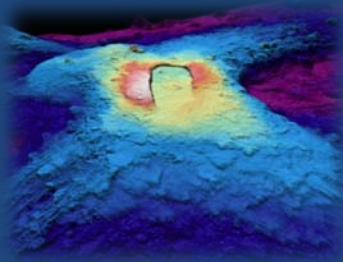


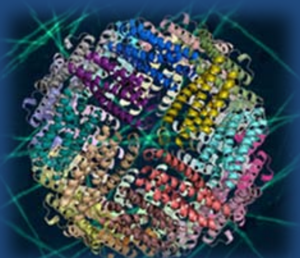


Report of the Advisory Committee for GPRA Performance Assessment

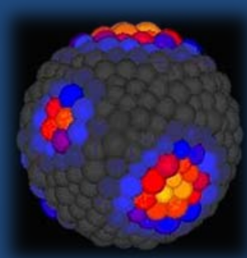
FY 2009

David B. Spencer, Sc.D.
Chair

Sharon Dawes, Ph.D.
Vice Chair







Advisory Committee for GPRA Performance Assessment (AC/GPA)

The Advisory Committee for GPRA Performance Assessment (AC/GPA) was established in June 2002 to provide advice and recommendations to the NSF Director regarding the Foundation's performance under the Government Performance and Results Act (GPRA) of 1993. The Committee meets annually to assess the Foundation's overall performance according to the strategic outcome goals in the current NSF Strategic Plan (FY 2006 – 2011). The Committee is comprised of representatives from academia, industry, and government research organizations. For 2009, the committee was directed to assess the three strategic outcome goals of Discovery, Learning, and Research Infrastructure. In addition, we were charged with examining alternate methods of performance assessment, which we did by organizing a Future Assessment Task Group to undertake a more holistic view of ways in which NSF might demonstrate longer-term achievement of its strategic goals. This report was compiled by the Chair, David Spencer, and the Vice Chair, Sharon Dawes, from contributions from all Committee members. It features an Executive Summary with conclusions and recommendations, followed by detailed reports of the Task Group and three subgroups organized by strategic goal.

See Page 52 for information about the images that appear on the cover of this report.

NSF – 09-068

Contents

Advisory Committee for GPRA Performance Assessment (AC/GPA)

2009 Membership List

* *Denotes a new member for June 2009 meeting*

David Spencer – Chair (SBIR AC)
Chairman & Chief Technical Officer
wTe Corporation
Bedford, MA

Sharon Dawes - Vice-Chair (B&O AC)
Senior Fellow, Center for Technology in Government
University at Albany
State University of New York
Albany, NY

Mary R. Albert
Professor of Engineering,
Director, Ice Drilling Program Office
Dartmouth College
Hanover, NH

Diran Apelian
Howmet Professor of Mechanical Engineering and Director, Metal Processing Institute
Worcester Polytechnic Institute
Worcester, MA

Wendy Baldwin *
Director, Poverty, Gender and Youth Program
Population Council
New York, NY

Legand Burge * (ENG AC)
Dean, College of Engineering, Architecture, and Physical Sciences
Tuskegee University
Tuskegee, AL

Cinda-Sue Davis * (EHR AC)
Program Director, Women in Science and Engineering Program
University of Michigan
Ann Arbor, MI

Jorge L. Díaz-Herrera (CISE AC)
Professor and Dean, Golisano College of Computing and Information Sciences
Rochester Institute of Technology
Rochester, NY

Ed Getty *
Group Director, External Technology Acquisition, Global Research and Innovation
The Coca Cola Company
Atlanta, GA

Ira Harkavy (SBE AC)
Associate Vice President and Director Netter Center for Community Partnerships
Office of Government and Community Affairs
University of Pennsylvania
Philadelphia, PA

Wayne Johnson * (SBIR AC)
Weston, MA

Marian Johnson-Thompson * (CEOSE)
Retired Director of Education and Biomedical Research Development
National Institute of Environmental Health Sciences (NIEHS)
Durham, NC

Deanna Paniataaq Kingston (OPP AC)
Associate Professor
Department of Anthropology
Oregon State University
Corvallis, OR

Maria (Mia) Ong * (CEOSE)
Director, Diversity Resource Group
TERC
Cambridge, MA

Pamela O'Neil
Associate Provost
Brown University
Providence, RI

Mary Jane Perry * (GEO AC and ERE AC)
Professor, Marine Sciences
University of Maine
Walpole, ME

Saifur Rahman * (OISE AC)
Director, VT Advanced Research Institute
Virginia Tech
Arlington, VA

Mary Ellen Sheridan (B&O AC)
Associate Vice President for Research (retired)
The University of Chicago
Worthington, OH

James Stith *
Vice President, Emeritus
American Institute of Physics
Mitchellville, MD

Joel E. Tohline (MPS AC)
Professor of Physics and Astronomy
Louisiana State University
Baton Rouge, LA

Daniel Wubah * (BIO AC)
Vice-President and Dean for
Undergraduate
Education
Virginia Tech
Blacksburg, VA

EXECUTIVE SUMMARY

It is the unanimous judgment of the 2009 Advisory Committee for GPRA Performance Assessment (AC/GPA) that the National Science Foundation successfully met its performance objectives by demonstrating *significant achievement* for each of the following three long-term, qualitative, strategic outcome goals in its 2006-2011 Strategic Plan:

- **DISCOVERY**: Fostering research that will advance the frontiers of knowledge, emphasizing areas of greatest opportunity and potential benefit and establishing the nation as a global leader in fundamental and transformation science and engineering.
- **LEARNING**: Cultivating a world-class, broadly inclusive science and engineering workforce, and expanding the scientific literacy of all citizens.
- **RESEARCH INFRASTRUCTURE**: Building the nation's research capability through critical investments in advanced instrumentation, facilities, cyberinfrastructure and experimental tools.

The Committee's assessments were made during its June 18 and 19, 2009 meeting to consider the activities and achievements of NSF relative to its performance under the Government Performance and Results Act (GPRA). Our charge was to assess NSF's performance with regard to the three long-term strategic outcome goals for FY 2009, using primarily performance highlights prepared by NSF program officers and staff and to provide a report to the NSF Director. Program highlights provided the Committee with evidence of specific scientific achievements, as well as with a body of data to identify substantive themes and patterns which are reflected in this year's subcommittee reports.

We were also charged with examining alternate methods of performance assessment, which we did by organizing a Future Assessment Task Group to undertake a more holistic view of ways in which NSF might demonstrate longer-term achievement of its strategic goals. The task group organized presentations and discussions around those topics, which occupied a large part of our two-day meeting. As a result, the task group has put forth the following five recommendations, which have been endorsed by the full Committee (see the next section of this report for detailed information about the task group's work and recommendations):

RECOMMENDATIONS

1. *Consider an assessment framework that uses multiple measures and methods, applied over various time scales. Use both quantitative and qualitative evidence, including highlights.*
2. *Emphasize the dynamic relationships among strategic goals and outcomes.*
3. *Use performance assessment as an opportunity and means to document the strategic value of NSF's science investments to the nation and the public.*
4. *Engage the scientific community as a partner in performance assessment.*
5. *Build assessment into the organizational and programmatic infrastructure of NSF.*

Details on NSF's performance evaluation under the Discovery, Learning, and Research Infrastructure strategic outcome goals are presented in subsequent sections of this report, along with several examples or highlights that illustrate specific achievements. Those sections represent the deliberations of three subgroups organized according to the three goals. Based on the deliberations of each subgroup, and after discussion and evaluation by the Committee as a whole, the opinions of each subgroup were supported unanimously by the entire AC/GPA Committee.

The Committee did not form an assessment or opinion of NSF's performance under the fourth goal: *Stewardship*, which is: *to support excellence in science and engineering research and education through a capable and responsive organization*. Performance outcomes under Stewardship are reported internally within NSF using a number of measures and milestones developed by NSF senior leadership.

The 2009 AC/GPA was comprised of 21 members, each of whom had strong academic credentials and substantial experience in academia, government, and/or industry. More than half the AC/GPA members presently serve on advisory committees within the Foundation. As a group, the Committee is familiar with NSF processes and procedures and, as individuals, the Committee members have personal experience with NSF and a wide range of its programs.

NSF Response to 2008 AC/GPA Recommendations

A key part of overall performance is following up to be sure the agency has adequately responded to the prior year's recommendations. Each year, the Committee reviews the progress NSF has made in responding to the recommendations of the previous year's Committee. The recommendations of the 2008 AC/GPA Committee are categorized as follows:

Summary of FY 2008 Recommendations:

1. *Track future outcomes from "people" trained and supported by NSF.* Consider ways of capturing the longer term "people" outcomes. This extends beyond principal investigators, and includes advisors and professors, particularly junior professors who oversee the work, and graduate students, staff, and other researchers. The current performance outcomes (annual highlights) do not capture this essential "value added" aspect of NSF investments.
2. *Consider ways to convey the long view of NSF investments in science and engineering.* While highlights are an excellent way to document and illustrate the breadth of NSF's investments in a wide variety of fields and disciplines at a particular point in time, Committee members expressed interest in finding ways to demonstrate the long-term impacts of NSF support. Committee members look forward to ways to tell this deeper, more comprehensive story of scientific advancement supported by NSF funding.
3. *Reconsider the format and value of COV reports.* The Committee recommended that Committee of Visitor (COV) reports be reviewed annually at the NSF Director level in order to gain insight into common process issues that may affect performance on an agency-wide basis. In addition, the Committee concluded that Part B (Research and Education Outcomes) is not very informative and provides little, in fact far less, outcome information than the Committee receives in the performance highlights. The Committee recommended that Part B of the COV reports should be either enhanced or eliminated.
4. *Continue to improve assessment processes and contextual information available to the AC/GPA.* The Committee recommended that the methods and guidelines that program officers use to select and describe highlights be shared with Committee members as part of their preparation for the annual meeting. NSF should continue to provide access to other reports to give the Committee a broader context in which to consider performance goals under the strategic

goals. In addition, the Committee recommends continuation of the practice of having NSF program officers available during the Committee meeting.

The Committee is pleased to report that each of these recommendations has been fully addressed, or is being addressed, by NSF staff and NSF management to the satisfaction of the Committee, as follows:

Regarding the first and second recommendations, NSF responded by recommending that a task group of the AC/GPA be organized in preparation for the 2009 meeting. The task group focused on alternative ways to assess the impact of the people that NSF supports as well as ways to take a longer, deeper view of NSF investments. As a result, the majority of time at the 2009 meeting was spent on discussing these important issues for NSF's future performance assessment activities. A report by the task group, with details about their recommendations, may be found in this report.

Regarding the third recommendation, NSF stated that the Office of the Director now conducts an annual review of COV reports to identify common themes and issues. In addition, the guidance to COVs for completion of Part B of their report on outcomes has been revised. COVs are asked to comment on the impact of NSF-supported contributions to the field, in addition to identifying *noteworthy* accomplishments or highlights.

Regarding the fourth recommendation, NSF provided the Committee with information on guidelines for Program Officers in writing their highlights, and informed the Committee about the result of staff interviews with Program Officers about how they decide what to write about. NSF staff has continued to provide the Committee with reports and other performance-related information throughout the year through the Committee's website. In addition, several program officers attended the 2009 meeting to provide additional insight and answer questions when needed.

Committee Members' Comments on the Issue of Broadening Participation

On several occasions during the meeting, but especially in the closing session, Committee members spoke with both eloquence and passion of their vision of the scientific community of the future. They imagine a community not only enhanced but potentially transformed by an infusion of new experiences and perspectives from groups that are traditionally underrepresented in science and engineering, such as women, African-Americans, Hispanics, and Native Americans, as well as others. The unique histories, backgrounds, and cultural traditions and orientations of these groups can bring dramatically new approaches to the strategic goals of scientific discovery and learning that are the core of NSF's mission. By aggressively providing opportunities to these groups and expanding their participation in NSF programs and STEM disciplines, the discovery and learning missions can be taken beyond their historical boundaries and lead to new ways of understanding and experiencing the universe, which could be transformational. Thus the goal of broadening participation is not only an issue of fairness and equal opportunity, but is the means of bringing diversity and intellectual breadth to the transformation of science itself.

Acknowledgements

The Committee is most grateful to the NSF staff for the tremendous effort made in preparing the AC/GPA website and providing all the documentation which was assembled for review in advance of the formal meeting. There were many organizational meetings and subcommittee telephone calls needed to prepare our efforts so face to face meeting time could focus on group analysis, collaboration, and consensus building. In particular, we would like to extend our deepest gratitude to Jennifer Thornhill and Pat Tsuchitani, for their work in diligently gathering data in preparation for the Committee meeting, making arrangements for the meeting, and helping prepare and edit this report. They deserve special recognition for their contributions to the processes and to the final product. In addition, we would like to recognize the contribution of Amber Baum, AAAS Fellow, who worked with the task force examining alternative methods of performance assessment. We also thank Michael Sieverts for his insights and advice. Lastly, we thank the NSF program officers for their thoughtful reporting of program highlights, and NSF's Director, Dr. Arden L. Bement, Jr., for his commitment to this effort and for his insightful remarks at our meeting.

Future Assessment Task Group Report

Toward a more holistic assessment of NSF performance

This year marks a transition from the assessment approaches used in previous years. While program highlights continued to constitute a large and important part of the evidence we used to make our judgments about *significant achievement* of NSF's strategic goals, the Committee also began to look critically at alternative approaches to assessment and other kinds of evidence. These included additional ways to analyze highlights to draw out substantive themes as well as statistical patterns, which are reflected in this year's subgroup reports. We also prepared case studies of internal evaluation efforts that take a more comprehensive look at the value of specific NSF programs. By exploring these more holistic ways to take a longer and deeper view of NSF's performance, our ultimate goal was to make recommendations that will lead to a richer understanding of the inherent value of NSF's investments in science and the nation.

To begin to explore the feasibility and usefulness of alternative performance assessment frameworks, the Committee this year formed a "Future Assessment Task Group" to look at different ways in which NSF might demonstrate achievement of its goals. The group conducted its review by examining a wider variety of data sources, such as budget, award, and other trends; workshops and reports; program evaluations; evaluation research; career tracking mechanisms; and case studies.

To gain a better understanding of how different approaches might be of benefit, Task Group member Mary Ellen Sheridan conducted a case study of the Information Technology Research (ITR) program to explore how a longitudinal program perspective might enhance performance assessment. Suzi Iacono, Senior Science Advisor, Directorate for Computer Information Science and Engineering (CISE), gave considerable assistance and was present at the AC/GPA meeting to answer questions. ITR was a five-year, $1.116 Billion program to expand the horizons of computing research. It encouraged inter-institutional partnerships across disciplines aimed at high-risk research to design tools for the nation's

Task Group Members:

Sharon Dawes (Chair)
Senior Fellow, Center for Technology in Government
University at Albany
State University of New York

Diran Apelian
Howmet Professor of Mechanical Engineering and Director, Metal Processing Institute
Worcester Polytechnic Institute

Mary Ellen Sheridan
Associate Vice President for Research (retired)
The University of Chicago

cyberinfrastructure. ITR supported more than 500 large and medium-sized grants as well as hundreds of smaller grants. As such, it drew an overwhelming number of proposals and involved nearly every NSF directorate, requiring the invention of a complex internal proposal management and review process that had not existed before. ITR grants produced significant advancements in software design and quality, scalable information infrastructure, high-end computation, and insights into the workforce and socio-economic impacts of technology. It fueled new interdisciplinary areas such as bioinformatics and geoinformatics which are now formal NSF program areas, as well as grid computing and visualization, which continue to impact many other fields.

