REPORT OF THE ADVISORY COMMITTEE FOR

GPRA PERFORMANCE ASSESSMENT

FY 2007

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AC/GPA FY 2007 REPORT

I. EXECUTIVE SUMMARY

Charge: The 2007 Advisory Committee for GPRA Performance Assessment (AC/GPA) was charged to provide a report to the National Science Foundation (NSF) Director that included an assessment of whether NSF had demonstrated "significant achievement" for overall performance for each of the following three Strategic Outcome Goals identified in the *2006-2011 Strategic Plan (http://www.nsf.gov/pubs/2006/nsf0648/NSF-06-48.pdf):*

- **DISCOVERY:** Advancing frontiers of knowledge
- **LEARNING**: Science and engineering workforce and scientific literacy
- **RESEARCH INFRASTRUCTURE**: Advanced instrumentation and facilities

The fourth strategic goal, "**STEWARDSHIP**: supporting excellence in S&E research and education," will be assessed within NSF using a number of metrics developed internally.

Although not in the formal charge, the Committee was also asked to provide comments to the Foundation regarding "transformative research" and general comments about the AC/GPA process.

Process: To determine significant achievement on the three strategic outcome goals of the 2006-2011 Strategic Plan, the AC/GPA reviewed 1,147 summaries of NSF funded projects, performance highlights ("highlights"), written by NSF program officers and approved by Division Directors and the Directorate. The Committee had access to additional materials including reports from Committees of Visitors (COV) and NSF Advisory Committees as well as the Program Assessment Rating Tool (PART). The Committee also had the benefit of the expertise of NSF staff members who provided materials on the AC/GPA members only secure website, topic presentations, and served as resource to the Committee throughout the process. Work was carried out both in small groups (subgroups) representing each of the three assigned NSF strategic goal areas, and in meetings of the Committee as a Whole. The Committee members participated in a web-based orientation and had access to all materials in advance of the meeting. Each subgroup member conducted reviews and documented preliminary findings prior to the formal meeting. The Committee met on June 14 and 15, 2007, to finalize its findings and develop recommendations.

Findings: Based on the review of materials provided, the Committee concluded that NSF demonstrated **significant achievement** in the 2006-2011 strategic goals: Discovery, Learning, and Research Infrastructure. Detailed level assessments of performance against each of three strategic goals are provided in Section IV of the report.

Deliberations relating to transformative research resulted in three primary comments and recommendations:

- there is a need for a formal definition of "transformative research" which encourages high potential proposals in a risk-taking environment,
- an agile review process should be developed that is not constrained by program-level status, and;
- in identifying and funding transformative research, the keys to success appear to not just involve the proposed research, but also the personal characteristics and/or traits of the

principal investigator, the capabilities of the institution conducting the work, and a partnering relationship with NSF's program officer.

Recommendations: The Committee made several comments about the AC/GPA process based on the 2006-2011 NSF Strategic Plan. There were five primary recommendations:

1. Highlight selection process: The selection process for highlights by NSF needs to be reviewed to ensure that the Committee has access to a broad range of projects that are representative of all the projects funded by NSF and classified by the strategic goal areas.
2. Criteria for goal assessment: In order to provide more focused recommendations and greater value to NSF, the Committee's work would be facilitated by having specific criteria for each of the strategic goals that could be used by the subgroups in their assessment of goal achievement.
3. Materials for review: A greater diversity of information (not greater amount of information) should be provided to the subgroups and a greater emphasis be placed on COV and Advisory Committee reports as a focus of member review efforts.
4. Portfolio balance: Information needs to be provided that enables the AC/GPA subgroups and the Committee to determine portfolio balance among and within the strategic goal areas.
5. Availability of assessment data: For the Learning strategic outcome goal, the highlights lacked information on quantitative and/or qualitative assessment results and baseline data that could be used to determine whether or not funded projects had achieved their objectives.

II. 2007 STRATEGIC OUTCOMES GOALS

The National Science Foundation's (NSF) *Strategic Plan FY 2006-2011* lists four strategic outcomes goals: **Discovery, Learning, Research Infrastructure, and Stewardship.**

> **DISCOVERY**: Foster 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.
> **LEARNING**: Cultivate a world-class, broadly inclusive science and engineering workforce, and expand the scientific literacy of all citizens.
> **RESEARCH INFRASTRUCTURE**: Build the nation's research capability through critical investments in advanced instrumentation, facilities, cyberinfrastructure and experimental tools.
> **STEWARDSHIP**: Support excellence in science and engineering research and education through a capable and responsive organization.

The formal charge for the 2007 National Science Foundation (NSF) Advisory Committee for GPRA Performance Assessment (AC/GPA) was to assess whether NSF "has demonstrated significant achievement for the Discovery, Learning, and Research Infrastructure strategic outcome goals" and to convey its assessment in a report to the NSF Director.

III. FOUNDATION-LEVEL ASSESSMENT SUMMARY OF FY 2007 INVESTMENTS IN BASIC SCIENCE, ENGINEERING, AND EDUCATION RESEARCH

Overview

Committee: The 2007 National Science Foundation (NSF) Advisory Committee for GPRA Performance Assessment (AC/GPA) consisted of eighteen independent experts drawn from the science, technology, engineering and mathematics communities in both the private and public sectors. AC/GPA Committee members are from a diverse range of backgrounds including academia, national laboratories, and private industry, among others. Most of the members have also served on other internal NSF advisory committees within the Foundation. The varied backgrounds of the Committee membership ensured that a broad spectrum of experience would be brought to the deliberations of the Committee. Of the eighteen Committee members, twelve served on the AC/GPA for two or more years while six were new appointees.

Charge: The 2007 (AC/GPA) formal charge was to assess whether NSF had demonstrated significant achievement of three of the NSF strategic outcomes goals related to the 2006-2011 Strategic Plan and to submit its findings in a report to the NSF Director. The three strategic goals assessed were Discovery, Learning, and Research Infrastructure. The fourth goal of the current Strategic Plan, Stewardship, was not part of the charge, and thus was not assessed by the AC/GPA this year. In previous strategic plans, this fourth goal was called "Organizational Excellence" and its merit review performance indicator was part of the Committee assessment. In 2007, annual performance measures for the Stewardship goal have been developed by NSF and are being monitored and evaluated within the Foundation. However, the Committee did have the opportunity to evaluate many aspects of Stewardship through its review of reports of both the Committees of Visitors (COV) and the Advisory Committees (AC) for various divisions and directorates throughout the Foundation and had the opportunity to make comments as a part of the Committee's deliberations.

In addition to the formal charge related to goal achievement, the Committee was also asked to provide comments concerning transformative research and the overall AC/GPA process.

AC/GPA Structure: In order to accomplish its work, the Committee was divided into three working groups representing the strategic goal areas of Discovery, Learning, and Research Infrastructure. These subgroups were chaired by AC/GPA Committee members who served as valuable resources to the other committee members and facilitated the work of their respective subgroups, as well as leading much of the discussion for the Committee of the Whole. The AC/GPA Committee began its work in the spring of 2007 with teleconferences designed to review the Committee's charge, review resources available, and discuss processes and timelines. During the pre-meeting work, members of the subgroups reviewed the performance highlights and made preliminary selections of those that they believed supported their overall assessment. Each subgroup chose the final number of highlights, which are found in the Appendix.

