of such research more difficult. There must be an appreciation by all who support the use of taxpayer money for good and valid national purposes that advancing the frontiers of human knowledge requires, indeed demands, that our research portfolio contain investments with long odds of success (but, if successful, with the ability to fundamentally transform our understanding)."

[1] National Science Foundation. Grant Proposal Guide. 2003. Available online at: http://www.nsf.gov/pubs/2004/nsf042/2.htm

[2] National Science Foundation. Guide to Programs. 2004. Available online at: http://www.nsf.gov/od/lpa/news/publicat/nsf04009/cross/priority.htm

[3] Dr. Joseph Bordogna. Awards for the Integration of Research and Education in the 21st Century. Available online at: http://www.nsf.gov/od/lpa/forum/bordogna/jb0401 foreword.htm

[4] National Science Foundation. Division of Design, Manufacture and Industrial Innovation. Program Description. 2003. Available online at: http://www.eng.nsf.gov/sbirspecs/Program/program.htm

[5] National Science Foundation. Division of Design, Manufacture and Industrial Innovation. Biotechnology. Available online at: http://www.eng.nsf.gov/sbirspecs/BT/bt.htm

[6] National Science Foundation. Division of Design, Manufacture and Industrial Innovation. Information-based Technologies. Available online at http://www.eng.nsf.gov/sbirspecs/IT/it.htm

[7] SRI International. Suggested Revisions to NSF's Committee of Visitors (COV) Template. March 2005. Unpublished report to NSF's Directorate for Engineering.

[8] All AC/GPRA excerpts are from the Committee's report dated July 30, 2004. Available online at: http://www.nsf.about/performance/acgpa/index.jsp

Note: All COV reports completed since 2001, including those cited below, are available online at http://www.nsf.gov/od/oia/activities/cov/covs.jsp, where they are listed by Directorate and Year of COV meeting.

[9] 2001 COV review, Division of Engineering Education and Centers

[10] 2004 COV review, Division of Mathematical Sciences

[11] NSF reply to 2002 COV review, Division of Atmospheric Sciences [12] 2004

COV review, Division of Earth Sciences [13] 2003 COV review, Division of

Ocean Sciences

[14] 2002 COV review, Division of Electrical and Communications Systems [15]

2002 COV review, Division of Ocean Sciences

[16] 2003 COV review, Division of Design, Manufacture, and Industrial Innovation [17] 2004

COV review, Division of Atmospheric Sciences [18] 2004 COV review, Division of Earth

Sciences [19] 2003 COV review, Office of Polar Programs

[20] Report to the National Science Board on the National Science Foundation's Merit Review Process, Fiscal Year 2004 (NSB 05-12, March 2005), available at: http://www.nsf.gov/nsb/documents/2005/MRreport_2004.pdf

[21] 2004 COV review, Division of Social and Economics Science (SES) [22] 2002

COV review, Division of Earth Sciences [23] 2001 COV review, Division of

Civil and Mechanical Systems