ITR was not only an investment in computing research, it also provided an opportunity to evaluate the issues associated with collaboration across disciplines and institutions. One evaluation took the form of a research grant to better understand the benefits and problems of such collaborations.[1] The investigators collected social network data from the medium and large grant awards involving nearly 4000 pairs of senior personnel from 475 ITR projects. The research found that successful collaborations had "the right mix" of specialism and diversity and were more likely to occur when investigators had already worked together. The research further found that explicit attention to and resources for coordination, as well as specific coordination activities were associated with success. The most diverse teams were the least productive and those that involved larger numbers of universities were at greatest risk of not publishing; both these findings were explained in large part by insufficient coordination. The investigators concluded that preference for multi-disciplinary research and partnerships bears further examination and that NSF should consider ways to encourage the formative processes of collaborations and the training of scientists to manage them.

Task Group member Diran Apelian organized a group of NSF program officers from the Engineering Directorate who discussed their approach to and lessons learned from assessment. Dr. Allen Soyster, Director of the Division of Engineering Education and Centers (EEC), Dr. Rathindra DasGupta, Program Director for the Industry/University Cooperative Research Centers (I/UCRC) Program, and Dr. James Brown, American Association for the Advancement of Science (AAAS) Fellow, gave presentations that reflected their experiences in assessing the Engineering Research Centers (ERCs) and I/UCRCs, as well as the full range of Industrial

---

[1] Cummings, J. N., & Kiesler, S. (2007). Coordination costs and project outcomes in multi-university collaborations. *Research Policy, 36(10),* 1620-1634.
Cummings, J. N., & Kiesler, S. (2008). Who collaborates successfully? Prior experience reduces collaboration barriers in distributed interdisciplinary research. *Proceedings of the ACM conference on Computer-Supported Cooperative Work, (November 10-12),* San Diego, CA.

Innovation Partnerships. The presenters emphasized the value of a "systems approach" that focuses on programs and portfolios, rather than individual projects. Such an approach needs to be structured to allow assessment in a more holistic and historical way. A discussion of EEC division-wide assessment identified a taxonomy of concepts and measures that encompass knowledge, human, and economic impacts, as well as the products of their interactions, such as innovation, publications, degrees, and jobs. This taxonomy is illustrated as follows:

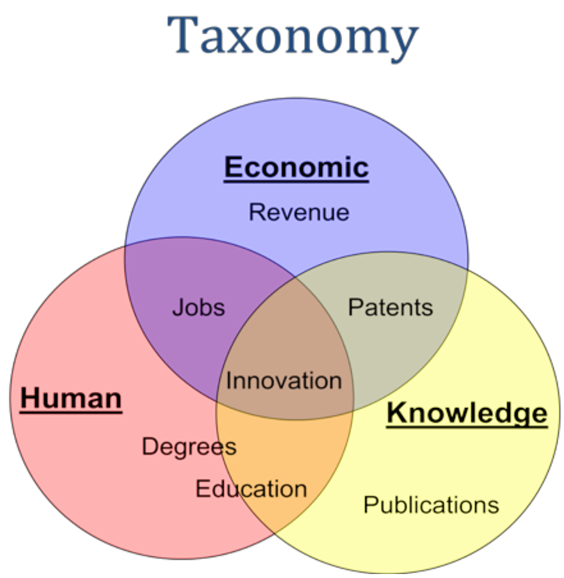


Figure 1. Illustration of a taxonomy of assessment concepts and measures that encompass knowledge, human, and economic impacts as well as the productions of their interactions. Credit: Dr. James Brown, AAAS Fellow, NSF

The Engineering presentation and discussion further highlighted the importance of setting expectations among and building long-term relationships with grantees. The program officers stressed the importance of cultivating Principal Investigators (PIs) as partners in assessment and highlighting the value to PIs of having NSF as a funder and outlet for their work. One example is the publication of an annual compendium of engineering breakthroughs that highlights the work of centers and which provides an incentive to participate actively in reporting and evaluation. These NSF programs encourage grantees to engage in self-assessment and require reporting on scientific, technological, technology transfer, or educational achievements, such as patents and trends in workforce diversity. Throughout the discussion, the speakers emphasized the importance of tracing development over time, linking different measures to the interests of different audiences, and treating assessment as an integral part of the responsibility of PIs and NSF.

The Task Group, along with the subgroup chairs, also tested a different approach to using program highlights this year. The subgroup chairs looked for cross-cutting themes within the highlights assigned to their groups, and the NSF staff provided additional kinds of analysis from the highlights database. As a result, several important themes emerged that had not been visible before. In brief, impressive achievements represented in the highlights seem to signify work that is *integrative* (i.e., it links Discovery, Learning, and Research Infrastructure), *interdisciplinary* (i.e., it draws from multiple fields to generate new fields, questions, or insights); *enabling* (i.e., it lays the groundwork for other discoveries or new directions), and *cross-boundary* (i.e., it builds bridges across the full spectrum of education, across institutions, and between sectors). This different way of considering highlights was aided by the preparation of two "extended highlights" on behavioral economics and polymer science, which demonstrated how NSF investments over time in programs, fields, or subfields have led to significant breakthroughs in our understanding.

In short, NSF investments in science and engineering research and education generate a dynamic set of effects that is much more compelling than has been possible to see through individual highlights alone. This exploration of alternative assessment methods using different kinds of evidence shows how infrastructure investments pay off in discoveries and how the process of discovery embodies learning, both of which enlarge and enhance the STEM workforce. Together with carefully crafted research investment strategies, these investments generate both knowledge impacts and economic impacts of value to the nation and the world. This is the larger story that performance assessment should tell.

Accordingly, the task force offers the following recommendations for constructing a more holistic performance assessment program that will not only better demonstrate the value of NSF investments, but return learning dividends to NSF itself. We understand such a significant shift from current practice represents more than a one-year effort. We therefore look forward to an ongoing discussion in future years about the Foundation's efforts to move in this direction. These recommendations have been endorsed by the full AC/GPA.

RECOMMENDATIONS

1. *Consider an assessment framework that uses multiple measures and methods, applied over various time scales. Use both quantitative and qualitative evidence, including highlights.*
2. *Emphasize the dynamic relationships among strategic goals and outcomes*
3. *Use performance assessment as an opportunity and means to document the strategic value of NSF's science investments to the nation and the public.*
4. *Engage the scientific community as a partner in performance assessment*
5. *Build assessment into the organizational and programmatic infrastructure of NSF.*

1. *Consider an assessment framework that uses multiple measures and methods, applied over various time scales. Use both quantitative and qualitative evidence, including highlights.*

The Committee recognizes that NSF programs represent a portfolio of investments of different size, scope, and duration embodying varying levels of risk. Moreover, these investments represent different kinds of value to different stakeholders. Consequently, we urge the Foundation to consider a matrix of assessment methods and measures that captures a more complete range of impacts and employs simple, easy-to-communicate rubrics and language. Assessment focus areas should include knowledge impacts, people impacts, research strategy impacts, and economic leverage. Alternative methods and measures in each of these focus areas could include:

- Knowledge impacts: tracking results according to themes in the strategic plan and annual budgets, and commissioning internal or external studies on the impact of investments in certain thematic areas of science or on the strategies that NSF uses to encourage cutting edge discovery.
- People impacts: looking at programs and experiences whose purpose is to invest in the STEM workforce, such as Research Experiences for Undergraduates (REUs), Graduate Research Fellowships, the Faculty Early Career Development (CAREER) program, and relationships among PIs and graduate students.
- Research strategy impacts: investigating the efficacy of different kinds of solicitations, proposal requirements, and review processes to address the desire for risk-taking and broader impacts.
- Economic leverage: considering the long-term economic effects of NSF investments in such programs as the Small Business Innovation Research Program (SBIR), ERCs, or via retrospectives on major investment areas such as nanoscience or computer science.

Similarly, the full impact of NSF performance cannot be discerned solely through annual exercises. We believe each of the impact areas listed above can and should be assessed in different ways over multiple time periods. Short term assessments would most likely be annual and largely quantitative, medium term assessments would take place periodically and focus on selected thematic or synergistic topics, and highly selective long-term assessments would take a long retrospective view of major areas of scientific development over time (see Figure 2).

Although many other data sources are salient, we believe highlights will continue to be a useful form of evidence for assessment. We therefore recommend that future highlight databases include the amount and duration of the grants from which the highlights are drawn. We also encourage NSF to continue to prepare idea-centric, and person (career)-centric extended highlights. In addition, more complete contextual information would be useful, including placing NSF's role, contribution, and leverage in the context of the larger science enterprise that includes both private sector and other federal investments in research. Finally, we urge the Foundation to catalog and make use of many existing in-house data sources, such as budget trends and other reports that are useful evidence for performance assessment.

Figure 2. Matrix of assessment areas and timeframes

	Short-term	Medium-term	Long-term
Knowledge			
People			
Research Strategies			
Economic			

2. Emphasize the dynamic relationships among strategic goals and outcomes.

Each strategic goal is important in itself, but far greater value comes from the dynamic interaction among Discovery, Learning, and Research Infrastructure. The Foundation would be well-served to compile and tell that larger story. Committee members suggest thinking in terms of meta-analysis, and multiple, simultaneous outcomes generated by the portfolio, rather than rely so heavily on the accumulated but unconnected results of single investigations.

The Committee also recommends that the Foundation develop and use a taxonomy of assessment concepts and measures that demonstrate the synergy among human, economic, and knowledge impacts. This could be useful not only in the assessment process, but as a way to communicate outcomes with a variety of audiences.

3. ***Use performance assessment as an opportunity and means to document the strategic value of NSF's science investments to the nation and the public***

NSF enables scientific advancement as well as education of the STEM workforce and the public. Its investments leverage other resources and encourage risk-taking in the service of discovery and learning. Its work is an important link in a chain of multipliers that deliver the value of scientific investment. The full value of NSF's work may not be measurable in quantitative terms, but it is surely a story worth documenting in the richest possible way.

The Committee recommends that NSF consider selecting a few measures used consistently over a long time period. Suggestions include framing performance in terms of "grand challenges," connecting the past with the future, broadening the concept of scientific infrastructure to include human and knowledge elements, and tracing the global flow of knowledge and scholars through the U.S. research and education enterprise. To communicate effectively, measures and presentation styles need to be customized to address the needs and interests of different stakeholder groups, including an increasingly global and more diverse public.

4. ***Engage the scientific community as a partner in performance assessment.***

We endorse the idea that PIs must become partners in performance assessment. We recommend that NSF build assessment requirements into its awards, find ways to widely publicize achievements that return value to PIs and their institutions, and develop ways to track the productivity and creativity of people supported by multiple NSF awards throughout their careers.

In addition, discussions in our Committee meeting returned often to the human dimension. In the context of changing U.S. and world demographics, we urge the Foundation to emphasize the inherent value of broadening participation in science and engineering. To the extent that NSF can foster full participation and career development among women and minorities, it will be advancing not only STEM capability but also the breadth and diversity of scientific inquiry. For example, women's health research has advanced dramatically over the decades since women began to comprise a substantial portion of investigators in that field. A significant increase in currently underrepresented groups within the STEM workforce will not only engage the fastest growing portion of the population in scientific careers, it will open new sets of questions and new approaches to research that are simply not possible when genuine diversity in culture, experience, and world view is not present. Toward that end, it would be very useful to find easier ways to collect diversity data and to prepare and disseminate information about the strategic value of diversity.

5. Build assessment into the organizational and programmatic infrastructure of NSF.

All of the foregoing recommendations rest on the belief that assessment must be treated as a regular ongoing function of the Foundation, with suitable staff and other dedicated resources. As a permanently and professionally-trained staff function, performance assessment can become a process of continual feedback and learning. NSF could begin to capture and share the learning that is already taking place in program- and directorate-level assessments such as those done for ITR and ERCs. Regular, ongoing review of Committee of Visitor (COV) reports and responses to their recommendations should also be part of this more comprehensive assessment function. Such an approach would allow the Foundation to link assessment to changing needs and priorities. It would also allow NSF to consider what it is not doing regarding assessment and communicating impacts, such as finding ways to learn from unsuccessful investments as well as successful ones. Moreover, we urge the Foundation to focus some research energy and resources on assessment by embedding evaluation research into major programs and placing some of the focus of the Science of Science Policy Program on NSF itself. This will be a cultural shift for NSF, but one we believe will bring lasting value to it as an organization.

Reports from AC/GPA Subgroups

Discovery Subgroup Report

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

Introduction

The Discovery Subgroup of the Advisory Committee for GPRA Performance Assessment was charged with the task of assessing whether the NSF has demonstrated significant achievement for the Discovery goal outlined in the NSF Strategic Plan (2006-2011) 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 transformative science and engineering."

Process Followed and Criteria Used

Members of the Discovery Subgroup reviewed 600 out of a total of 1362 highlights submitted by the NSF staff. The specific highlights reviewed were selected using a random list generator and divided evenly among the 10 Discovery Subgroup members. Each subgroup member was assigned 60 highlights to review but was provided with access to all of the 1362 highlights. Subgroup members were asked to select at least five highlights that exemplified the accomplishments of the Foundation in the area of Discovery and discuss how they address the following criteria:

Research Grants

- Strengthen fundamental research across the full spectrum of science and engineering through support for NSF's core disciplinary programs.
- Foster discoveries that have the potential to transform disciplines or fields of science, engineering, or education research.

Subgroup Members:

Pamela O'Neil (Chair)
Associate Provost
Brown University

Mary R. Albert
Professor of Engineering
Dartmouth College

Legand Burge
Dean, College of Engineering, Architecture, and Physical Sciences
Tuskegee University

Jorge L. Diaz-Herrera
Dean, Golisano College of Computing and Information Sciences
Rochester Institute of Technology

Wayne Johnson
Weston, MA

Deanna Paniataaq Kingston
Associate Professor of Anthropology
Oregon State University

Mary Jane Perry
Professor of Marine Sciences
University of Maine

Saifur Rahman
Director, VT Advance Research Institute
Virginia Tech

James Stith
Vice President, Emeritus
American Institute of Physics

Daniel Wubah
Vice President and Dean for Undergraduate Education
Virginia Tech

- Investigate the human and social dimensions of new technology and knowledge.
- Advance the fundamental knowledge base on learning.
- Foster research that improves our ability to live sustainably on Earth.
- Support outstanding junior faculty who exemplify the role of teacher-scholars through integration of education and research (CAREER Program).
- Promote innovation and partnerships with industries to stimulate the development of new technologies and processes to further U.S. economic competitiveness and benefit the nation.
- Support international research collaboration among U.S. investigators and partners in other countries and regions.