AC/GPA Review Process: The NSF database of performance highlights served as the primary source of review by the Committee. There were a total of 1,147 Highlights provided to the Committee of which 455 were designated by NSF program officers as "transformative," representing roughly 40% of the total highlights submitted. The highlights, which were selected by program officers and approved by Division Directors and the Directorate, represented projects that were active during the period March 1, 2006 and March 1, 2007; however, some of the projects had been funded by NSF several years ago. This presented a challenge to the Committee because it was asked to infer goal achievement from these projects against the new 2006-2011 Strategic Plan. It is important to note that the 2006-2011 strategic outcome goals of Discovery, Learning, and Research Infrastructure are similar to the 2003-2008 Ideas, People and Tools. In the 2003-2008 Strategic Plan each strategic outcome goal was comprised of several "performance indicators." In previous AC/GPA processes, the Committee independently reviewed and evaluated each of the performance indicators related to each of the goals to determine "significant achievement" of the overall goals. This year the Committee was charged to conduct its assessment with respect to NSF performance against the overall goals without performance indicators or linkages to investment criteria. In addition, the charge issued to the Committee this year did not include making an assessment of relevance and quality of the portfolio as had been requested in the previous year.

The primary medium for information to the Committee was the AC/GPA secure "members only" website that was prepared by NSF staff to facilitate the work of the Committee. In addition to the Foundation-provided highlights, website links were provided to other resources for the AC/GPA Committee to review. These included the NSF Strategic Plans, Reports to Congress and the Office of Management and Budget, NSF Audit reports, Performance and Accountability Reports, NSF Budget Requests to Congress, Reports from the National Science Board, Performance Highlight Reports, Program Assessment Rating Tool (PART) Reports, and Director's testimony to Congress and its committees. The website was invaluable to the Committee in its work and NSF staff is to be congratulated on the development of this website that has enabled the committee members to work more efficiently.

In addition to the web-based information sources, background information was provided to the Committee on the first day of the AC/GPA meeting. NSF staff gave presentations on the following topics: Communication Results of NSF Investments, Budget and Performance

Integration at NSF, Performance Assessment Framework, Broadening Participation: Status Report of Working Group Activities, Impact of Proposal and Award Management Mechanisms: Study Update, Merit Review, and Status of 2006 AC/GPA Recommendations. Information from these presentations was used, as appropriate, throughout the Committee deliberations.

Overall Findings and Recommendations

Goal Achievement

The Committee was unanimous in its conclusion that NSF has demonstrated **Significant Achievement** for the strategic goals of Discovery, Learning, and Research Infrastructure. The Committee has based its opinion of "Significant Achievement" not only upon the quality, quantity, and outcomes of NSF-provided highlights, but also upon the overall performance across the agency as determined from other reports made available for review. From novel discoveries in the basic sciences and engineering to educational advancements across the Science, Technology, Engineering and Mathematics (STEM) disciplines, NSF has demonstrated continued commitment to its basic goals of pursuing the highest quality research, in innovative and transformative ways, while broadening the participation in science and engineering of people from all parts of society. A detailed assessment of each of the strategic outcome goals reviewed is found in section IV.

Transformative Research

Although not in the formal charge for the AC/GPA, the Committee was asked that each subgroup consider the concept of "transformative research" as it related to their specific goal assessment. The Committee of the Whole also discussed the issues which were raised in the subgroups. The comments below are based on a review of materials provided on the AC/GPA website as well as from the NSF-related experiences of the Committee members. The Committee was asked to consider the following three questions:

1) Is there evidence that NSF supports transformative research?
2) Could transformative research have been identified at the time the proposal was submitted?
3) How would we identify transformative research if we saw it?

In the discussion of these questions, the Committee offered the following recommendations and comments:

1. Define transformative research: Because of lingering confusion, the AC/GPA believes that NSF should consider adopting the transformative research definition proposed by the National Science Board in its report, Enhancing Support of Transformative Research at the National Science Foundation (see box) (http://www.nsf.gov/nsb/documents/2007/tr_report.pdf)

2. This definition is consistent with the results of an affinity exercise conducted by the Committee in which the Committee identified the following attributes of transformative research: revolutionize entire disciplines; produce impacts that are far reaching; create new fields of science

> NSB Proposed Transformative Research Definition
>
> *"Transformative research is ... 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."*

and engineering; produce radical change in our existing understanding of science and engineering; alter existing scientific concepts; disrupt current paradigms, or lead to a new expanded reality.

In the absence of a definition, judging whether research is or has the potential to be transformative will continue to be a challenge. As an example, this year program officers were asked to designate from among the performance highlights they chose for AC/GPA review, the ones they deemed to be "transformative" and to write a brief explanation as to why the highlight was chosen. In the absence of a definition of "transformative," 455 of the 1,147 (about 40%) of the total projects represented by the highlights in the AC/GPA database were designated by program officers to be transformative. Although the Committee was not asked to comment on their view of the quality of the program officers' selections, the Committee recognized a wide variability in the nature of the highlights designated as "transformative." It was clear that the selections would have been more meaningful if the NSF staff had a common definition from which to work.

3. Examine the merit review process as it relates to funding of transformative research. The merit review process is a gold standard, and has been a mainstay for the NSF. However, the current merit review process is conservative in nature. Nonetheless, it was the consensus of the Committee that NSF does not need a new program for funding transformative research but that it could be formalized within the existing structure with new guidelines for program officers. Instead of using the current process for review, it is recommended that program officers consider using an external "SWAT" team made up of individuals with demonstrated success in conducting transformative research. The review process should be multidisciplinary and represent multiple programs, divisions, and agencies where appropriate. It is also recommended that a special "advisory panel for transformative research" be established to add value and definition to the overall process. Program officers should have flexibility and latitude within the award and project management process. The application and review process should be kept relatively simple, review should be "light," and budget competition with traditional merit review budgeted pools should be minimized. The process should be applied uniformly across NSF.

   The Committee also offers a caveat on creating a formal process for transformational research. There should be a balanced research portfolio at NSF. The various terms being used to describe the range of possible research includes: safe science, frontier science, evolutionary science, revolutionary science, and transformational science. None of these research labels are effectively defined, including the "safe science" that the NSF Director stated should not be funded by NSF (http://www.nsf.gov/news/speeches/bement/07/alb070104_texas.jsp).

   The Committee recommends that NSF consider defining these research types, creating an appropriate review process, and maintaining balance between these research categories.

4. Create partnerships: In identifying and funding transformative research, the key to success appears to not just involve the proposed research, but also the personal characteristics and/or traits of the principal investigator, the capabilities of the institution conducting the work, and a partnering relationship with NSF's program officer. The Committee believes that some types of proposals and some types of investigators are more likely to produce transformative results than others, while past performance does

not necessarily assure success in new transformative outcomes, consideration should be given to the principal investigator and the institution in terms of successful past performance. Individual principal investigator characteristics that are agreed to most likely to produce transformative research generally include high quality, multidisciplinary researchers who have access to major research facilities and are not constrained by current conventions but are willing to push the boundaries. NSF program officers also play a key role in identifying projects that have the potential to be transformative. This would include working in partnership with the principal investigator and demonstrating a willingness to take risks, make programmatic changes when needed, and willingness to accept and learn from projects that fail.