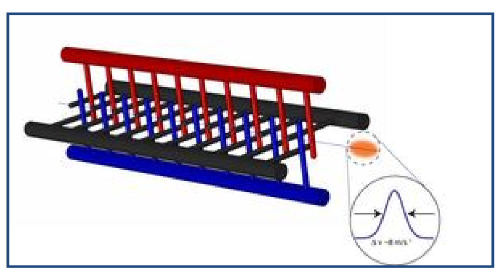
Centers

- Enable academic institutions and their partners to integrate discovery, learning, and innovation on scales that are large enough to transform important science and engineering fields and interdisciplinary areas, and stimulate increased innovation.
- Provide unique opportunities for students to broaden their research horizons.
- Provide opportunities for industrial partners to be actively involved in center research and interact with top academic researchers.

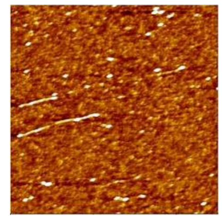
Analysis Overview

Based on our analysis of highlights, the subgroup concluded that the NSF has demonstrated significant achievement in meeting the goals of the strategic plan in the area of Discovery. There was clear evidence that NSF has served to strengthen fundamental research across the full spectrum of science and engineering through support of NSF's core disciplinary programs. The research supported spanned multiple scales – from new studies carried out by young investigators funded by the Faculty Early Career Development (CAREER) Program to extensive collaborations of many investigators at centers, from examination of single molecules to the study of climate interactions at the planetary scale. The highlights capture just a few examples of the diverse and innovative science supported by NSF.

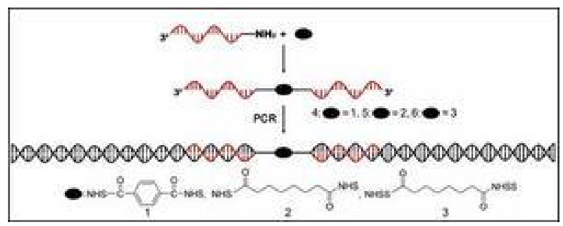
A stellar example of research at the smallest dimension was an award to a young investigator. Heather Lewandowski of the University of Colorado has developed a new method for slowing the speed of molecules in a beam: a critical step required to understand the control of chemical reactions on a microscopic level ***(Precision Control of Molecules;*** *Highlight 18477, Award 0748742)*. It is extremely difficult to observe the dynamics of chemical reactions, such as breaking one chemical bond



and forming another, at a microscopic level because molecules are in constant motion. The ideal way to observe such reactions would be to have the molecule stand still and allow another molecule to approach it. Although this has not been achieved, the new method by Lewandowski uses a Stark decelerator to produce a beam of molecules that are moving in one direction and at the same velocity by rejecting molecules that deviate from the central velocity. This research has enormous potential to impact the future of chemistry and atmospheric science. The CAREER award integrates education with research through discovery-based laboratory courses to mimic a research environment, introduce middle school age girls to experimental science, and develop a new graduate level course that emphasizes experimental measurement.

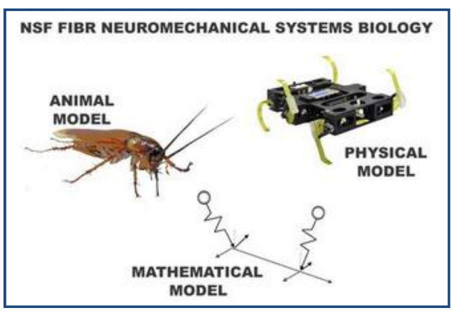


Another example of progress in the science of small things is a Nanoscale Interdisciplinary Research Teams (NIRT) award to Zhenan Bao at Stanford University ***(Towards Single Molecule Electronics****; Highlight 17969, Award 0507296****)***. Understanding and potentially controlling individual molecules is fundamental to developing molecular scale devices for computing, telecommunications, medicine, and other applications. The goal of this research is to construct a metal-single organic molecule-metal structure, which could then become the foundation for the design of organic electronic devices, including organic transistors, solar cells, and light emitting devices. This research has made significant advancement toward this goal by using DNA as a template to connect molecules having specialized chemical connectors at each end. By providing a metal–molecule interface, this research is enabling study of fundamental details of single molecule electronics and is providing the basis for fabricating nanostructures with specified optical or electrical characteristics.

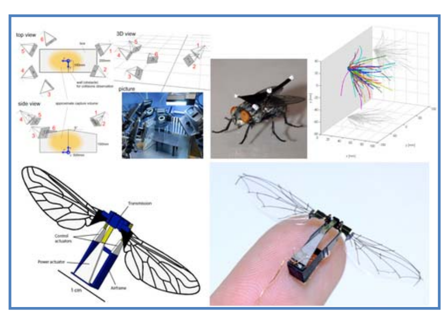


We also found numerous examples of research with the potential to transform disciplines or fields of science. Some of the most striking examples of transformative research came in the form of the potential for one field of science to influence another. For example, there are many funded projects addressing an engineering challenge that use biological examples to solve a mechanical problem. There were also examples of research in cognitive science that could be transformative to the field of artificial intelligence. Although center funding or the funding of interdisciplinary programs was responsible for some of these breakthroughs, some of the most striking examples involved single investigator research through core programs or young investigators funded by CAREER awards. Thus, NSF has succeeded in encouraging a new generation of scientists and engineers to look beyond disciplinary boundaries for their inspiration to solve core disciplinary problems.

Several examples of interdisciplinary research related to robotics illustrate the potential that the funding of fundamental research has to transform fields of science and engineering. In these examples biological models have been used to design machines. In some cases the primary objective was to understand more about a biological system by building mechanical or mathematical models. In others the objective was to use a living organism to provide clues to ways to solve mechanical problems. Robert Full from the University of California Berkeley led a team of researchers funded by the Frontiers in Integrative Biological Research Program to investigate systems-level models of how animals move reaching from neurons to muscles to the skeleton, to the whole body. ***(The Science of Motion;*** *Highlight 16936, Award 0425878****)***. The approach used by Full's team was to integrate direct experimentation on an animal model (the cockroach) with a physical model (a hexipedal robot) and mathematical models. Cockroaches provide a tractable model because their nerves and muscles are easily monitored and they produce force patterns indistinguishable from other legged animals such as humans, horses, lizards, and crabs. Results from the experiments demonstrate that cockroaches do not change the neural signals to their leg muscles unless they encounter obstacles or crevices more than three times the height of their hip. Mechanical control of normal leg movement does not require active adjustments from a brain. Although this research was aimed at providing a better understanding of neural control of movement, the results have the potential to inspire novel controllers in engineering or lead to the development of artificial muscles.



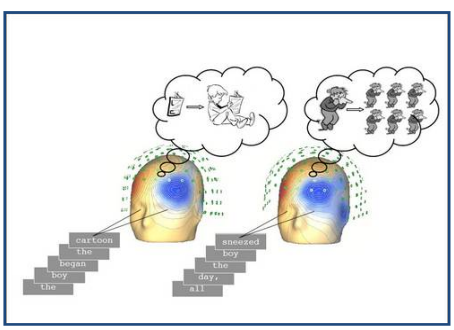
Robert Wood from Harvard University used data obtained from observing the movement of a fly wearing a motion capture suit to help design control methods for robotic flight. ***(The Harvard Microbiotic Fly: Design of a Bio-Inspired Insect-like Robot;*** *Highlight 17733, Award 0746638****)*** High speed video and analysis of three dimensional positioning and orientation data tracked the response of the fly to obstacles and provided the fly's response to landings and collision events. The data were used to design electromechanical control actuators for robot flight that function like those found on a fly's thorax. The research provides the foundation for faster and more efficient control systems for robots. Robotic insects could be used to perform tasks that are too dangerous for humans such as searching for survivors of natural disasters or exploring hazardous environments. Flying robots also have the



potential to perform high fidelity environmental monitoring, or pollinate crops. This research resulted from a CAREER award to a young investigator.

There are other examples of biological models inspiring the field of engineering. Material properties of organisms often hold clues for manufacturing new types of materials. Researchers at the Materials Research Science and Engineering Center (MRSEC) at the University of California, Santa Barbara, have discovered the mechanical properties of jumbo squid beaks ***(Squid Beaks Use Novel Materials Trick to Prevent Detachment;*** *Highlight 17223, Award 0520415)*. The squid beak is one of the hardest organic materials known; its extreme rigidity at the tip allows the squid to cut through its prey like butter. However, squid are gelatinous plankton, composed mostly of soft tissue; the mystery has been why the beak does not tear off from stress induced at the junction of materials with greatly differing mechanical properties. By creating a stiffness gradient of two orders of magnitude between beak tip and base, the beak becomes softer and more flexible as it approaches the soft muscle tissue. The research findings have implications for engineering of mechanically mismatched materials.

In another example, the field of cognitive linguistics has the potential to inspire new research in computer science. Research on the ***Neural Bases of Semantic Interpretation (****Highlight 17446, Award 0545186)* from Liina Pylkkanen at NYU provides a new understanding of how the human brain solves complex problems of language interpretation and could have important implications for the study of artificial intelligence. Pylkkanen used magnetoencephalography (MEG) to noninvasively measure changes in magnetic fields caused by electrical activity in the brain while subjects were reading semantically complex sentences. By comparing MEG results from complex sentences to parallel expressions involving no hidden meaning, the researchers identified the area of the brain responsible for the interpretation of ambiguous phrases or sentences. This research establishes a starting point for studying the brain bases of semantic composition in healthy individuals as well as in a wide variety of neurological and developmental disorders involving semantic impairment, such as aphasias, schizophrenia, autism, Alzheimer's disease, and semantic dementia. Although the fundamental goal of this research was to address important questions in neural linguistics, it has potential benefits to the study of artificial intelligence and machine learning. Understanding how the human brain solves complex problems of language interpretation could result in more efficient algorithms



for automated processing of language, which in turn has useful applications for web search engines or military intelligence.

Because of the enormous investment that the National Science Foundation has made in encouraging interdisciplinary research, we suggest that the AC/GPA continue to follow the long term effects on the culture of how science is conducted. Are young investigators who have been trained in a world with fewer disciplinary boundaries more likely to reach beyond their borders for inspiration? Has the blurring of disciplinary boundaries resulted in the convergence of disciplines?

Last year the Discovery subgroup of this committee asked that we specifically address research that investigates the human and social dimensions of new knowledge and technology. Our review identified numerous examples that address this question. A CAREER award to Charles Schweik from the University of Massachusetts Amherst ***(Understanding Factors Leading to Success or Abandonment in Open Source Software 'Commons';** Highlight 18338, Award 0447623**)*** resulted in a greater understanding of "technology mediated" forms of collaboration through analyzing the success or abandonment of open source software projects. Open source software projects are distributed over the internet to others without any monetary cost. Open source licensing has resulted in teams of collaborators who organize themselves in "commons" to work on software. The research has resulted in a book entitled The Collaborative Principles of Open Source Software Commons, currently under review with MIT Press. Understanding what makes open source software projects succeed could help improve the efficiency of collaborative problem solving.

Kathryn McKinley at the University of Texas, Austin ***(Next Generation Automatic Memory Management;** Highlight 17061, Award 0429859**)*** also seeks to understand how humans interface with technology. The PI and her collaborator at the Australian National University have provided a fundamental new building block for memory management algorithms with outstanding performance characteristics that have the flexibility to handle diverse workloads. This algorithm, the first new building block for memory management in over 25 years, has the potential to change the way modern automatic memory management systems are built. This is a significant achievement because memory management is an essential part of every runtime system for managed programming languages, such as Java, C plus, Ruby, and Python. Because this research contributes to systems that execute software, i.e., software infrastructure, and almost all aspects of modern life now depend on software running correctly and with high performance, it is likely to have a significant impact on how humans interface with computers.

Several examples of investigations of the human and social dimensions of new technology explore the use of technology as a collaborative tool for learning or to advance the fundamental knowledge base on learning. A CAREER award to William Tomlinson at the University of California-Irvine ***(An Agent-Based Approach to Human-Computer Interaction for Systems of Collocated Devices;*** *Highlight 18626, Award 0644415)* resulted in the EcoRaft project, a multi-device museum exhibit that helps children learn about restoration ecology. The project demonstrates novel mechanisms for people to use multiple nearby computing devices that work together while enabling children to learn about global environmental issues and effective science-based ways to address them. The Program supports an effort that impacts the groundwork for a wide range of potential applications involving multiple people and multiple devices cooperating to perform a task, whether for business, communication, or learning. More important, the rich connections between devices help to create an environment conducive to collaborative, discovery-based learning. In another example, Alexander Renkl (University of Freiburg), Vincent Aleven, and Ron Salden (Carnegie Mellon University) have discovered a way in which artificially intelligent computer tutors can be improved ***(Faded Examples Improve Cognitive Tutors;*** *Highlight 19328, Award 0354420****)***. Prior research had shown that "Cognitive Tutors" improve students' math achievement over typical classroom instruction. The current work presents the students with "solved example problems" and "fades out" problem steps as the students demonstrate progress. The researchers found that adding faded examples in this manner improves students' learning outcomes and they performed better on tests that were administered several weeks after the learning phase was conducted. For their work, the researchers were awarded the Cognition and Student Learning Prize by the Institute of Education Sciences. This work has the potential to increase learning so that students across a range of populations have a better chance of succeeding in STEM disciplines.

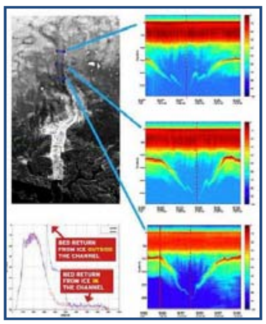
Thomas DeFanti and colleagues at the University of Illinois at Chicago (UIC), through a grant provided by NSF's International Research Network Connections (IRNC) program, used the evolving global optical network infrastructure (IRNC's TransLight/StarLight network) to create a virtual classroom between UIC and Louisiana State University (LSU) in order to teach videogame design ***(Sharing Data on a Global Scale;*** *Highlight 19181, Award 0441094****)***. For this class, they took advantage of high-definition video-conferencing and online discussion groups for class instruction and team

projects. Through this process, they also sought to understand how to make the subject matter compelling and effective over distance, and to learn how students work together in teams separated by time and space. The success of this endeavor has resulted in interest from international collaborators at Moscow State University in Russia and Masaryk University in the Czech Republic.

Last year the Discovery subgroup of this committee also asked that we specifically address research that improves our ability to live sustainably on earth. The highlights that we reviewed had numerous examples of projects that address important questions in energy and climate change research. An example of research that addresses challenges in storing energy also involves an industry partnership. Small Business Innovation Research (SBIR) funding to Christopher Rhodes of Lynntech, Inc. has developed an innovative, low-cost nano-structured composite electrode for high energy and power density asymmetric electrochemical capacitors ***(High-performance, Low-cost Hybrid Electrochemical Capacitors;*** *Highlight 17293, Award 0750183****)***. This project demonstrated the material's improved performance compared with existing technologies, and designed a low-cost manufacturing process. The availability of low-cost and high energy density storage devices of any kind will go a long way to absorb large amounts of intermittent sources of electricity (e.g., wind and solar) into the electric power grid, thus encouraging the development of green sources of power, which reduce the country's carbon footprint and dependency on imported fossil fuel. Since this was an SBIR grant, the researchers are expected to be driven by their commercial instincts to bring this low cost storage technology to the marketplace soon rather than leaving this as an academic exercise that sometimes take a long time to come to fruition. Having this storage technology commercialized sooner rather than later will help U.S. competitiveness in a fast growing market for low cost, high efficiency, and non-polluting storage devices for application in commercial and residential buildings.

One of the most globally important issues of our time is climate change and understanding human impacts. The Intergovernmental Panel on Climate Change (IPCC) 2007 concluded that global warming is occurring now, and that human contributions from greenhouse gas emissions are involved. The impacts of climate change in the Arctic and on the Antarctic Peninsula regions have been clearly seen from rapid melt and demise of ice shelves over the recent decade. New results published in Nature and the Proceedings of the National Academy of Sciences show that most of Antarctica is warming now, although to a greater degree in the West Antarctic ice sheet than the East Antarctic ice sheet. ***(New Data Reveal Recent Antarctic Warming,*** *Highlight 17984, Awards 0126161 and 0440414****)***. In addition, the research team led by Ed Brook at Oregon State

has used evidence from gases trapped in ice cores to clearly show that during abrupt climate change events, atmospheric carbon dioxide rose each time that Antarctica has warmed significantly in the past ***(Gas from the Past Gives Clues about the Relationship Between Climate and Ocean Circulation,*** *Highlight 17987, Awards 0337891 and 0602395****).*** Natural abrupt warming events in Greenland and Antarctica between 10,000 to 100,000 years ago have occurred in opposite patterns, due to changes in ocean transport of heat. Models predict that carbon dioxide is released from the deep ocean in times when Antarctica warms significantly. If that were to occur, a natural release of carbon dioxide from the deep ocean would add to anthropogenically-induced rise in the greenhouse gas, accelerating climate change. In another example, new sensitive radar technologies are being used by the Center for Remote Sensing of



Ice Sheets to understand the impact of bed geometry under a glacier on its discharge rates ***(STC-II: Channel Geometry under Jakobshavn Isbrae, West Greenland from Airborne Rader Sounding,*** *Highlight 19130, Award 0424589****)***. This glacier has been showing variable but accelerated rates of flow and discharge since 1995. The melting of the Greenland ice sheet is contributing to sea level rise due to global warming. Improving estimates of future sea level rise is a primary goal of the center. In three grants grouped under the heading, ***Melting on the Arctic Express*** *(Highlight 18536, Awards 0531026, 0531173, and 0632130)* researchers were able to determine the amount of melting at the top and bottom surfaces of the sea ice cover. Their observations indicate that there was an extraordinarily large amount of bottom melting of the ice in the summers of 2007 and 2008 and that solar heating of the upper ocean was the primary heat source. Their calculations seem to confirm that solar heating in the open water was sufficient in magnitude and in timing to produce the observed bottom melting. This is a very significant discovery given the many instances of loss of Arctic sea ice cover that have been reported recently in the scientific press. When the issues of global warming and climate change are capturing the headlines globally, it is necessary to have such data and models to help separate fact from fiction.

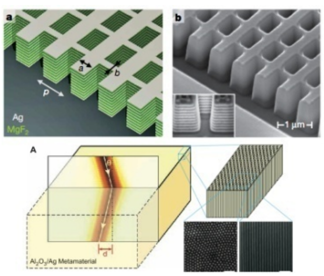
In addition to global sea level rise from climate change, by comparing data from the geological record, researchers discovered that local, relative increases in sea level rise in estuaries of the upper Gulf Coast are occurring, most likely due to oil and gas extraction and/or sediment starvation at the mouth of the Mississippi River. ***(Response of Upper Gulf Coast Estuaries to Holocence Climate,*** *Highlight 17459, Awards 9905230, 0002807, and 0107650).* The accelerated sea level rise in this region of the U.S. is likely to lead to rapid and dramatic reorganization of estuarine environments, coastal erosion, and wetland loss, as global sea level rise continues in the next few centuries.

An award to Juan Valdes at the University of Arizona ***(Initiation of a Prototype Ecohydrologial Observatory at the Valles Caldera National Preserve,*** *Highlight 19094, Awards 9876800)* demonstrates the importance of large scale ecological research to address environmental challenges. Water availability in the western states is primarily determined by high mountain hydrology, yet current information about actual processes is limited. Research at the Center for Sustainability of Semi-Arid Hydrology and Riparian Areas combines environmental instrumentation of a watershed at a scale sufficient to collect meaningful data with fine-resolution modeling of hydrologic processes and water partitioning vegetation, runoff, and groundwater discharge. Data were collected over an annual cycle on a basin scale; as a result, researchers are able to better quantify the processes that govern flood and drought flows in western rivers. This research was conducted at an NSF Science and Technology Center. Because the research was carried out on a sufficient spatial scale, the results make a substantial contribution to management and preservation of western water resources, an essential commodity for ecosystem and human sustainability.

NSF has also funded projects to develop environmental modeling tools to help biologists and ecologists address important questions with applications to global climate change and the corresponding impetus on sustainable practices for environment-related activities ***(Networked Infomechanical Systems (NIMS),*** *Highlight 18846, Award 0331481)*. Researchers funded by this project have created NIMS, a Networked Infomechanical Systems robotic sensor technology that combines working, embedded computing, and electromechanical systems to monitor environments with spatio-temporal dynamics efficiently. NIMS is a breakthrough in sensing technology since it provides autonomous and precise control of sensors in complex environments while exploiting the existing infrastructure available in-field. NIMS has been used successfully in both terrestrial (rain forests in La Selva, Costa Rica; White Mountains, California; and San Jacinto confluence zone, California) and aquatic (Lake Epecuen, Argentina; Lake Fumor, California; and San Joaquin confluence zone, California) environments. NIMS has been used and adopted by biologists and ecologists to address critical problems including characterizing light distribution. NIMS provided unprecedented, high resolution data for critical environmental monitoring applications that were not possible before.

The above selected projects include several interesting examples of center-level research. However, there are many other highlights that illustrate specific mechanisms that NSF centers have used to enable academic institutions and their partners to integrate discovery, learning, and innovation on scales that are large enough to transform important science and engineering fields and interdisciplinary areas and stimulate increased innovation. NSF centers provide unique opportunities for students to broaden their research horizons and also provide opportunities for collaboration with industrial partners.

Transformative research that manipulates light at the nanoscale from two groups of researchers at the Center for Scalable and Integrated Nanomanufacturing at the University of California Berkeley puts us a step closer to the possibility of "invisibility cloaking" or making a material invisible ***(Bending Light Backward Towards Invisibility;*** *Highlight 16944, Awards 0751621).* These projects using two very different fabrication methods each resulted in the first



demonstrations of a bulk material designed to bend light. Metamaterials are composites that have extraordinary optical properties and can negatively refract light. One of the metamaterials being studied is a novel composite with a fishnet structure. The second is made with silver nanowires embedded in an alumnia matrix. This work is significant because it is the first demonstration of negative refractive index and optical negative refraction of bulk optical materials. The exploration of optical phenomena associated with zero and negative refraction indices could lead to applications such as new ways to create novel high powered optical lenses or increased storage capacity in optical media. This research involved the collaboration of an interdisciplinary team of mechanical engineers, physicists, and chemists from three UC campuses (UNCC, UCLA, and Berkeley). Because of the transformative potential, the research has attracted industrial support from Hewlett Packard, Boeing, and Northrop Grumman.

Research at the Center for Environmentally Responsible Solvents and Processes at the University of North Carolina at Chapel Hill *(Highlight ID 18479, Award 9876674)* resulted in the ***Lemelson-MIT Prize to PI Joseph M. Simone***. This project has led to groundbreaking solutions in green manufacturing, producing applications in gene therapy and drug delivery, as well as in medical device design and manufacture. This project uses supercritical fluids, which are a special phase of matter that has both gas and liquid properties. Supercritical fluids produce a class of high performance plastics known as flouropolymers. This breakthrough impacts environmentally sustainable manufacturing. Fluoropolymers are used in wire and cable insulation, flexible tubing, and industrial films – applications that span the fields of data communications, electricity storage, and automotive design. "DuPont has licensed this breakthrough fluorpolymer-creation process, and we have built commercial facilities based on the technology, leading to unique products and more environmentally sustainable manufacturing," said Nandan S. Rao, Global Technology Director, DuPont Fluorproducts. This work has also been applied to the medical device field. Dr. Rao, working with Duke University and Synecor LLC, is developing a fully bioabsorbable stent, and progress is being made to eliminate the need for permanent prosthetics in opening blocked or closed blood vessels. Work is underway utilizing fabrication processes from the microelectronics industry to create tiny drug carriers.

Learning Subgroup

The Committee concluded that there has been significant achievement for the Learning outcome goal.

Introduction

The Learning Subgroup of the Advisory Committee for GPRA Performance Assessment was charged with the task of assessing whether the NSF has demonstrated significant achievement for the Learning goal outlined in the NSF Strategic Plan (2006-2011) to "cultivate a world-class, broadly inclusive science and engineering work force, and expand the scientific literacy of all citizens"

Subgroup Members:

Ira Harkavy (Chair)
Associate Vice President and
Director, Netter Center for
Community Partnerships
University of Pennsylvania

Cinda-Sue Davis
Program Director, Women in Science
and Engineering Program
University of Michigan

Marian Johnson-Thompson
Retired Director of Education and
Biomedical Research Development
National Institute of Environmental
Health Sciences (NIEHS)

Maria (Mia) Ong
Director, Diversity Resource Group
TERC

Process Followed and Criteria Used

The subgroup members read and analyzed 261 highlights classified under the Learning outcome goal. Each member of the subgroup reviewed approximately 65 highlights.

The Subgroup was asked to review and evaluate the accomplishments against one or more of the following criteria:

K-12 Education and Teacher Training

- Support research to improve the education of K-12 students in science and mathematics
- Support education research that develops successful models for K-12 teaching and learning
- Support active involvement of K-12 teachers in NSF-funded research and workshops to bring fundamental knowledge and technological innovations into their classrooms

Undergraduate through Postdoctoral Training

- Prepare and support the next generation of STEM professionals and attract and retain more Americans to STEM careers.

- Support active research participation by undergraduate students in NSF-funded projects.
- Support active research participation by graduate students in NSF-funded projects.
- Support community college faculty in NSF-funded research to bring fundamental knowledge and technological innovation into their classrooms
- Broaden the participation of individuals and groups that are underrepresented in STEM and diverse institutions throughout the United States in NSF-supported research and education activities and programs.

Public Understanding of STEM and Lifelong Learning

- Increase interest, engagement, and understanding of STEM by individuals of all ages and backgrounds and within a variety of different formal and informal educational settings that contribute to lifelong learning.
- Prepare and support the next generation of STEM professionals and attract and retain more Americans to STEM careers.

Based on the review of the accomplishments against the above goals, each member selected about five highlights that she or he believed are the best examples of NSF's achievement of the Learning Outcome Goal. Subgroup members were asked to be reflective about the rationale behind the choice of selected highlights. They were also encouraged to identify any themes or threads that run through the highlights they chose.

In addition, NSF staff members were asked to provide the subgroup with various statistical breakdowns of highlights. Variables analyzed included: number of categories chosen, most commonly selected categories, category combinations for all selected highlights, and highlights by Transformative Research, Broadening Participation, and Benefits Society. These data helped to provide a fuller picture of the highlights and identify common themes.

Analysis Overview

Accomplishing NSF's Strategic Outcome Goal for Learning: to "*cultivate a world-class, broadly inclusive science and engineering work force, and expand the scientific literacy of all citizens* " is crucial to the future of science and democracy itself. The Foundation has invested resources in programs across the various directorates designed to strengthen learning through advances in K-12 Education and Teacher Training, Undergraduate through Postdoctoral Training, and Public Understanding of STEM and Lifelong Learning. Importantly, NSF has made broadening participation of previously underrepresented groups such as women and historically underrepresented minorities in STEM fields a significant component of its work to accomplish the Strategic Outcome Goal for Learning.

NSF has also made a commitment to integrate research with education, which is a cornerstone for effective learning across all levels of schooling. This commitment is highlighted in the "Translating the Plan into Action" section of Investing in America's Future (NSF Strategic Plan FY 2006-2011) under the heading *Integration of Research with Education*: "Strengthen connections between learning and inquiry. Deciding factors include whether investments present a rich environment for encouraging future scientists, engineers, and educators, and whether they provide opportunities for teachers and students to participate in research activities at the K-12, undergraduate, graduate, and postdoctoral levels."

A component of its commitment to integrate research with education is the Foundation's identification of "discovery-based learning" as a particularly effective means to increase the effectiveness of math and science education. This approach is discussed in the "Introduction" section of the Strategic Plan: "Discovery-based learning–from hands-on activities in kindergarten to public participation in research sample collection—is becoming an integral feature of formal and informal education at all levels. As new practices take root they are transforming education research and practice in ways that are not yet well understood."

Central to NSF's success is its merit review system for review, assessment, and selection of projects. Two criteria are utilized in the merit review: intellectual merit and broader impacts. The criterion of broader impacts has significant implications for the Strategic Outcome Goal for Learning, as well as the variety of means and indicators of accomplishing that goal. According to the Strategic Plan: learning itself, the integration of research and education, and broadening participation are components of broader impacts: "Broader impacts include aspects of teaching, and learning, integration of research and education, technology transfer, societal benefits, technological innovation, infrastructure development, and opportunities to include a diversity of participants, particularly from underrepresented groups in science."

The subgroup selected highlights that are components of broader impacts, involving active, hands-on, discovery-based learning; the integration of research with education; and broadening participation. The broadening participation category was represented in every selected highlight; benefits society in 20 of 22. Fifteen of the twenty-two selected highlights demonstrated significant achievement in more than one research and education outcome and evaluation criteria. In fact, 12 involved from 3 to 6 research and education outcomes and evaluation criteria. A significant number (15) and percentage (68%) of projects involved K-12 students and/or teachers; an equal number and percentage also involved a focus on undergraduate through graduate research. Ten (45%) involved programs across a continuum of schooling, joining K-12 and higher education. This finding led the Subgroup to develop an additional criterion: P-20 Plus: Integrating PreK-12 Education through Higher Education.

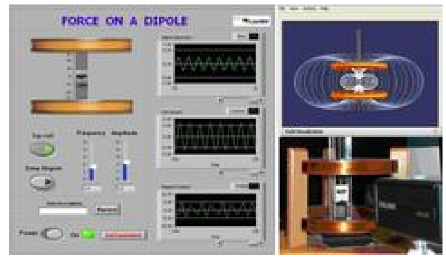
Integration of research with education, connecting projects across levels of schooling, and combining a number of research and education outcomes and evaluation criteria are among the most impressive strengths of NSF's work to accomplish its Strategic Outcome Goal for Learning. This emphasis on integration, broadening participation, and broader impacts denotes a powerful approach to advancing learning; increasing the public's interest, engagement, and understanding of STEM; and producing positive societal impacts, including sustainable institutional change of K-12 and higher education.