Challenges and Recommendations related to the AC/GPA Assessment Process

During Committee deliberations, several issues were raised related to the AC/GPA process. Each subgroup identified issues that related to their particular goal area as well as the process as a whole. The following issues represent the Committee's comments and recommendations:

1) Highlight selection process: The selection process for highlights by NSF needs to be reviewed to ensure that the Committee has access to a broad range of projects that are representative of all the projects funded by NSF and classified by the strategic goal areas. The majority of Committee members' time was spent reviewing hundreds of highlights that had already been selected as representing "notable accomplishments" by program officers and subjected to Division and Directorate approval before submission into the AC/GPA database. In addition, some of the projects selected as highlights had been funded by NSF several years ago, although the Committee is asked to infer goal achievement from these highlights against the new 2006-2011 Strategic Plan. The use of this judgmental sample (not representative sample), coupled with the fact that the current assessment is only at the highest level (goal level achievement), resulted in the Committee reaching the conclusion of goal achievement. This conclusion would be much more robust if the Committee had a better sense of whether the chosen highlights represented the diversity of projects in a goal area. This is an issue which is raised consistently by the AC/GPA and needs to be addressed to enhance the credibility of the assessment process.

2) Criteria for goal assessment: In order to provide more focused recommendations and greater value to NSF, the Committee's work would be facilitated by having specific criteria for each of the strategic goals that could be used by the subgroups in their assessment of goal achievement. The revised AC/GPA process for 2007 required a very broad review of achievement of NSF strategic goals. In the absence of specific criteria (e.g., performance indicators, investment priorities), the assessment is at such a high level as to lack focus for specific areas of assessment within the strategic goals making the assessment process almost perfunctory (see #1 above).

3) Materials for review: The Committee recommends that a greater diversity of information (not greater amount of information) be provided to the subgroups and a greater emphasis be placed on COV and Advisory Committee reports as a focus of member review efforts. Although the Committee was encouraged to review the COV and Advisory Committee reports, these reports had been submitted under a format aligned with the previous strategic plan and, although they were of interest, it was not clear how these would be useful at the goal level assessment. It needs to be made clear how COV and Advisory Committee reports can provide information that would be useful in

addressing goal achievement. Once that connection is made, a review of selected COV and Advisory Committee reports, in addition to the review of highlights, would provide a broader perspective on NSF performance.

4) Portfolio balance: Information needs to be provided that enables the AC/GPA subgroups and the Committee of the Whole to determine portfolio balance among and within the strategic goal areas. Both the Learning and the Research Infrastructure subgroups had concerns about the balance of highlights within the AC/GPA highlight database. For example, in some cases, because the highlights were dominated by one particular aspect of the goal area (e.g., cyberinfrastructure in the case of Research Infrastructure) it was not possible to comment about the other elements of the goal area (e.g., facilities, experimental tools, etc., in Research Infrastructure). Where the strategic goals are made up of several categories, the subgroup looks for balance within the highlights database to determine goal achievement. In several cases, this was difficult to ascertain and it was not clear if the portfolio was balanced or if there appeared to be an imbalance because of the selections made by the program officers. The Committee recommends that program officers be encouraged to submit highlights that reflect the balance of the portfolio of funded projects.

5) Availability of assessment data: For the Learning strategic outcome goal, there was a concern that the highlights lacked information on quantitative and/or qualitative assessment results and baseline data that could be used to determine whether or not funded projects had achieved their objectives. This should be encouraged where available and made part of the highlight summary. This is an issue that has been raised by previous AC/GPA subgroups.

IV. DETAILED GOAL ASSESSMENTS

Discovery Outcome Goal

*The Committee concluded that there has been **significant achievement** in the Discovery outcome goal.*

The outcome goal for DISCOVERY is to: "Foster 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."

The Committee found that the National Science Foundation has fulfilled its strategic goal of Discovery and is doing so with research that encompasses ever-more complex systems of technological and societal relevance. Of a total of 1,147 highlights generated for Committee assessment, 768 were identified by the Foundation's program officers as primarily representing NSF's Discovery strategic outcome goal. Another 173 highlights were identified as having Discovery as the secondary outcome goal. This was not a surprise as the largest part of the NSF portfolio is aimed at research that advances discovery and innovation. As could be expected, a significant number of the Discovery highlights were also designated as "transformative."

Of the 768 highlights provided by NSF as Discovery outcomes, over 70 highlights were initially selected by the subgroup members. Many exciting discoveries were described and the project outcomes provided clear examples of goal achievement. The subgroup found most of the highlights to be exemplars of the NSF research investment and did capture uniformly interesting scientific research. This set of highlights consistently underscores the success the NSF has achieved in freeing their grantees from “one-flavor” research and encouraging them in their proposals to explore scientific problems that cross multiple scientific disciplines. Many of the projects have significant broader impacts components, including opportunities for underrepresented groups in science and engineering, and precollege and college students.

After final deliberations and, at the request of the Chair, the subgroup selected ten highlights for inclusion in the appendix of this report as the best, most representative examples of Discovery goal achievement. These selected highlights include work at the University of Oregon, Eugene where researchers are examining how mosquitoes tell time by looking at mosquitoes' genes; research at Georgia Institute of Technology resulting in the development of nanoscaffolds that hold great promise for repairing damage to peripheral nerves; the Integrated Ocean Drilling Program project in which geologists, hydrologists, and biologists collaborate to explore the sub-ocean water reservoir; the use of prairie grass as a new biofuel which could be an important renewable energy source; and research at the University of California–Santa Barbara, that has led to novel algorithms that more effectively exploit the power of underlying computer hardware silicon. Many of the highlights selected are multidisciplinary and collaborative efforts, with projects that span the gamut from the atomic to the cosmic and represent innovative work.

Learning Outcome Goal

The Committee concluded that there has been ***significant achievement*** *in the Learning strategic outcome goal.*

The outcome goal for LEARNING is to: “Cultivate a world-class, broadly inclusive science and engineering workforce, and expand the scientific literacy of all citizens.” The Learning subgroup reviewed the highlights classified under the LEARNING strategic outcome goal. Of the 227 highlights provided by NSF, the subgroup selected nine highlights for inclusion in this report as outstanding examples of performance.

In the process of accomplishing its work, the Learning subgroup has listed, summarized, and analyzed its 227 highlights in the context of four criteria.

- Performance in K-16 and graduate education.
- Preparation of a diverse, globally engaged science, technology, engineering and mathematics (STEM) workforce.
- Integration of research with education.
- Education of the public in STEM areas.

The spectrum of funded projects analyzed by the Committee shows that the portfolio of the NSF provides meaningful opportunities for educators, students, and the general public to engage in the many facets of science and technology. Several projects address broadening access to science and engineering education and target the challenges faced by groups historically underrepresented in STEM challenges. Also included are descriptions of excellent efforts to address the needs of students with limited mobility, hearing impairment, or sight impairment. In some instances projects are designed to result in better understanding of how all people learn, while addressing the specific challenges faced by a target population. To that end, not only are traditional classroom strategies being revisited, with much needed effort being expended in teacher training, but students are also being exposed to research activities as early as possible in the curriculum. Finally, public resources such as museums are being leveraged in new ways to enhance learning while drawing the attention of and engaging the general public.