The subgroup selected the following highlights as examples of significant achievements in the area of Learning:

K-12 Education and Teacher Training

These projects emphasize meaningful, contextualized STEM teaching and learning that pose real-world, hands-on, interdisciplinary, project-based problems. One major outcome of such an emphasis on context is that solutions to these problems often involve those who live in developing countries and/or in underserved communities. For example, the ***Elementary School Teachers'*** project (*Highlight 17025, Award 0822236)* involves innovative, hands-on science education. Faculty members and lab personnel from the University of Oklahoma work as facilitators, encouraging elementary school teachers to conduct their own research, raising questions, developing hypotheses, and testing them without prior knowledge of the field (biology of the fruit fly). The project involves a summer science camp for the teachers, and it has been expanded to sixth graders, engaging them in hands-on experience with brain research. Teachers and students learn science by doing science. They develop an interest in scientific work through active engagement in the scientific process of discovery. This work, done in an EPSCoR state (Oklahoma), highlights broadening participation, as well as broader impacts, by providing a replicable approach for science education and university collaboration with pre-K to 12 education. In another example, ***Rollercoaster Fun!*** *(Highlight 17417, Award 0808107*)

researchers at North Carolina State University have partnered with North Carolina's New Schools Project, Elizabeth City State University (a Historically Black College and University), and two diverse high schools to actively engage high school students in engineering, mathematics, and science through a hands-on, interdisciplinary, real-world approach of studying the motion of rollercoasters.



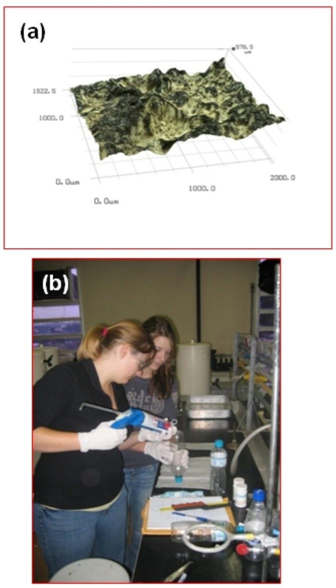
In ***CI-TEAM Implementation Project - The iLab Network: Broadening Access to Hands-on STEM Learning via Remote Online Laboratories*** (*Highlight 19220, Award 0753324*), the Massachusetts Institute of Technology and Northwestern University have collaborated with the Chicago Public Schools and online schools to provide a remote laboratory cyberinfrastructure for STEM education that will offer access to real experimental devices. While virtual (and therefore not "hands-on"), the project still has great potential to enhance users' access to laboratory devices in real time, thus improving high school curricula and laboratory experiences for students and teachers, particularly those in schools located in low-income areas. Furthermore, the free nature of the remote laboratory encourages wide public use in informal settings such as science museums. These wide-reaching, informal educational tools are likely to contribute to deeper, lifelong learning and appreciation of STEM and may attract and retain more Americans to STEM careers.

Undergraduate through Postdoctoral Training

Two projects involve the successful integration of research and education. ***The Florida International University Center for Research Excellence in Science and Technology*** (*Highlight 17776, Awards 0317692 and 0833093*) has implemented synergistic research and education activities that have substantially increased the number of underrepresented students pursuing doctoral degrees in computer science in the United States. FIU CREST has graduated 39 Ph.D. students in computer science and computer engineering. Of these, 33 percent have been underrepresented minorities and 38 percent have been women. In fact, FIU soon expects the CREST-induced enrollment diversity to result in four Hispanic Ph.D. graduates in computer science per year, compared to approximately 10 Hispanic PhD graduates per year nationally. This initiative is significantly broadening participation, an important NSF theme, in computer science. As a result of this grant, FIU has institutionalized changes in training and involving studentsin research. The program has used NSF funding as a bootstrap to attract additional support, including support from other NSF directorates, as well

as synergistic collaborations with other partners. Lastly, FIU CREST is tracking the participation of students in an effort to assess its success in maintaining and graduating a diverse cohort.

The Scout Robotics Platform Advance and Reinvigorates Computer Science Enrollment *(Highlight 17900, Awards 0420836 and 0531859)* developed software for the Scout robotics platform with an emphasis on search and rescue operations while at the same time developing an excellent educational tool for students who are learning to work with robotics. Berea College has put it to use in the entry-level Introduction to Robotics course. Computer science enrollments at Berea have doubled due in part to the implementation of this entry-level course and to undergraduate research opportunities in robotics as part of this project. Other colleges are exploring the possibility of using this curriculum in their introductory courses. Another excellent example of a project that integrates research with education is ***Water Treatment*** *(Highlight 18090, Award 0404874)*. In this project undergraduates at the University of Pittsburgh, seven of whom are racial/ethnic underrepresented minorities, in collaboration with UNICAMP University in Brazil have conducted interdisciplinary research to develop and test an effective model of a low-cost, ceramic water filter that would enable cleaner drinking water and better sanitation, thus yielding a higher standard of living in Brazil and in other developing countries. Students, particularly those from underrepresented populations in STEM, are more attracted to, and retained in, STEM if their studies and research have social meaning and real, immediate impact.



A program that has demonstrated tremendous overall success is the ***Alliance for Graduate Education and the Professoriate (AGEP) Broadens Participation among the Nation's Faculty*** *(Highlight 19019, Award 0823766)*. AGEP institutions report increasing enrollments, high retention, increasing Ph.D. graduations, and successful transitioning of Ph.D.s into the workplace. The AGEP at Georgia Tech is noted as one of the top producers of engineering and science doctorates for underrepresented minorities and ranks number one in engineering doctoral degrees awarded to African-Americans and number 3 in those awarded in all categories to minority students. In the past 3 years (2005-2007), the Facilitating Academic Careers in Engineering and Science (FACES) AGEP has produced 77 Ph.D.s from underrepresented groups. FACES is a collaboration among Emory

University, Morehouse College, Spelman College, and Georgia Tech and assists underrepresented engineering and science students with navigating the path to an academic

career. This stellar NSF program demonstrates the effectiveness of collaborations and the importance of support programs beginning early in the academic pathway and remaining along the continuum even after the initial academic appointment. The AGEP at Georgia Tech has successfully addressed NSF evaluation criteria of supporting the next generation of STEM professionals, attracting and retaining more Americans in STEM fields, supporting undergraduate and graduate students in NSF funded research programs, broadening the impact of science, and broadening the participation of underrepresented groups in STEM careers and NSF supported programs.

Public Understanding of STEM and Lifelong Learning

Another major outcome of real-world, contextualized STEM teaching and learning is effectiveness in increasing the public's interest, engagement, and understanding of STEM. For example, Elizabeth Hausler, a civil engineering graduate student at the University of California at Berkeley ***"Build Change" Exports Earthquake Engineering Techniques to Developing World*** *(Highlight 17865, Award 9701568)* has founded a worldwide non-profit organization whose members travel to developing countries that are prone to earthquakes and teach residents how to build low-cost, earthquake-resistant housing, using locally available materials and tools. In another example, Public Broadcasting System (PBS) has developed Season 3 of ***Design Squad: Inspiring a New Generation of Engineers*** *(Highlight 18166, Award 0810996)*, a reality series featuring two teams of kids competing to solve hands-on engineering problems. The program, which has engaged nearly 95,000 children and families, has an accompanying outreach campaign (282 events around the country) and active website. Evaluation has found that the program has increased kids' knowledge of engineering, challenged their negative stereotypes of engineering, engaged a significant proportion of girls and minorities, and improved the public image of engineering as a discipline that helps to improve lives and affects real people.

FETCH! Increases Children's Knowledge of Science Careers *(Highlight 18169, Award 0714741)* uses a large scale approach to address the issues of increasing the numbers and broadening participation in science. FETCH! is a children's television series airing nationally on PBS with approximately 3.5 million viewers weekly on 325 PBS stations. FETCH! has done a particularly good job at evaluation using the Goodman Research Group. Fourth-graders who watched

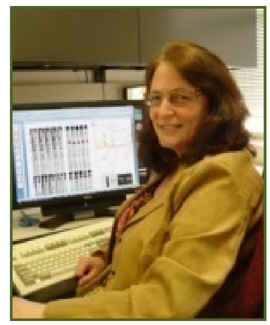
FETCH! made significant gains in their understanding of science content, ability to apply content to new situations, and recognition of science and engineering process skills. In the third season, the FETCH! production team made changes to the production model in order to emphasize science careers. This, too, has made an impact. Fourth-grade students who watched 5 episodes of FETCH! showed significant increases in their scores on questions related to science careers. Specifically, students were better able to describe what scientists do, give less stereotypical answers to questions that asked about scientists' work habits and settings, and broadened their ideas about what constitutes a science career. The target audience of 6- to 10-year olds is significant in that most outreach is done with older audiences. In addition to the television program, FETCH! Outreach serves an estimated 680,000 kids through partnerships with museums, libraries, and afterschool groups. The FETCH! Web site draws about 18,000 visitors a day. FETCH! makes special efforts to reach out to underserved audiences with the result that there are an equal number of girls and boys watching the show, and 43% of the viewers are African American or Hispanic. This model, which sparks an interest and understanding in science and science careers, has the capacity to transform an entire generation of youth to the fun and excitement of STEM fields.

ATE-Sponsored Wind Energy Project Trains Turbine Technicians *(Highlight 19102, Award 0801212)* is an Advanced Technological Education (ATE) program at Laramie County Community College (LCCC) in Wyoming that will train and educate technicians who will service wind turbines. As wind energy becomes a key source of renewable energy, more and more wind turbines will be needed. (The PI notes that 3,200 new wind turbines were installed across the nation during the last year.) The LCCC program centers on designing and implementing career pathways in wind energy technology by developing wind energy certification, diploma, and associate degree programs and community information seminars/workshops on wind energy technology and related renewable energy topics. This program supports community college faculty in providing fundamental knowledge and technological innovation into their classrooms, broadening impacts as trained LCCC students potentially can provide services to a variety of other geographic locales, attracting more Americans to STEM careers, and increasing the understanding of renewable energy topics to community groups.

P-20 Plus: Integrating PreK-12 Education through Higher Education

This category includes highlights that successfully integrate the research and education outcomes of **K-12 Education and Teacher Training** and **Undergraduate through Postdoctoral Training.** In addition to successfully integrating these two outcomes, a number of highlights also involve significant achievement in **Public Understanding of STEM and Lifelong Learning.**

The highlight titled ***From Television to Local Schools: NSF PI is Making a Difference*** *(Highlight 17445, Award 0615154)* provides an excellent example of P-20 Plus achievements. This highlight illustrates how the outreach activities led by Dr. Anne Simon, a NSF supported plant virologist and consultant for X-Files TV programs and movies, have led to improved student biology performance as well as increased teacher understanding of science and delivery of information to students at Duval High School (98 percent minority and low achieving) in Prince Georges County (PGC), Maryland. Dr. Simon, author of The Real Science Behind the X-files (2001, Touchstone Press), has used her ability to effectively interest and engage the general public in scientific issues to engage and teach students and teachers. She also presents a positive image of what science is and how it is done. Dr. Simon's outreach efforts, which have included teacher training, weekly sessions with Advanced Placement biology students, and pairing University of Maryland graduate students with students for after school tutoring, resulted in student biology assessment scores increasing by 42 percent (from 2005-2006) at this school. Subsequently, Dr. Simon received an NSF grant to conduct a summer workshop for all PGC teachers. The year after teachers completed the workshop, the same cohort of Duvall students' scores increased by 66 percent (overall) in 2007. This success led PGC administrators to continue the program in 2007 and expand its focus on improving science teaching in PGC K-12 schools by agreeing to participate in a 5 year, $12.5 million NSF Math and Science Partnership Program grant in partnership with the University of Maryland and other local institutions of higher learning.



Developing the Scientist of the Future *(Highlight 17535, Award 0710709),* a project located at the University of Richmond, involves teams of university students and high school students and teachers doing research on how the brain works. The project involves significant team building activities in order to help create an integrated research team. All three groups learn about science through research-based inquiry, and high school teachers receive valuable assistance in their classrooms since undergraduates also work as science tutors. Undergraduates not only learn about science through teaching science, they also learn how to

teach. The program highlights broadening participation since it involves minority students in the greater Richmond area. The project is of significant societal benefit since it provides a replicable approach for effective STEM education across all levels of schooling.

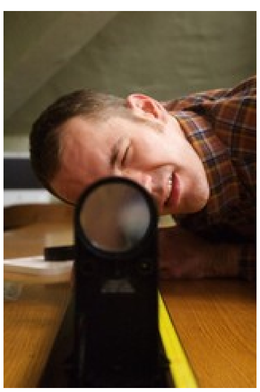
The Future Scholars Program Introduces Young Students to the Pharma Field *(Highlight 18029, Award 0540855)* is also an excellent example of increasing and broadening participation. NSF's Center for Structured Organic Particulate Systems, which is headquartered at Rutgers University, works with the Rutgers Future Scholars Program, an unusually intensive outreach program aimed at disadvantaged populations. This multi-year program provides opportunities for education, growth, and enrichment, exposing students to career paths they may not have thought possible. Particularly interesting components are the development of a Parent Learning Community and the promise of four years of tuition and fees for Future Scholars who meet admission requirements and choose to attend Rutgers.

More Scientists and Stronger Materials in Our Future *(Highlight 18092, Awards 0547976 and 0606040)* is a particularly innovative project, involving 6 research and education outcomes and evaluation criteria. Working with the Harlem Children's Zone, an extraordinarily influential school and community improvement program, a Cornell Professor, Itai Cohen, brings hands-on science to at-risk youth in Central Harlem. This project involves first grade students with the field of materials science through exploring the characteristics of everyday and unusual materials. The project is linked with Professor Cohen's research on understanding materials properties by means of experimentation with colloidal materials. Connecting a major research project with a highly successful community program and outreach efforts to school children is extraordinarily innovative, creative, and significant. The project offers a model for integrating frontier research with frontier educational and community outreach involving STEM and underrepresented minorities. This work could well result in new materials for everyday applications, as well as a replicable approach for STEM education and strengthening STEM pathways.

Creating K-12 Teacher and Counselor Leaders in Biotechnology *(Highlight 18368, Award 0757292)* is conducted by the Biotechnology Education Infusion (BEI) project. BEI is a multiphase Northwest Regional project funded by NSF's Advanced Technological Education (ATE) program and a collaboration among Washington State University (WSU), Spokane

Community College, and Eastern State University with significant participation of regional biotechnology industry and research institutes at WSU. BEI is designed to provide laboratory instruction, mentoring, and material support to 90 teachers and counselors to help better inform and prepare students for biotechnology fields. This program is significant because only 35 percent of the entering teachers and none of the counselors were aware of biotechnology careers prior to beginning the BEI program. Additionally, at the beginning of the BEI program, less than a third of teachers reported ever having worked with counselors. As a result of the BEI program, teachers and counselors gained sustained awareness of biotechnology careers and began working together. There is now more in-depth student counseling related to biotechnology careers and greater use of biotechnology labs by several thousand students each year in middle, high school, and community college science courses throughout Washington, Montana, Idaho, and Oregon (representing 38 urban, suburban, and rural schools). Given teachers' and counselors' lack of biotechnology knowledge, this represents an extremely important program for ensuring that a broad number of students in a wide geographic area gain information in biotechnology instruction and biotechnology careers and demonstrates the importance and significance of collaborations. It also supports the involvement of K-12 teachers in workshops to bring fundamental knowledge and technological innovations into their classrooms, improving the education of K-12 students in science and math and broadening the participation of underrepresented groups (over half of participating schools have significant high-needs and minority student populations and one BEI school is on an American Indian reservation).

Marcel Agueros, an NSF Postdoctoral Fellow who is a member of an underrepresented minority group, has developed a research and professional development program in New York City.



New York City Science Teachers Observe Variable Stars from the Rooftops *(Highlight 18634, Award 0602099)* brings culturally diverse cohorts of public high school teachers (and NSF-funded graduate students) to the rooftops of buildings in urban neighborhoods, the contexts in which they live and work, to participate in authentic astronomy research: observing low-mass flare stars. Teachers then bring new research methods, astronomy knowledge, renewed enthusiasm for science, and knowledge about technological innovations back into STEM classrooms. This collection of projects underscores the importance of teacher *leadership* development as well as the paramount importance of collaborations across levels (i.e., high school, college, graduate school), professional roles, and institutions in attracting and retaining more young Americans, particularly those who are underrepresented.

Collaborative Research: BPC-DP: Improving Minority Student Participation in the Computing Career Pipeline with Culturally Situated Design Tools *(Highlight 18954, Awards 0634342 and 0634461)* Rensselaer Polytechnic University, Texas A&M, and University of North Carolina, Charlotte have established a collaboration of university faculty, teachers, and community partners to develop, evaluate, and implement "Culturally Situated Design Tools" (CSDTs). Based on the concept of ethnomathematics, CSDTs relay the mathematical knowledge embedded in cultural designs such as Native American beadwork and Latino percussion rhythms. CSDTs were integrated into standardized curricula in inner-city schools (grades 3-12) with large populations of African-American, Latino, and Native Americans in seven states throughout the country. Preliminary evaluations indicated statistically significant increases in kids' mathematics achievement and attitudes towards technology-related careers, thus indicating a successful model for K-12 teaching and learning.

PIRE: A Global Living Laboratory for Cyberinfrastructure Application Enablement *(Highlight 19251, Award 0730065),* which involves Florida International University/Florida Atlantic University (FIU/FAU) in a Partnership for International Research and Education (PIRE) project, is a research effort that focuses on developing cutting edge science and technology to use the Internet to address critical societal problems (e.g., disaster management, healthcare, energy efficient buildings, etc.) in the United States and around the world. Seven international institutions in Mexico, China, Spain, India, and Argentina to include industry research labs and national supercomputing centers, 18 FIU/FAU BS, MS, and PhD students and 28 faculty and scientists from partner institutions form this consortium. As an innovative global living laboratory, this consortium allows for a multitude of collaborative research studies that will be able to take advantage of existing and developing cyberinfrastructure to access large data bases through grid technology. PIRE represents an excellent model for enhancing international research opportunities for students and investigators and helps to strengthen U.S. leadership in sustainable global partnerships and innovations. This program prepares the next generation of STEM professionals, supports research participation of undergraduate and graduate students in NSF-funded research projects, and broadens the impact of NSF funded research. Additionally, the PIRE program illustrates how to apply cyberinfrastructure to advance the understanding of global issues and provide more authentic and motivational STEM learning opportunities for students.

Updating Understandings of Gender and Mathematics Performance *(Highlight 19311, Award 0635444)* provides the research underpinnings necessary to increase the number of girls and women potentially entering STEM education and careers. These NSF funded researchers have analyzed mathematics standardized test results for over seven million students in grades 2 through 11. Their analyses of state assessments of cognitive performance from ten states indicate no gender difference in average mathematics performance. These findings refute common stereotypes that girls lack mathematical ability and that boys are better at math than girls.

Involving a partnership among Salish Kootenai College, Montana State University, University of Montana, 30 K-8 schools and consultants form Crow, Flathead, and Northern Cheyenne Indian Reservations, the ***Linking American Culture and Science under the Big Sky Project*** *(Highlight 19003, Award 0634587)* works to improve the science achievement of American Indian students in grades 3-8. Through creating and utilizing cultural contextualized teaching materials and methods, the project hosted a "Cultural Camp" as part of an institute which focuses on developing Master Teachers in science. The project, which had successful results as measured by at least three indicators, engaged over 50 teachers throughout the year in quarterly classes and a summer institute by taking courses collaboratively designed by both faculty and tribal consultants. These courses focused on topics such as Greenland glaciers, Mars exploration, paleaoclimatology, weather and climate and Crow astronomy and the relation of these topics to indigenous perspectives. This project obviously has a strong focus on broadening participation. It provides an approach that connects science and science education to the experiences and culture of an underrepresented minority, making instruction in the sciences more compelling and effective. The project also educates teachers in the culture of the underrepresented minority they are educating. This approach of connecting science education to a cultural setting, educating teachers about the culture of their students, and finding linkages between local scientific understandings and broader scientific knowledge is applicable across cultural groups and settings. It also provides a model for higher education--K-12 partnerships-- as well as an effective approach to teacher education.

Another highly integrative project, involving 5 research and education outcomes and evaluation criteria, is ***University of Hawaii-Manoa NSF Graduate Teaching Fellows in K-12 Education Bridge Research and Education through Partnerships*** *(Highlight 19317, Award 0538550).* Joanna Philippoff, a GK-12 Fellow at the University of Hawaii-Manoa, conducts research on determining the feasibility of collector urchin to act as a biological control agent in suppressing the growth and spread of alien and invasive macroalgea. Philppoff's research is connected to a GK-12 program that currently involves 6 graduate fellows working with 750 K-12 students and 19 teacher participants on four of the Hawaiian Islands monitoring between 15 and 20 inter-tidal sites each year. The project data, which are collected by K-12 students, is utilized by resource managers and researchers. The project also provides an educational forum that integrates traditional Hawaiian land management concepts with modern tools and technologies. Together, graduate fellows, K-12 students, and teachers work as scientists investigating streams, inter-tidal organisms, corals, sand, algae, and deep-water ecosystems. These data have contributed to doctoral dissertation research and a manuscript accepted for publication. This 6-year project is a model for integrating significant research and education, as well as field and lab research. It also is an outstanding example of engaging learners at all levels in an ongoing research project. It also highlights broadening participation and broader impacts in that it involves an underrepresented minority in a highly replicable project with significant educational and societal impacts.

Research Infrastructure Subgroup Report

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

Introduction

The Research Infrastructure Subgroup of the Advisory Committee for GPRA Performance Assessment was charged with the task of assessing whether the NSF has demonstrated significant achievement for the Learning goal outlined in the NSF Strategic Plan (2006-2011) to "build the nation's research capability through critical investments in advanced instrumentation, facilities, cyberinfrastructure and experimental tools."

Subgroup Members:

Joel E. Tohline (Chair)
Professor of Physics and Astronomy
Louisiana State University

Wendy Baldwin
Director, Poverty, Gender and Youth Program
Population Council

Ed Getty
Group Director, External Technology Acquisition
The Coca Cola Company

Process Followed and Criteria Used

The Research Infrastructure (RI) Subgroup reviewed all 153 highlights that were submitted and approved, and that indicated that RI was the primary Outcome Goal. For the purposes of this review, the highlights were divided equally and randomly (using a random list generator www.random.org) between the three RI subgroup members with each member receiving 51 highlights. Subgroup members were asked to read and evaluate the reported accomplishments against one or more of the following criteria:

Major Multi-User Research Facilities

- Promote discoveries at large multi-user research facilities supported by NSF, which may be centralized or may consist of distributed installations;
- Expand opportunities for U.S. researchers, educators, and students at all levels to access state-of-the-art science and engineering facilities, laboratory instrumentation and equipment, databases, and advanced computing resources, research networks, and other infrastructure.

Major Research Instrumentation Program

- Support the acquisition and development of state-of-the-art instrumentation that is too costly to be supported through core NSF programs;
- Promote partnerships between academic researchers and private sector instrument developers;
- Support teaching-intensive and minority-serving institutions that have a focus on research training;
- Expand opportunities for researchers, educators, and students at all levels to access state-of-the-art laboratory instrumentation and equipment, databases, advanced computing resources, research networks, and other infrastructure.

Cyberinfrastructure

- Support research and development of tools, concepts, and technologies;
- Provide leading-edge cyberinfrastructure systems;
- Apply cyberinfrastructure to advance our understanding of the world around us, respond to emergencies, and provide more authentic and motivational STEM learning opportunities for students, teachers, professionals, and the general public.

Analysis Overview

The NSF annually funds the operation of high-profile, multi-user research facilities and, via the Major Research Equipment and Facilities Construction (MREFC) account, funds the construction of new major multi-user projects. In addition, as indicated above, the NSF annually funds a significant number of smaller-scale infrastructure projects through its Major Research Instrumentation (MRI) program. The research highlights that the Research Infrastructure Subgroup reviewed tend to emphasize successes that result from MRI-funded projects, perhaps because MRI projects are more closely associated with (and take ownership from) single-investigator-scale projects.

Notably successful MRI projects have several things in common that exemplify NSF's approach to furthering the Nation's goals: they are designed not only to facilitate great scientific research but also to facilitate interdisciplinary projects and to excel in their outreach activities. From the research highlights identified below, it is also clear that many successful instrumentation projects display evidence of past research enabling present research. Key enablers are the cyberinfrastructure, 3D visualization tools, robotics, and instrumentation that enables discovery on very small spatial and temporal scales.

NSF investments facilitate the exploration of harsh and/or remote environments:

Our understanding of Nature is often significantly improved when we study how Nature behaves in extreme environments. As the highlights below illustrate, recent investments by NSF have supported the construction and deployment of instruments that are enabling researchers to collect data from some of the Earth's harshest environments.

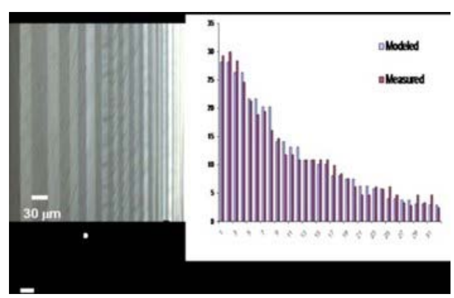
The drilling vessel, JOIDES (Joint Oceanographic Institutions for Deep Earth Sampling) Resolution, has undergone a complete transformation and is now poised to help the NSF-funded international Integrated Ocean Drilling Program (IODP) push the frontier of science by collecting unique sub-seafloor samples and data that would otherwise remain out of reach to researchers (***U.S. Scientific Ocean Drilling Vessel Gets Extreme Makeover*** *Highlight 18314, Award 0352500*). For example, cores recovered from the subsurface oceanic crust by the IODP yield an incredible view of life in deeply buried marine sediments; and the results of drilling in the Palmer Deep (an ocean basin in the Antarctica) have provided the first glimpse of the pace of rapid climate and oceanographic change in the Southern Ocean. The JOIDES Resolution is resuming operations for IODP expeditions at an extremely important time, when the need for scientific understanding of Earth and its oceans – and climate and energy challenges – is at its greatest.

The first live feed video images from deep in the ocean have been received from the Eye-in-the-Sea (EITS), an instrument designed to provide uninterrupted and unobtrusive observation of life in the deep-sea for the first time. (***First Live Feed Video Images Received from Eye-in-the-Sea (EITS) Deep in the Ocean,*** *Highlight 18319, Awards 0451333 and 0612332*). The deep sea is full of life. What it lacks is any light to allow this life to be seen, studied, and understood. Until this point, most deep sea research relied on lights from intrusive submersibles or other deep-diving vehicles to see. Using low-light-level imaging in combination with non-intrusive red illumination in a camera system, the EITS will provide new insights about life in the deep ocean. For example, it can provide real-time, continuous *in situ* measurements of marine activity, record spontaneous bioluminescence activity, carry out experiments on organisms' reactions to light, and document feeding patterns at food drops. Development of the EITS by the Harbor Branch Oceanographic Institution and the Bigelow Laboratory for Ocean Sciences was made possible through a standard instrumentation award from NSF's Division of Ocean Sciences (See www.mbari.org/earth/mar_tech/EITS/ deploy.html.) .

NSF MRI funding has been used to develop a new instrument package to study gas, seismic activity, infrasound, and GPS geodesy (precise measurements of the Earth's surface) on active volcanoes (***Scientists Develop Integrated Seismic, Geodetic and Volcanic Gas Surveillance Instrumentation for Volcanic Research,*** *Highlight 18256, Award 0116577)*. These instruments recently were deployed on one of Earth's most remote volcanoes, Mount Erebus on Ross Island, Antarctica, during 2002-2004 as a key component of the Mount Erebus Volcano Observatory. Seismic, infrasound, and geodetic data have been shown to be the most useful means of forecasting volcanic eruptions and illuminating the complex interior processes of active volcanoes. These stations had to have very low power requirements (just a few watts in some cases) and to run unattended year-round under the harshest of environmental conditions (perpetual winter darkness, winds exceeding 100 knots, and temperatures as low as -60^{o} C).

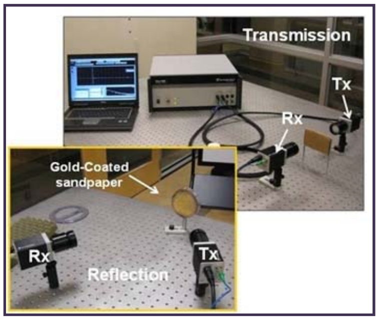
NSF investments enable discoveries on very small spatial and temporal scales:

Our understanding of Nature also is often significantly improved when we study how physical or biological systems behave at very small spatial and temporal scales. As the highlights below illustrate, recent investments by NSF have supported the development and acquisition of instrumentation that facilitate discoveries at extreme scales.



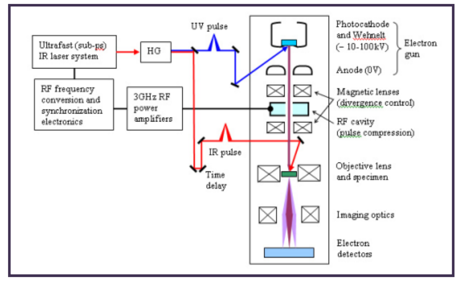
The Science and Technology Center for Layered Polymeric Systems (CLiPS) – managed by the Polymers Program in the NSF's Division of Materials Research – has developed instrumentation for creating and fabricating multilayered films (consisting of up to thousands of layers) with each individual layer having a thickness in the nanoscale range ***(Novel Infrastructure for Creation of Unique Multilayer Polymer Films,*** *Highlight 16851, Award 0423914)*. In addition, as a result of research lead by Professors Eric Baer and Anne Hiltner, a method has been devised to fabricate such films that have a continuously varying layer thickness. This technology produces polymer films with previously unattainable, large differences in layer thickness distributions. Gradient films with layer thickness distributions in the nanometer scale possess wide optical reflection bands that may be used as light enhancers, filters, and reflectors in electronic and informational devices.

Gradient films with thicker, micrometer-scale layers are currently under investigation for membrane and controlled-release applications.