The Committee finds that the highlights provide compelling - but not always complete - evidence that projects funded advance a variety of approaches to the cultivation of a science and engineering workforce that can compete in a global environment. Many projects are also expanding the scientific literacy of all citizens.

Performance in K-16 and graduate education: The highlights show that curriculum innovation can have very positive effects on schools. Funding from the NSF has also promoted the dissemination of guided inquiry approaches to high school science education across school districts in Washington, New Hampshire, Maine, Florida, and West Virginia. Summer enrichment activities focusing on the topic of alternative energy sources have had a significant impact on the education of students at the Navajo reservation in New Mexico. These examples, enhanced by additional highlights are not rich in data and assessment of outcomes, but do point to strategies that can be used broadly in the transformation of the K-12 science curriculum.

The design and implementation of strategies to enhance pedagogically the education of graduate students and post-doctoral fellows, an essential element to the creation of a stronger professoriate, is not a major theme of the highlights supplied the Committee. However, data available indicate that, among the thousands of graduate students supported by the NSF in 2005-06, 2,694 students received Graduate Research Fellowships, 1,484 students participated in the Integrative Graduate Education and Research Traineeship (IGERT) program, and 871 students received Graduate Teaching Fellowships in K-12 (GK-12) fellowships. There is evidence in the dataset of highlights that the IGERT program has the potential to be transformative and that the GK12 program is building useful bridges between graduate and K-12 students, enhancing the educational experience among younger and more seasoned students alike.

Preparation of a diverse and globally engaged STEM workforce: The Committee identified a relatively large number of highlights that address directly and significantly the need to prepare a diverse and globally engaged STEM workforce. Three major themes emerge from the analysis of the data: 1) efforts to broaden access to science and engineering education for under-represented groups in the STEM workforce, including ethnic minorities, students with disabilities, and women, 2) training of K-12 teachers, and 3) engagement of students in global issues.

The highlights show several successful approaches to broadening access to science and engineering education. For example, Native American students at Navajo Technical College benefited from an overhaul of the school's information technology infrastructure at Navajo Technical College. A program led by University of Puerto Rico Mayaguez demonstrates the importance of undergraduate research experiences in advancing the goals of attracting students from under-represented groups to the study of science and engineering.

Quite a few highlights demonstrate the power of support from the NSF in preparing large numbers of students with disabilities for the STEM workforce. A number of projects show that students have had extraordinary learning opportunities by being engaged in projects which design assistive devices that allow the disabled to race sailboats, the blind to perform chemistry experiments, and for students with mobility and visual impairments to use microscopes. Language barriers in STEM education are being addressed by yet another NSF project through a tri-lingual strategy using English, Spanish, and sign language. The outcomes of these projects suggest that, in some cases, it is possible to gain universal insight into how all students learn, regardless of physical challenges.

Women are still under-represented in both the academic and private sectors. A publication, entitled Science Can Take Her Places!. aims to give parents the tools to encourage young girls to pursue interests in science, mathematics, and technology. A program at the University of Washington fosters networking and peer mentoring among women faculty members and promises to be a model with wide applicability. Particularly worthy of mention because of its potentially broad impact is a training program for mid-career women that helps them start technology-based companies.

Often neglected and yet a vital part of the STEM workforce, K-12 teachers, play indispensable roles in the early development of STEM practitioners. A number of highlights show successful approaches to establishing partnerships between Colleges, Universities, and K-12 teachers to foster development of curriculum in STEM disciplines. Some of the projects are unusually broad in scope. A program at UCLA shows how two important goals can be achieved simultaneously: recruitment (and retention) of graduate students to become knowledgeable science teachers while at the same time broadening access to science for underprivileged students. Collectively, the highlights also show that providing research experiences for teachers and high school students is also an effective strategy for motivating student interest and curriculum development in STEM disciplines.

Scientific research is by its nature an enterprise that becomes richer when it takes advantage of opportunities for global collaborations, so the Committee expected that the portfolio of the Foundation would be replete with examples of global engagement at a deep level, where science curricula are infused with a sense of sustained collaborations between students and teachers at all levels. However, few highlights in the Learning category spoke directly to unique ways in which the STEM workforce of the future is being trained to be effective in global academic and business environments. One of the very important exceptions is the GLOBE Program, funded by the NSF, which has created pedagogical paradigms in the sciences in a large number of countries.

Integration of research with education: The overarching theme found in the highlights that addressed integration of research with education was the need to expose students at all levels to recent developments and state-of-the-art techniques in STEM disciplines. But it is perhaps the involvement of K-12 and undergraduate students in research activities that yields the greatest benefits for educators and researchers alike. Several projects, including those funded with NSF REU grants, show that these students can master high-level concepts and techniques in genomics, chemical biology, astronomy, and engineering.

Education of the public in STEM areas: Highlights point to three general approaches that are proving effective in engaging and informing the public in STEM areas. First, exhibits at museums and other venues, such as Disney World's EPCOT, are educating the public about advances in astronomy (such as LIGO) and nanotechnology. Inventive strategies can be used to attract students to exhibits. For example, professors at Case Western Reserve installed a polymer science exhibit at the Cleveland Museum of Natural History on Martin Luther King, Jr. Day, attracting large numbers of students and their families. Second, meetings between scientists and the general public in coffee shops, libraries, and Boys and Girls Clubs have enhanced awareness of nanotechnology. Lastly, the production of educational products geared toward the general public and course materials for arts and humanities students represent thoughtful models for exposing all citizens to relevant science in our surroundings, on TV shows, in the news, and in the courts.

Research Infrastructure Outcome Goal
*The Committee concluded that there has been **significant achievement** for the Research Infrastructure outcome goal.*

The outcome goal for RESEARCH INFRASTRUCTURE is to: "Build the nation's research capability through critical investments in advanced instrumentation, facilities, cyber-infrastructure and experimental tools." The Research Infrastructure subgroup reviewed 152 highlights which were classified under this goal. Seven highlights were selected for inclusion in the report for this strategic outcome goal. Not only do the projects, tools and facilities have the potential of being transformational on their own merit, but they enable society to also conduct important transformational research activities or verify the results of new transformational research activities. The Committee notes that highlights were not provided for all categories of performance under the Research Infrastructure goal (i.e., instrumentation, facilities, cyberinfrastructure, and experimental tools), and that in future years, NSF may wish to insure that the highlights submitted cover each element within the Research Infrastructure outcome goal.

As the issues researchers face increasingly involve phenomena at or beyond the limits of our measurement capabilities, their study requires the use of new generations of powerful research infrastructure. NSF investments provide state-of-the-art infrastructure for research and education, such as distributed instrumentation networks and arrays, multi-user facilities, digital libraries, accelerators, telescopes, research vessels, aircraft, and earthquake simulators. In addition, funding devoted to the Research Infrastructure strategic outcome goal provides resources needed to support large surveys and databases as well as computational and computing infrastructures for all fields of science, engineering, and education.

NSF provides support for large multi-user facilities that meet the need for state-of-the-art, world-class research platforms vital to new discoveries and the progress of research. NSF support may include construction, upgrades, operations, maintenance, and personnel needed to assist scientists and engineers in the conduct of research at such facilities. NSF consults with other agencies and international partners to avoid duplication and optimize capabilities for American researchers.

All of these investments enable NSF to meet its mission of promoting the progress of science, while responding specifically to direction in the NSF Act of 1950 to foster and support the development and use of computer and other scientific and engineering methods and technologies, primarily for research and education in the sciences and engineering.

Twenty two highlights were initially selected that, together, clearly demonstrated significant achievement toward the Research Infrastructure goal and objectives. For example, there were highlights of the use of NSF sponsored cyberinfrastructure (TeraGrid resources) to analyze brain structures, modeling turbulent flow, 3-D earth surface topography, universe expansion, human blood flow, and much more. It was clear in these cases that there was little chance of scientific advances without access to cyberinfrastructure that permitted: (a) the execution of very large amounts of computations; (b) the processing of huge amounts of data; (c) multi-institutional processing pipe-lines and collaboration; and (d) the generation of high-resolution 3D visualizations of complex phenomena. This is a good indication that the Research Infrastructure goal has been achieved, at least from a cyberinfrastructure point of view. The majority of the work performed with these computational environments involves large-scale simulations for very complex systems in a number of scientific disciplines such as biology, geophysics, astrophysics, sociology, etc. Thus, the application domains using these computational environments are very diverse, and this is another indication that the investments in advanced cyberinfrastructure are being capitalized and even amortized through economies of scope.

In general, it is quite challenging to divide NSF Research Infrastructure investments into the four distinct categories reflected in the Research Infrastructure goal: (a) instrumentation, (b) facilities, (c) cyberinfrastructure, and (d) experimental tools. Many experimental tools, instruments, and facilities use cyberinfrastructure and there is no distinct definition that differentiates instrumentation, facilities, and experimental tools.

Many of the Research Infrastructure projects would not have been possible had it not been for the previously funded and enabling research infrastructure or cyberinfrastructure, upon which they depended. For example, using cyberinfrastructure for early diagnosis of brain disorders that transform treatment and care for millions, simulating turbulent flow in narrowed brain arteries could lead to new treatments, and simulating the formation of the universe, could lead to new fundamental insights It was not always clear that these projects would actually be considered truly transformative research (as defined in the strictest sense as creating new disciplines and being disruptive or enabling research that could not previously be pursued). This was largely because it was not easy to see the overarching impact of the work performed just from the reviewed highlights. Just because the work was possible due to the available research infrastructure may not be a sufficient indicator that the work was truly transformative research.

There is no doubt that access to cyberinfrastructure of the highest level will allow for complex simulations and visualizations to take place. The infrastructure and the simulations they produce may not be transformative, but may be a means to an end. However, some of these simulations are allowing scientists to use computations as a new method of investigation - acquiring insights that would be impossible using experiments or theory alone. For example, using cyberinfrastructure for early diagnosis of brain disorders that transform treatment and care for millions, simulating turbulent flow in narrowed human arteries could lead to new treatments, and simulating the formation of the universe could lead to new fundamental insights.

The Committee had some questions regarding the relevance of various highlights included under the topic of Research Infrastructure. For example, highlights for this goal included studies and reports, a book synthesizing the experiences of four environmental research site experiments, and educational projects. It was not always clear why these highlights were in the Research Infrastructure category since the relationship to infrastructure was not clear even though the long-term NSF funding point to significant impacts on research, industry, the economy, and underserved areas and groups. While these may be important resources for research communities, they are generally summaries of existing research or reviews of impacts of NSF investments. NSF might review these and provide additional guidance to NSF staff selecting highlights on whether these are appropriate performance highlights for the Research Infrastructure category.

V. ACKNOWLEDGEMENTS

It was regrettable that both Dr. Bement and Dr. Olsen were out of the country and unable to meet with the Committee, but our sincere appreciation is given to Michael Sieverts who

represented senior management. We believe his active participation and input was helpful in expressing the Director's views to the Committee.

The Committee would like to acknowledge the work that was done by the NSF as a result of the issues and recommendations raised at last year's meeting. The Committee appreciates that the input received was not only acknowledged but a great deal of progress is being made on many of the recommendations. The gratitude of the Committee is also extended to the NSF staff that has provided a great deal of support throughout the assessment process, especially Mileva Hartman and Pat Tsuchitani for their expert knowledge and efforts in assuring that the process worked smoothly.

Lastly, the Chair and Vice Chair specially wish to thank all of their committee members and especially the chairs of each of the subgroups, Julio dePaula, Jack Fellows, and J.K. Haynes for their leadership and time to ensure the charge was fulfilled. The success of the work of the Committee was dependent on their capable leadership.

APPENDIX

HIGHLIGHTS SELECTED BY THE SUBGROUPS

Discovery Outcome Goal Highlights

How Mosquitoes Tell Time **(**0445710)
Drs. William Bradshaw, Christina Holzapfel, and Derrick Mathias from the University of Oregon, Eugene are examining how mosquitoes tell time by looking at mosquitoes' genes. The team has identified over 10 regions of the mosquito genome that contribute to the evolution of the seasonal timer, the first genetic map of the seasonal timer in any animal. This newfound knowledge may provide the genetic tools to understand, predict, and manage changes in biogeographic range of animal species that will result from global climate change. Knowledge gained from this research will assist in evaluating the survival of important agricultural crops, the spread of vector-borne diseases, the impact of agricultural pests, and the composition of natural biotic communities.

Synthetic Scaffolds to Repair Nerves **(**9731643)
Researchers at Georgia Institute of Technology/Emory University Center for the Engineering of Living Tissues (GTEC) recently developed nanoscaffolds that hold great promise for repairing damage to peripheral nerves. A GTEC group led by Ravi Bellamkonda has developed a polymeric nanofiber-based 3-D scaffold that matches the performance of autografts in bridging a 17mm nerve gap in rats. This project demonstrated that a polymer scaffold alone can match the performance of an autograft in regeneration across a long nerve gap in rodents. This advance achieves a long-time goal of biomedical researchers to develop an off-the-shelf, engineered, polymeric graft that matches the performance of autografts in repairing peripheral nerve damage.

A New Biofuel **(**0080382)
Mixed prairie grasses, grown on degraded land, may be a better source of biofuel than corn ethanol or soybean biodiesel. The study, led by Dr. David Tilman at the University of Minnesota, showed that fuel made from prairie grass yields 51% more energy per acre than ethanol from corn grown on fertile land. Using prairie grass as a biofuel could be an important renewable energy, as the plants store more carbon in their roots and soil than is released by the fossil fuels used to grow and convert them into biofuels. This means that growing the prairie grasses not only provides an energy source, but also helps remove carbon from the atmosphere to help mitigate global climate change. Another advantage that the prairie grasses hold over corn or soybean crops is that the grasses can grow on otherwise unusable, abandoned agricultural land.