NSF funding, acquired through a National Nanotechnology Infrastructure Network (NNIN) MRI grant, has been used to purchase the Picometrix T-Ray 4000, a terahertz (THz) time-domain spectrometer ***(Verifying Terahertz Scattering Models Through Major Research Instrumentation (MRI) Acquisition of a THz Time Domain Spectrometer,*** *Highlight 17763, Award 0821756****)***. Recent advances in high-speed optics have made exploration of the THz frequency band possible. This opens up new possibilities for probing material structures, non-invasive medical imaging, and the detection of explosives obscured under clothing. The measurements obtained so far are some of the first THz spectrum resulting from diffuse scattering. Recent work by Dr. Lisa Zurk at the Northwest Electromagnetics and Acoustics Research Laboratory (NEAR-Lab) at Portland State University has identified scattering from rough surfaces as a major component of the overall spectrum and has developed scattering models that agree with THz measurements. Because almost all future imaging applications will rely on the more robust non-specular (i.e., diffuse scattered) reflection imaging, characterization of this response is critical. The NEAR-Lab is investigating this topic with the development of both theoretical scattering models and a comprehensive measurement capability.

NSF funding, also acquired through a National Nanotechnology Infrastructure Network (NNIN) MRI grant, has made it possible for Drs. Lund and Parviz (University of Washington) to apply the techniques of Atomic Force Microscopy (AFM) to their studies of DNA sequencing ***(Improving DNA Imaging and Analysis through Major Research Instrumentation (MRI) Acquisition of an Atomic Force Microscope,*** *Highlight 17772, Awards 0335765 and 0521211)*. In their research, a smooth substrate suitable for AFM imaging was produced by depositing DNA on a mica substrate, evaporating platinum on the mica surface, and peeling away the platinum from the mica, leaving a smooth platinum surface with embedded DNA molecules. DNA typically behaves as an insulator during AFM experiments, making imaging difficult as the AFM will often displace or destroy the DNA. By embedding the molecules in a smooth metallic layer, the position of the molecules is easy to identify, and they remain in place during imaging. Once the location of DNA on the surface is identified, one can perform experiments measuring the behavior of electrons tunneling through the DNA to identify molecular features. DNA sequencing and analysis is a high-priority field of study as improvements to sequencing techniques represent enabling technologies for personalized medicine.



With funding from NSF's MRI program, Dr. Andreas Schroeder and Dr. Alan Nicholls at the University of Illinois at Chicago together with Dr. Nigel Browning, University of California, Davis and Lawrence Livermore National Laboratory (LLNL), are developing a revolutionary laboratory-scale research instrument - an ultrafast electron microscope ***(Ultrafast Electron Microscopy,** Highlight 18880, Award 0619573*). This project is notable as it aims to combine the high temporal resolution (sub-picosecond (ps); less than 10^{-12}s) afforded by today's ultrafast pulsed laser systems with the high spatial resolution (sub-nanometer (nm); less than 10^{-9}m) available in electron microscopy. The key challenges are to generate and accelerate a high-quality electron pulse and thereafter to compensate for the natural tendency of negatively-charged electrons in the pulse to repel each other. Preliminary studies suggest that this can be achieved by employing a large-area electron emitter (the photocathode) that is patterned on the nanometer scale and temporal electron pulse compression using RF cavity technology from the accelerator physics community. An instrument with such unprecedented dynamic visualization capability is likely to impact many fields of science (from molecular biology to semiconductor physics and nanoscience) by facilitating the understanding of the many fundamental physical processes in nature that involve small dimensional motions (e.g., atomic-scale) occurring on very fast timescales. The low-divergence, laser-driven electron gun developed as part of this project has already attracted attention from the dynamic transmission electron microscopy effort at LLNL.

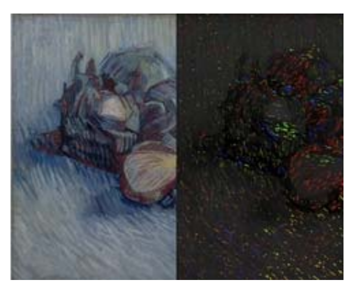
Cyber-enabled discoveries:

It is perhaps not surprising that advances in computer technology – both hardware and software – are enabling new discoveries in virtually every area of science and engineering. NSF has a strong track record of supporting cyber-enabled discovery. As is illustrated through the following highlights, recent NSF-funded research efforts have been made possible through resources developed by the rapidly growing community of open-source software developers, through advances in scientific (and especially 3D) visualization tools, and through the utilization of Field Programmable Gate Arrays (FPGAs).

The NSF-funded ***Virtual Zooarchaeology of the Arctic Project (VZAP)*** *(Highlight 18172, Awards 0508101, 0722771, and 0808933*), centered at Idaho State University, seeks to develop the world's first comprehensive online (and fully interactive) three dimensional virtual vertebrate reference collection. Composed of photographs and interactive three dimensional models, this project is producing a virtual collection of all the skeletal elements from 132 polar taxa. By

doing so, this project will provide the comparative resources necessary for northern scientists to conduct analyses from any location. Archaeological sites from Polar Regions are often rich in well-preserved animal bone. These animal remains provide a wealth of information about ancient human behaviors, past environments, and climate change. To analyze these materials appropriately, zooarchaeologists (archaeologists that specialize in the study of animal remains) require a comprehensive comparative collection of the bones of all northern mammals, fish, and birds. Unfortunately, such collections are very rare (only four complete collections exist in North America). Therefore, northern researchers are hampered in their study of these important remains both by the lack of existing comparative natural history collections and appropriate reference materials (photos and drawings) that may aid in their analysis. The result of these difficulties is an analytical bottleneck - while most archaeological excavations in the north result in large, high resolution faunal collections, there are few locations where they can be adequately analyzed, therefore impeding, or halting northern archaeological and ecological research altogether. In reality, the vast majority of northern-derived faunal samples have gone unanalyzed. This is ironic, because polar-derived faunal assemblages, due to their often excellent preservation, represent some of the best data available for conducting fundamental research on the relationship between humans and the ecosystems they inhabit.

As museums continue to digitize their art collections, it becomes increasingly easier for paintings to be forged. Two Pennsylvania State researchers are part of an international team working on a digital system to help detect original works from counterfeit ones (***New Computer Technology to Fight Art Forgery,*** *Highlight 18403, Awards 0333036 and 0347148)*. According to the Federal Bureau of Investigation, American collectors pay $6 billion a year on forged, misattributed, and stolen art. James Z. Wang, associate professor of information sciences and technology, Jia Li, associate professor of statistics, and their colleagues published their work in the July issue of IEEE Signal Processing. The team's findings are based on 101 high-resolution grayscale scans of van Gogh paintings provided by the Van Gogh and Kröller-Müller Museums in the Netherlands. Wang and Li broke each scan down into sections measuring 512 by 512 pixels, or about 2.5 by 2.5 inches in canvas size, and analyzed them based on patterns and geometric characteristics of the brush strokes. From the 101 scans received from the museums, art historians identified 23 as unquestionably authentic van Gogh works. These were used by the computer system as a training database for van Gogh's brushstroke styles. Statistical models were created to capture the unique style, or "handwriting," that became the artist's signature in 23 of the scans. The other 78 -- either works of van Gogh, works of van Gogh's peers



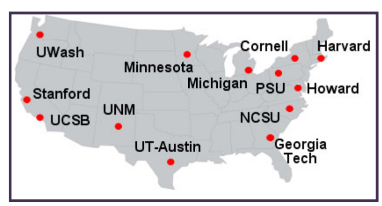
or paintings that had at one time been attributed to him but later found to be unauthentic – were compared against the generated models to test the algorithms. Wang and Li, along with their doctoral students, compiled those findings into an online system that allows any painting to be compared against existing data to help determine its authenticity.

Although astronomical research with radio telescopes often brings exciting discoveries (including three Nobel prizes), radio astronomy instrumentation has never been cheap. A major component of the expense is the highly specialized processors required to digest the vast amounts of raw data produced by a radio telescope. Now, a research group at the University of California Berkeley has created an engineering solution to substantially reduce the cost ***(Low-Cost Modular Instrumentation Brings Affordable Radio Astronomy Closer,*** *Highlight 18291, Award 0619596)*. Employing modular, flexible, and reprogrammable processors driven by open-source software, the group, led by Berkeley's Dan Werthimer, is leading a worldwide revolution to reduce the cost of high-end radio astronomy instrumentation. The hardware component of the modular system is based upon Field Programmable Gate Arrays (FPGAs), which are essentially high-end computer processors whose core functions can be reprogrammed based upon specific applications. Combined with analog-to-digital converters that can quickly turn vast amounts of analog signals into digital 1s and 0s, the FPGAs provide a low-cost and easy-to-implement solution for radio telescopes of today and tomorrow. And because the hardware operates under the direction of free, open-source software, improvements made at one facility can be quickly and cheaply implemented at others.

Broader Impacts:

Students at all levels of study benefit from exposure to different types of science to help them focus their interests and skills. Large facilities and their related instruments open up a world of inquiry that is very different from what students usually can experience by working with an individual investigator. Hence, one important contribution of infrastructure projects is their capacity for exposing students to the type of work that can be done in these settings and providing an expanded learning environment for them. It is clear that, across the board, NSF researchers appreciate the role that they should play in transferring knowledge and the excitement of discovery to the extended community that traditionally resides outside of the research laboratory. Undergraduate students are very actively being incorporated into research projects, extra effort is being exerted to ensure that individuals from traditionally underrepresented groups have opportunities to share in the process of discovery, and outreach to the K-12 classrooms and the public at large is pervasive. It is also clear that NSF's efforts to actively promote interdisciplinary and inter-institutional collaboration are paying big dividends: virtually all of the highlights already identified above show evidence of this. A few additional examples of the broader impacts of recently funded projects follow.

The NSF CREST Program (Centers of Research Excellence in Science and Technology) supports a Center for the Sharing of Cyber Resources to Advance Science and Education (Cyber-ShARE) at the University of Texas at El Paso (UTEP) under the leadership of Dr. Ann Quiroz Gates (***CREST Cyber-ShARE Center of Excellence,*** *Highlight 17871, Award 0734825*). This project seeks to strengthen the research and education infrastructure at UTEP and, importantly, respond to the need to accelerate the number of scientists and engineers at UTEP who have the education and training to use TeraGrid high performance computing and visualization resources for interdisciplinary projects. Cyber-ShARE's partnership with TeraGrid also provides the training and resources to faculty and students that can assist them in their research. In Fall 2008, UTEP enrolled 20,458 students; more than 75 percent of UTEP's students are Hispanic and approximately 56 percent of UTEP's students are women. Over the next three years, the CREST CyberShARE project is expected to directly impact the research activities and education of approximately 200 UTEP students from underrepresented groups who will subsequently enter the workforce with knowledge and advanced skills in the use of cyberinfrastructure. The Center, through outreach to middle and high school students in the El Paso area, faculty workshops, and special coursework across important STEM fields such as geology, environmental science, computer science, computational science, and engineering, expects to impact the education and research opportunities for more than 1,000 students over the next three years. The TeraGrid project has the most powerful distributed cyberinfrastructure for open scientific research in the world. Cyber-ShARE is facilitating creation of start-up accounts, use of resource time allocations, and access to expert knowledge in application porting to HPC resources, performance tuning, and scientific visualization.



The NSF-funded (***National Nanotechnology Infrastructure Network (NNIN)****)* is an integrated network partnership of 13 university-based nanotechnology laboratories that provide open access to nanotechnology resources and expertise to researchers across the country *(Highlight 18495, Awards 0335765 and 0619495*). NNIN provides the infrastructure that is an important means to achieving the objectives of the National Nanotechnology Initiative (NNI). It serves the critical objective of facilitating research of the academic community as well as of the industry and government communities. Nanotechnology spans the breadth of science and engineering disciplines and is a frontier research and development area for electronics, optics, materials science, physics, chemistry, and life sciences. NNIN provides tools, training, knowledge, and affordable access for all of these fields so that new and experienced researchers can pursue new nanotechnology research ideas without impediments.

NNIN research has made contributions to the improvement of solar cell efficiency. Thin film silicon solar cells are widely considered the best candidate for next generation solar electricity applications due to their potential low cost, ease of fabrication, and low use of silicon (Si) feedstock. In order to achieve high efficiency, effective light trapping is essential to increase the absorption path length in the thin film. Dr. L. C. Kimerling at the Massachusetts Institute of Technology (MIT) developed a novel photonic crystal backside reflector to increase the optical path length by more than 104 times the film thickness for almost complete light absorption. The grating fabrication requires a period of around 300 nm, and it cannot be fabricated in MIT clean rooms. Using the interference lithography tool at the University of New Mexico node of NNIN, the design was fabricated with an interference process that is capable of low-cost scale-up. For a 2 mm thick Si thin film solar cell, the relative efficiency enhancement by the back reflector is expected to be as high as 53 percent.

In the area of health sciences, lung cancer is responsible for the largest number of cancer-related deaths in the world, and the World Health Organization estimates that there are 1 million new cases worldwide per year. Most lung cancers are diagnosed late, which minimizes chances of survival. VisionGate, Inc. is developing a screening test using confocal microscopy at the University of Washington node of NNIN to detect lung cancer at an early, curable stage. The basis of this test is an entirely new imaging system (Cell-CT^{TM}) that allows visualization of cells in high definition and in 3-D. Cells shed from the inner surface of the lung into mucus (sputum) exhibit characteristic changes during cancerous transformation. When analyzed in 3-D, these changes can be detected with higher sensitivity and specificity compared to 2-D-based approaches.

Several NNIN projects also address basic science issues that have potential applications for the Department of Defense. For example, over the past three decades Infrared Scene Projectors (IRSP) have become a critical laboratory tool for evaluation of high performance IR imaging systems and their embedded algorithms. This technology offers an accurate, realistic, and dynamic IR scene for the testing of sensors such as infrared missile seekers. Reaching the desired testing temperatures for the next generation of IRSPs requires the development of high temperature materials such as HfO2 and HfC that are extremely difficult to process. In order to address this problem, a research team led by Dr. Stephen Campbell at the University of Minnesota node of NNIN obtained a confocal microscope through a Major Research Instrumentation (MRI) grant to NNIN, allowing the team to closely monitor the size of components in individual pixels through each step of fabrication. Because the design used high aspect ratio features of difficult-to-process materials, it was crucial to use confocal microscopy to provide immediate process feedback on depositions and etches without destructive cross section electron microscopy. The pixels fabricated by Dr. Cambell's team have demonstrated record maximum temperature for IRSPs.

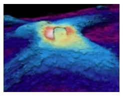
The network also has a substantial national and local effort in support of education, public outreach, safety, and examination of the societal and ethical implications of nanotechnology. In FY 2007 the NNIN Research Experience for Undergraduates (REU) program hosted 70 REU interns from institutions across the United States. Since 2005, an editorial board under the guidance of Dr. Carl Batt at the Cornell University node of NNIN has published a nanotechnology webzine focused at educating children about nanoscience. *Nanooze* is published in English, Spanish, and Portuguese, and has a worldwide audience.