The Ocean below the Ocean **(**0431095)
The importance of interdisciplinary collaboration to tackle complex problems is exemplified by this Integrated Ocean Drilling Program project in which geologists, hydrologists, and biologists collaborate to explore the sub-ocean water reservoir. The oceanic crust is the largest fractured water-bearing formation (aquifer) on Earth. The water within this aquifer transports enormous amounts of heat, nutrients, and dissolved minerals across vast distances; influences volcanic activity and earthquakes, seafloor mineral formation, ocean circulation and currents; and

supports largely unexplored ecosystems that live in an "ocean" below the ocean. An international team of scientists and graduate students from the U.S.A, Japan, and Europe, led by Professor Andrew Fisher of University of California-Santa Cruz and Dr. Tetsuro Urabe of University of Tokyo, recently studied this vast aquifer system off the coast of Washington. The discoveries made in this research will inevitably alter our knowledge of the Earth. There is even the possibility that similar environments exist on other bodies in our solar system and may be important for harboring life outside of the Earth.

Integrating Climate Science, Risk Assessment, and Policy Analysis **(**0433679)
Professor Rosamond Naylor and a team of colleagues in economics and climate science from Stanford, the University of Washington, and University of Wisconsin have made significant progress in understanding the effects of climate variability and climate change on Indonesian agriculture. Professor Naylor and her colleagues have developed forecasting models that anticipate both year-to-year changes in Indonesian rainfall (related to El Nino events in the Pacific) and longer run changes in rainfall under conditions of global warming, and then link these changes to agricultural decision-making in Indonesia. Their findings suggest that changes in the timing of the monsoon rains explain much of the observed variation in agricultural productivity, and that these rains will come later and later as the earth warms - with negative implications for poor farmers in Indonesia's main rice-growing regions, Java and Bali. The team's models are being used by policy-makers in the Indonesian Ministry of Agriculture to anticipate immediate and future needs with respect to the agricultural sector. Under a new NSF grant, this work is being replicated and extended in China, with the hope of aiding hundreds of millions of Chinese farmers faced by similar climate fluctuations. The tools and methods generated are likely to be applicable to other regions of the world in which the impact of climate change on agriculture and food security is a very serious policy issue.

Hiding Confidential Data While Posting Public Data on the Web **(**0347968)
Information owners (governmental, academic, commercial entities or private citizens) are subjected to two conflicting requirements: they need to publish certain portions of their data on the Web for the benefit of data consumers (such as peer institutions, business partners and customers, friends, etc.) but for legal, business or personal reasons, they must preserve the privacy of the confidential information residing in their database. Professor Alin Deutsch at University of California - San Diego has developed concepts and tools which assist database owners in identifying the portions of their data that can be safely published without compromising the privacy of the confidential information in the database. The research has laid the theoretical foundations for privacy-preserving database publishing, shedding light on the trade-off between meaningfulness and practicality in the formulation of privacy guarantees, as well as introducing algorithms for checking these guarantees.

Architectural Support for Online Security Analysis **(**0448654)
Having methods to protect computers from network-based attack is critical to our nation's infrastructure. Dr. Timothy Sherwood's research at the University of California–Santa Barbara, has led to novel algorithms that more effectively exploit the power of underlying computer hardware silicon. This research has developed an architecture that is 10 times more efficient than the best previously known approaches. Functional correctness of the architecture has been verified with the implementation of a prototype system, which has been made available to the research community to increase research infrastructure. The goal of this computing architecture work is to enable a new generation of powerful network security devices, greatly reducing the damages caused by viruses, worms, and malicious attacks.

Everything Depends on Topography **(**0120914)
Scientists at the National Center for Earth-surface Dynamics and at the University of California, Berkeley, are discovering the surprising degree to which local properties such as fish population, channel properties, nutrient dynamics, and water temperature can be estimated from high resolution topography. These findings have for the first time demonstrated and begun to unravel the tight coupling between physical and biological processes in the generation of a landscape. The use of high-resolution topographic imagery to predict related characteristics of the landscape, whether physical or ecological, comes about through the development of physically based geomorphic process rules, an advance that departs from the traditional and largely empirical approach used in the past. The implications of these results reach far into the socio-economic arena in that they pave the way for policy makers to make significantly better informed decisions bearing on land-use management and best practices.

The Origin of Life: New Chemical Theories (0526747)
Life on Earth has been estimated to have originated over four billion years ago, and has developed and evolved into extraordinarily complex systems despite constant disturbance from geological, climatological, and astronomical events. The emergence of life from abiotic geochemistry remains one of the central problems of chemistry and biology. Scientific observations of both simple and complex organisms have identified a set of core metabolic pathways common to all life on Earth. This study of the emergence of life, headed by Dr. Harold Morowitz (Santa Fe Institute and George Mason University), has established a core metabolic map from the genetic databases for hyperthermic anaerobic bacteria to create a molecular blueprint, or matrix, of core chemicals (about 300 molecules) thereby drawing up a “periodic table” of biochemistry. This research suggests a new hypothesis that life evolved not from a common universal ancestor but from a community of gene-swapping organisms. It also offers insight into how specific associations may have arisen in the evolution of the genetic code. This multidisciplinary research applies genetic information in a new and innovative way, utilizing state-of-the-art computational models to aid in the understanding of the origin of life.

Regional Partnership Results in Innovational and Economic Benefits (0227899)
The University of Toledo will receive an $18.6 million award from the State of Ohio to establish the Wright Center for Photovoltaics Innovation and Commercialization. This award follows closely on the heels of a completed NSF $600,000 Partnership for Innovation (PFI) award to the university. The Wright Center for Photovoltaics Innovation and Commercialization is to be a research development and commercialization organization dedicated to the promotion of alternatives to traditional fossil fuels. This includes the fabrication and evaluation of photovoltaic devices, or solar cells, that convert sunlight to electricity as well as photoelectrochemical cells that use sunlight to electrolyze water for clean hydrogen fuel. The new Wright Center builds on an earlier $2M grant from the State of Ohio to the University of Toledo that has already spun off three new photovoltaics and photovoltaics-hydrogen companies, Solar Fields, Midwest Optoelectronics, and Midwest Optoelectronics Solar. Solar Fields has developed an atmospheric deposition process for thin film CdTe solar panels; Midwest Optoelectronics (which was founded as a direct result of the PFI grant) has developed an integrated module for generation of hydrogen with a photoelectrochemical process; and Midwest Optoelectronics Solar is commercializing a glow discharge process for thin-film silicon solar modules. Not only will this collaborative program will increase academic research on alternative energy systems, resulting in innovations in manufacturing of these systems, but it will also develop the workforce for these companies and increase the participation of underrepresented populations in alternative energy systems technology.

Learning Outcome Goal Highlights

IT Academy Model Promotes Student Retention **(**0202249)
Curriculum innovation can have very positive effects on schools. A program using information technology is turning around a failing high school in Nashville, Tennessee and student retention in the program is outstanding. For the first time in its history, Stratford High School in Nashville, Tennessee is getting more requests to transfer into the school rather than out of the school. Until the NSF-supported Stratford IT Academy (SITA) was established at this inner-city high school, which serves a mostly African-American and low-income population, students wanted to leave rather than attend. When word got out about the technological focus of the high school in 2003, three of the 13 freshmen who enrolled were transfers into the school from other school zones and in 2004, six of the 48 freshmen were transfers into the school. SITA, supported through the NSF-funded Center for Information Technology Education (CITE), is based on the school-within-a-school model. Support for the effort among local business and industry is strong. Partners include EDS, Saturn, Centresource, the local Workforce Investment Board, Vanderbilt University, the State of Tennessee Department of Labor, and many others. Students from SITA participate in internships at local companies to gain valuable work experience and to further develop their workplace knowledge and skills.

Out of the Box Bioinformatics Solutions **(**0504304)
Linking biologists and computer/informaticians with the interdisciplinary training required for both to effectively solve complex interdisciplinary problems is the goal of Iowa State's Integrative Graduate Education and Research Traineeship (IGERT) project in Computational Biology for Biological Researchers, led by Principal Investigator Dr. Daniel Voytas. Using what they have learned from integrating the disciplines of biology and informatics with leadership and communications training, IGERT Trainees independently created a free student-run lab to address problems in computational biology. This lab serves all the disciplines requiring expertise in computational biology across the entire university. Linked with New Mexico State University, an institution with a rich tradition of serving minority students, IGERT and the new lab also allow New Mexico State University students and faculty to participate and gain the training and research benefits afforded to their Iowa State colleagues.

Tropical Ecology and Conservation in Puerto Rico **(**0206200)
The Center for Applied Tropical Ecology and Conservation (CATEC) at the University of Puerto Rico at Mayaguez, with funding from NSF's Center for Research Excellence in Science and Technology (CREST) program, has demonstrated the importance of undergraduate research experiences in attracting students from underrepresented groups to the study of science and engineering. Among its education activities, CATEC hosted its first student research conference, an event that is now planned to be repeated annually. Graduate students have benefited from research experiences at partner locations including Duke University, North Carolina State University, and the Smithsonian Tropical Institute. In just four years of CREST support, CATEC student enrollment has increased from 25 to 143, almost all of whom are Hispanic and 66 percent of whom are female. Thirty-five percent of papers have been authored or co-authored by students; student authorship in excess of 50 percent is a stated goal and submitted publications increased 30 percent in the project's fourth year alone.

Creating Alliances for People with Disabilities Broadens Their Participation in STEM Education **(**0227995; 0124198; 0333316)
With support from NSF's Research in Disabilities Education (RDE) program, four regional alliances were created to increase the quality and quantity of students with disabilities

completing science, technology, engineering and mathematics (STEM) degrees in 14 states: Alaska, Idaho, Illinois, Iowa, Maine, Massachusetts, New Hampshire, New Mexico, Oregon, Rhode Island, Texas, Vermont, Washington, and Wisconsin. Over 6,000 primary, secondary, community college and university students with disabilities have been served through these projects, with over 9,000 students who do not have disabilities benefiting from the inclusive educational and research activities. These four alliances, which are based at New Mexico State University, the University of Washington, the University of Wisconsin-Madison and the University of Southern Maine, include networks of regional academic institutions partnering with industry, government, and national research labs to provide comprehensive educational and research experiences for students. International collaborations are also taking place with academic and government partners in Japan, Korea, Singapore and India. The alliances place students with disabilities in IBM, NASA, and university nanotechnology labs that offer research and mentoring experiences. In addition to working with students who have disabilities, the RDE alliances also educate teachers and parents about educational supports for students pursuing STEM education and careers.

The ACTiVATE Program for Technical Entrepreneurs (0438617)
The NSF PFI Program enabled the University of Maryland, Baltimore County to develop a new model for training technology entrepreneurs and equipping them to start new companies using university or Federal agency created technology. The ACTiVATE Program, which focuses on mid-career women, is a unique program in which participants select technologies identified and screened from regional research institutions, assess a technology's commercial potential, develop a business plan, and, when appropriate, form a new company and seek funding. During the program's first two years, 57 of 170 applicants were accepted into the program, 70 technologies from nine different research institutions were evaluated and screened, and nine new companies were formed. One of the companies, Foligo Therapeutics, is developing novel therapeutics for treatment of ovarian cancer. Foligo Therapeutics was the first ACTiVATE company to obtain funding. Foligo's founder, Dr. Jhaveri-Brown, is using the funds to support collaboration with a large biotechnology company.

Collaborative for Excellence in Teacher Preparation (9986753)
The Science Education Center (part of the Laser Interferometer Gravitational-wave Observatory (LIGO) site in Louisiana) is reaching out to K-12 students, parents, pre-service and in-service teachers, and interested members of the general public. The Science Center uses hands-on interactive science exhibits to communicate physics and mathematics concepts and to demonstrate the power of inquiry and evidence in building knowledge. A particular focus of the Center is to strengthen regional science and mathematics teaching, through direct student experiences and through focused professional development programs for pre-service and in-service teachers. Through partnership with Southern University of Baton Rouge, the San Francisco Exploratorium, and LaSIP/LA GEAR UP (Louisiana Gaining Early Awareness and Readiness for Undergraduate Programs), LIGO is developing a national model for collaboration among research, formal education, and informal learning communities to advance science education and public awareness of science.

GLOBE Program Heads in New Directions (0627941; 0627916; 0627909)
In the past decade, the Global Learning and Observations to Benefit the Environment (GLOBE) program has engaged over a million elementary and secondary students from 109 countries in the process of doing scientific inquiry. By connecting students and educators with scientists, and providing them with opportunities to engage in authentic research experiences, GLOBE helps to engage and support the next generation of Earth system scientists and improve science literacy about the environment. NSF has funded four new GLOBE projects that will

allow students, educators, and community groups to work together with scientists engaged in large, integrated Earth system science research projects. The four projects concern the Carbon Cycle and Climate Change (Principal Investigator: Scott Ollinger, University of New Hampshire, with the North American Carbon Cycle Program), Seasons and Biomes (Principal Investigator: Elena Sparrow, University of Alaska Fairbanks, and the International Arctic Research Center), Watershed Dynamics (Principal Investigator: Daniel Edelson, Northwestern University, with the Consortium of Universities for Advancement of Hydrologic Science), and From Local to Extreme Environments (Principal Investigator: Elizabeth Goehring, Pennsylvania State University, with the RIDGE 2000 and InterRIDGE programs). As one of the first activities for these new projects, the GLOBE Program Office at UCAR is facilitating the first "Pole to Pole" video conference and web chat linking International Polar Year scientists with students in the Arctic and Antarctica.

Teaching the Genome to Undergrads **(**0318944; 0520908)
The microarray reader and other instruments for genetic analysis are being used by a network of undergrad students and their teachers across the country. With the help of a DNA microarray reader and other instruments for genetic analysis, Professor Laura Hoopes at Pomona College and others are providing a network for undergraduate students to do sophisticated genomics research. Through the Genome Consortium for Active Teaching (GCAT) network, Prof. Hoopes' microarray reader is used by undergrads and their teachers all across the country, to read out the results of their microarray experiments. Professor Malcolm Campbell from Davidson College in North Carolina collects requests for DNA microarrays from students and undergraduate teaching faculty. The undergraduate students do their microarray experiments; no grad student microarray experiments are allowed! After the experiments, the microarrays are sent to Profs. Campbell or Hoopes for reading (scanning), and the results are posted on an FTP server. As of early 2006, 5000 undergrads from 120 schools had used about 3400 microarrays. GCAT lab courses produced significant improvement in students' abilities to design experiments and interpret data.

It's a Nano World **(**9876771)
The mysteries and the excitement of nanoscale science and engineering are explored in a hands-on traveling museum exhibition *It's a Nano World*. The 3000-square-foot exhibit was created through a unique collaboration of the Main Street Science education program of the Cornell University Nanobiotechnology Center (NBTC), a NSF-Science and Technology Center, the Sciencenter located in Ithaca, NY, and Painted Universe, a design/fabrication team in Lansing, NY. Coordination of this project was under the direction of Anna M. Waldron and Professor Carl A. Batt, of the NBTC. In creating this exhibition, intended to teach a target audience of children ages 5-8 and their families about the wonders of the nano world through interactive exhibits, the team of scientists, engineers, educators, and museum exhibition developers interviewed children and adults to ask questions such as "what is the smallest thing that you can see" and "what is the smallest thing that you can think of." The answers provided a foundation on which six interactive clusters were built that not only engaged visitors in the wonders of nanoscale science and engineering but also entertained them with hands-on action. Since 2003, with a 6-month display at Innovations at Epcot, Walt Disney World, Florida, the exhibition has toured six additional science museum locations throughout the United States, reaching over one million visitors to date.

Research Infrastructure Outcome Goal Highlights

Nanoscale Power Generators **(**9733160)
This transformative approach to power devices can potentially eliminate constant replacement of power sources such as batteries, an especially useful feature for biomedical implants and biosensors. Professor Z. L. Wang of Georgia Tech. has built a nanoscale electrical power generator capable of harvesting mechanical energy, biological energy, acoustic/ultrasonic vibrations, or even biological hydraulic energy (blood pressure) from its environment into useful electrical energy to power small devices. Professor Wang's demonstration of self-powered technology could greatly reduce the size of biosensors, biomedical monitoring devices, and microelectronics. These power generators pack a big punch, have high efficiency, and can run for a long time.

MorphoBank: New software to Facilitate Virtual Collaborations (9903964**)**
Many infrastructure efforts are aimed at creating databases, but Dr. Maureen O'Leary of New York's Stony Brook University and colleagues have designed a web application, MorphoBank, which is revolutionizing the field of morphological biology, the branch of biology that deals with the form and structure of organisms. With MorphoBank, teams of biologists across the globe can collaborate in a secure virtual workspace that houses powerful visual software used to compare the morphology of organisms to reach agreement on their descriptions and categorizations, an important process when scientifically classifying biological organisms. Currently, MorphoBank houses over 3,000 images that range from insects to fossil humans. Its ability to zoom and label features makes it a robust comparative tool for biologists. Applications such as MorphoBank are of increasing importance as scientific research grows to involve large international collaborative efforts.

Early Diagnosis of Brain Disorders Aided by TeraGrid (0525307; 0525308; 0525310)
Early diagnosis of brain disorders can transform the treatment and care of millions. Brain disorders are challenging to diagnose, which can confuse or delay beneficial treatments. Researchers Michael Miller, Anthony Kolasny, Mark Ellisman and co-workers in the Biomedical Informatics Research Network (BIRN) are building a multi-institutional processing pipeline that can handle the demanding analysis of brain structure data. High-resolution structural MRI brain scans at one BIRN site are segmented at a second BIRN site, then the data sets are accessed, aligned, and processed using TeraGrid computing resources. Using the unique resources made available by the TeraGrid staff at SDSC, the researchers were able to access sufficient computing resources by running some 130,000 CPU hours at both SDSC and NCSA. This was feasible because the researchers were able to use the General Parallel File System-Wide Area Network (GPFS-WAN) to move 29 terabytes of output in some four million files between NCSA and their data store at SDSC, as well as other sites.

Turbulent Blood Flow in Narrowed Arteries (0456541; 0525308)
Realistic simulation of turbulent flow in narrowed arteries will provide insights that can lead to new treatment and intervention modalities. A team led by Dr. George Karniadakis at Brown University used the TeraGrid computation and visualization resources to produce the largest ever three dimensional simulation of blood flow in the human body. The Karniadakis team simulated 55 arteries and 17 bifurcations, accounting for every artery in the human body larger than about two to three millimeters in diameter. They used a realistic geometric model of a 75 percent stenosed carotid artery (based on magnetic resonance images) and used TeraGrid computational resources at NCSA and PSC to complete several direct numerical simulations of blood flow through the partially blocked vessel. This was the first time that turbulence through a

narrowed carotid artery was realistically modeled in three dimensions. Realistic simulation of turbulent flow in narrowed arteries will provide insights that can lead to new treatment and intervention modalities.

Imaging of a Foundering Lithosphere (0454524; 0454535; 0454554)
Drs. Hersh Gilbert of Purdue University, Craig Jones of University of Colorado, Tom Owens of University of South Carolina, and George Zandt of University of Arizona analyzed NSF's EarthScope seismic data to identify a region where the mantle lithosphere is currently being stripped from beneath the Sierra Nevada batholith. As our understanding of processes related to the removal of mantle lithosphere improves, the important role played by lithospheric removal in continental deformation becomes increasingly apparent. Along the central portion of the western foothills of the Sierra, small earthquakes occur deep within the crust. These events may result from stresses associated with the lithospheric removal process. Resolution of EarthScope data has allowed a significant advance in understanding of the tectonics of mountain building and plate interactions.

Helping People with Motor Disabilities to Use Computers (0426125)
Researchers at Florida International University (FIU) are modifying typical human-computer interfaces so that individuals with severe motor disabilities are able to use computer systems. People with amyotrophic lateral sclerosis (ALS), muscular dystrophy, spinal cord injuries, and other disabilities characterized by lack of muscle control and body movement in the upper limbs are the focus of this project. Researchers sought to expand the functional capabilities of persons with disabilities, while merging engineering design with software development to create an assistive technology tool. With technologies such as Eye Gaze Tracking (EGT) and voice recognition, disabled subjects are able to use applications such as Microsoft Word. FIU and Miami Children's Hospital created a partnership in a new Neuro-Engineering Program to develop education and research aimed at using computing technology in neuroscience applications, disability research, and imaging.

Search for Gravitational Waves with Einstein@home (0555655)
The Laser Interferometer Gravitational-wave Observatory (LIGO) is poised to make the first detection of gravitational waves and open this new window on the universe. One of LIGO's possible sources is the gravitational wave signal of spinning neutron stars with bumps on them. LIGO has already set upper limits of bumpiness (less than one part in 100,000) for known neutron stars detected as radio pulsars. To search for these requires huge amounts of computing power because the single frequency of the gravitational wave signal is distorted by the earth's motion around the sun in a way that depends on the neutron's star's position in the sky. To provide the necessary computational capability, LIGO scientists, led by Bruce Allen at the University of Wisconsin at Milwaukee, have partnered with computer scientists who created SETI@home, led by David Anderson at the University of California-Berkeley, to produce Einstein@home to take advantage of unused cycles of computers around the world (distributed computing). At LIGO's most sensitive frequencies the depth of the search should extend to more than a thousand light years, a volume of our galaxy expected to contain approximately ten neutron stars. When the new version of Einstein@home is deployed this spring, the resulting search is expected to take between 12 and 18 months.