Under a grant from the NSF's MRI program, researcher Dr. Christopher Kitts and a group of graduate and undergraduate students at Santa Clara University are developing a ***Multi-Robot Control and Collaboration Testbed (****Highlight 18691, Award 0619940*) that allows researchers with interests in advanced robotic control and agent collaboration to rapidly integrate and experimentally evaluate their research innovations. A key element of the testbed is a modular internet-based software architecture that allows new control algorithms, written in the language or development environment desired by the experimenter, to be quickly plugged into the experimental testbed, even from remote locations. The rover testbed may be configured in a variety of ways to produce scenarios of interest, with the choice of several different mobile robots (to include differential drive, omnidrive, wheel-based skid steering, etc.), position/object sensing (wheel encoders, sonar, GPS, camera tracking, ultra-wideband tracking, etc.), communication links, etc. Although development continues, the testbed is now operational for the research community. During the past year, student researchers internal and external to the development team and to Santa Clara University successfully used the testbed to demonstrate a variety of new capabilities ranging from novel control laws to a spoken dialogue operator interface. During the past year, more than 10 undergraduate (from multiple institutions) and a dozen graduate students have been involved in the development and/or use of the testbed. This has involved and/or generated student accomplishments that include 2 peer-reviewed conference publications, 2 complete and 6 near-complete Masters theses, and undergraduate projects ranging from a year-long Capstone engineering project to class projects in a computational linguistics course. Furthermore, the research supported by the testbed has been significant with one innovative control strategy nearing journal publication, another progressing to use in robotic field applications involving autonomous boats, and a third that is leading to new industrial-academic collaborations on multi-robot-based sparse array antennae.

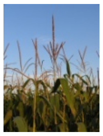
Images Information and Credits

These images are drawn from the NSF highlights reviewed by the Advisory Committee for GPRA Performance Assessment (AC/GPA) during their evaluation of FY 2009 accomplishments.

Cover Images

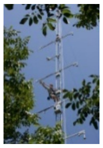


Axial Volcano, one of the most active volcanoes on the Juan de Fuca Ridge, not far off the coast of the northwestern United States in the Pacific Ocean, which last erupted in 1998. Researchers from Oregon State University and the Lamont Doherty Earth Observatory of Columbia University have been measuring its inflation and deflation through periodic underwater surveys. They have found a steady swelling of about five inches per year and are predicting that the volcano will erupt again by 2020.
Credit: William Chadwick, Oregon State University



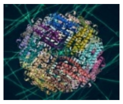
Researchers at Michigan State University's Kellogg Biological Station (KBS), which is one of NSF's 26 Long-Term Ecological Research (LTER) Network sites, are at the forefront of studying the benefits people received from ecosystems and how ecosystems can be integrated into agricultural landscapes. Demand for ethanol from corn has caused a decrease in the diversity of agricultural lands as a greater area is devoted to this crop.
Credit: KBS LTER

Danielle Miranda (pictured) has interned at the Fred Hutchinson Cancer Research Center with leading researcher for the Gardisal vaccine, Dr. Denise Galloway. The Gardisal vaccine is used in cervical cancer prevention. Ms. Miranda is pursuing post-baccalaureate research opportunities at NIH.
Credit: New Mexico Louis Stokes Alliance for Minority Participation, New Mexico State University



Scientists at the National Center for Atmospheric Research (NCAR) set up specialized instruments in a walnut grove near Davis, California to monitor plant emissions of certain volatile organic compounds (VOCs), which are important sources of pollution and can affect climate.
Credit: Photo by Carlye Calvin, ©UCAR

Ice flows in the Arctic Ocean. A team of U.S. and U.K. researchers believe that ice-sheet formation in the Northern Hemisphere cold have occurred 20 million years earlier than currently documented, and could explain a lot of mysterious sea-level variability over the last 25 million years that is difficult to explain with Antarctic ice alone.
Credit: Sue-Ann Watson



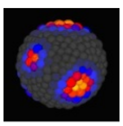
Crystal structure of the iron-concentrating protein ferritin. Researchers at the University of Washington have studied the ability of some diatom species to form large blooms in iron-poor regions by using this protein to store iron. This research is focused on diatom species along the coast that are harmful to humans, marine mammals and birds, and other marine life.

Credit: Michaela Parker, Virginia Armbrust, et al., University of Washington

A Tibetan healer with a patient. Researchers at the University of California-San Francisco are exploring the complex ways that scientific biomedical research is being translated in modernizing Tibetan medicine.
Credit: Vincanne Adams, University of California – San Francisco

The drilling vessel JOIDES Resolution has been completely refurbished to modernize and vastly improve its capabilities to explore and monitor the sub-seafloor. The ship operates as part of the NSF-funded International Integrated Ocean Drilling Program (IODP).
Credit: Consortium for Ocean Leadership

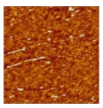
The self-cleaning property due to nanostructures on the surface of lotus leaves engages young visitors at a NanoDays event at the University of Wisconsin-Madison. NanoDays brings researchers, graduate students, and informal science educators together to raise public awareness, understanding, and engagement with nanoscale science and engineering.
Credit: University of Wisconsin-Madison



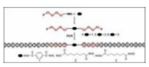
In the NSF-funded Computable Plant project, essential mechanisms of computing, microscopy, and molecular biology are combining to provide new insight into fundamental plant biology and could ultimately impact biotechnology and engineering. This is a top view of a computer simulation of pattern formation of floral buds in plant shoot growth. Future buds are indicated by the emergence of regions of high auxin (red and yellow). Cell growth and division displace older auxin peaks outwards, making room for new ones.
Credit: Eric Mjolsness, University of California - Irvine

Images within the Report

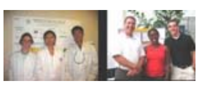
Page 15: The Stark decelerator is used to slow a beam of molecules to controllable velocity with a narrow spread in energy. A typical decelerator is one meter in length with approximately 150 electrode pairs. Each electrode pair generates an electric field of approximately 12 million volts per meter.
Credit: Heather Lewandowski, University of Colorado



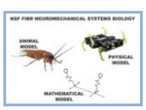
Page 16: Characterization of PCR (standard polymerase chain reaction used to lengthen the DNA segments) results by atomic force microscopy (AFM). The measured length of the stretched DNA is very close to the theoretical calculated value.
Credit: Zhenan Bao, Stanford University



Page 16: Schematic representation of building DOD structures using standard chemical reactions (amide-coupling reaction, followed by the polymerase chain reaction to lengthen the DNA segments). The next stage will involve metallization which is planned to proceed by electrochemical reduction of positively charged metal ions following their adsorbtion on the DNA segments.
Credit: Zhenan Bao, Stanford University



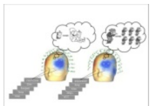
Page 16: Left: Internship undergraduate and high school students. Four graduate students (one female), seven undergraduate students (four female), two community college students (one female and one Hispanic), two high school students, two high school teachers, and two postdoctoral fellows (one female) have worked on research supported by this NSF Award. Right: High school teacher with other students.
Credit: Zhenan Bao, Stanford University



Page 17: The integration of direct experimentation on animal models, mathematical models and physical models, such as robots, allows new insights into how we all move - a hallmark of being an animal.
Credit: Robert Full, University of California – Berkeley

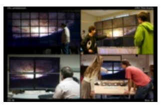
Page 17: Fig 1. Environment for observations of collisions and landings (top left). By attaching a motion capture "suit" to a live insect (top center), we can record all position and orientation data and all derivatives (assuming sufficiently fast capture). For example, a composition of the trajectories following multiple collision events is shown in (top right). Fig 2. Recent version of the Harvard Microrobotic Fly, including power actuators and smaller control actuators. (bottom right and left)
Credit: Robert Wood, Harvard University

Page 18: Giant Humboldt Squid and the unique structure of the beak - one of the hardest and stiffest wholly organic materials known.
Credit: Craig J. Hawker, University of California – Santa Barbara



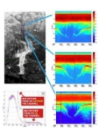
Page 18: The anterior midline field (AMF) of two individuals as they are reading semantically complex expressions, requiring a coercion of a basic meaning into a more complex meaning. The green spots around the head are MEG sensors, which measure changes in magnetic fields caused by electrical activity in the brain. In this figure, two regions of fluctuating magnetic fields are depicted in red and blue.
Credit: Llina Pylkkanen, New York University

Page 20: Children interact with the EcoRaft project, an interactive informal science education exhibit about the science of restoration ecology, built using a richly-connected multi-device system.
Credit: Bill Tomlinson, University of California – Irvine



Page 20: Shown here is a high-resolution Milky Way galaxy animation developed by the National Center for Supercomputing Applications that was simultaneously distributed to multiple sites using SAGE software. The animation was displayed on two different tiled displays at UIC's Electronic Visualization Laboratory (upper left, lower left), on a tiled display at SARA in The Netherlands (upper right), and at Masaryk University in Brno in the Czech Republic (lower right).
Credit: National Center for Supercomputing Applications

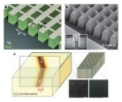
Page 21: Cover of January 22, 2009 Nature highlighting the work published by Steig et al. on Antarctic Warming
Credit: Background Image Credit: Eric Steig, University of Washington and Josefino Comiso, NASA-Goddard; Overall Image Credit: Nature



Page 22: Cross-channel soundings of the Jakobshavn glacier. The image of the channel in the left column (rotated so that north is left) depicts the location of the cross-channel flight echograms shown on the right. A-scope at the bottom left shows that ice in the channel is very lossy.
Credit: S. Prasad Gogineni, University of Kansas

Page 22: Melting Arctic Sea Ice. Observations of ice growth and surface and bottom melt have been made from autonomous ice mass balance buoys (IMB) that drifted with the ice pack. These buoys are equipped with a datalogger, satellite transmitter, barometer, acoustic rangefinders placed above the ice surface and below the ice bottom, and a thermistor string extending from the surface through the snow and ice into the upper ocean. The IMBs provide information on snow accumulation and melt, ice growth and decay, the onset dates of melt and freezeup, and the ocean heat flux. Modeling studies enabled the energy balance calculations.
Credit: Jeremy Harbeck

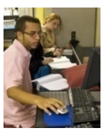
Page 23: Regional study area map of the northern Gulf of Mexico margin depicting the main rivers that flow into the estuaries studied (NU-Nueces River, LA-Lavaca River, TR-Trinity River, SA-Sabine River, CA-Calcasieu River, and MO-Mobile-Tensaw River), isopleths (dashed lines) of mean annual precipitation (in cm), and shelf bathymetry.
Credit: John Anderson, Rice University



Page 24: Two research groups within the NSF-supported Center for Scalable and Integrated Nanomanufacturing at the University of California-Berkeley devised methods for the design of metemeterials which bend light. Pictured first is the metamaterial composite of functional layers milled in a fishnet-like pattern (top) and second a metamaterial made with silver nanowires embeded in an alumnia matrix (bottom).
Credit: Xiang Zhang, University of California-Berkeley

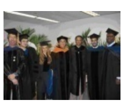
Page 29: Cari Elledge (center, Norman ISD), Donna Goodman (right, Moor ISD), and Mary Ridens (standing, OKC ISD) get ready for another fly climbing test. Stephanie Easter (OU Ungradate) examines her climbing data (top left).
Credit: Bing Zhang, Oklahoma University

Page 29: Stephen Hinkle (Norman ISD) and John Tauber (OU Undergrad) sort fruit flies under the microscope.
Credit: Bing Zhang, taken while science teachers worked at the University of Oklahoma in June 2008

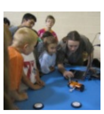


Page 29: Students designing a rollercoaster
Credit: North Carolina State University

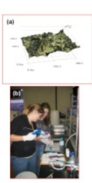
Page 30: The force on a dipole experiment couples real-time control of the current entering a Helmholtz coil with a synchronized visualization of the resulting magnetic fields generated by the coil and the suspended magnetic dipole.
Credit: MIT



Page 30: The FIU CREST has graduated 39 PhD students. Pictured here (from left to right) is the Spring 2008 graduating class: CREST Co-PI Xudong He, CREST PhD graduates Wei Peng and Maria Tito, CREST Co-PI Malek Adjouadi, CREST PI Yi Deng, CREST PhD graduate Jose Morales, and CREST Sr. Investigator Peter Clarke.
Credit: Yi Deng, Florida International University



Page 31: Demonstration of robotic GUI interface at a public library
Credit: Jan Pearce, Berea College



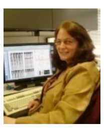
Page 31: (a) Silver nanoparticles (grey) segregated on the surface of the ceramic filter during drying. (b) During their visit to Brazil, students from the University of Pittsburgh conducted water quality tests with the ceramic filters
Credit: Ian Nettleship, University of Pittsburgh

Page 31:Three of the four history making graduates at the University of Mississippi (left to right): Carla Cotwright, Bryan Williams, and Adrian Wilson.
Credit: University of Mississippi

Page 32: Georgia Tech's FACES project (Facilitating Academic Careers in Engineering and Science) funded through the NSF program, Alliances for Graduate Education and the Professoriate (AGEP), works with doctoral students to prepare them for academic careers. Here, Gregory Triplett is hooded at the university's 2004 Ph.D. commencement ceremony. Dr. Triplett is currently Assistant Professor in Electrical Engineering department at the University of Missouri-Columbia.
Credit: Georgia Institute of Technology

Page 32: Dr. Elizabeth Hausler trains builders in developing countries to build earthquake-resistant houses
Credit: Elizabeth Hausler, University of California – Berkeley

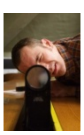
Page 33: Four LCCC Wind Energy Technician Program students prepare for their Wind Tower Climb of a Suzlon wind turbine at the Duke Energy Happy Jack Wind Farm just West of Cheyenne Wyoming.
Credit: Photo by Mitch Maxwell



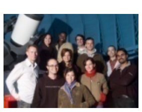
Page 34: Dr. Anne Simon from the University of Maryland - College Park is a key player in redefining how science is communicated to teachers and students. She has represented and advocated science across the boards from television to local public schools.
Credit: Anne Simon, University of Maryland

Page 34: Lisa Gentile and the students in her summer group
Credit: Lisa Gentile, University of Richmond

Page 35: *Three 7th-grade Future Scholar students perform an experiment in particle formation during the first summer program, conducted at Rutgers University in 2008*
Credit: Center for Structured Organic Particulate Systems (C-SOPS), Rutgers University



Page 36: New York City science teacher Thomas Cork of Queens High School for the Sciences eyes up his optics during an activity on telescope design.
Credit: Destry Saul



Page 36: Participants in the Rooftop Variables teacher-training program.
Credit: Destry Saul

Page 37: Partnerships in Research and Education (PIRE) student Simone Pasmore, who performed her PIRE research with collaborators at the Universidad Nacional de La Plata, Argentina, presents her research during the PIRE Poster *Session at the Sixth Latin American Grid Summit, October 2008, Florida*
Credit: Dr. Yi Deng, Florida International University (FIU)

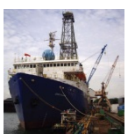
Page 37: PIRE students Jan Mangs, Lina Ortega, Christopher Holder, and Paula Carrillo performed collaborative research at Tsinghua University
Credit: Dr. Yi Deng, FIU

Page 38: Latrice Tatsey of Browning explains the Blackfeet calendar stick to teachers.
Credit: Regina Sievert, Salish Kootenai College

Page 38: Mary Jane Charlo teaches teachers how to make double balls and sticks.
Credit: Regina Sievert, Salish Kootenai College

Page 38: Pat Pierre and Mike Durglo, Sr. and Myrna Adams talk to teachers about cultural issues and traditions, historic and contemporary.
Credit: Regina Sievert, Salish Kootenai College

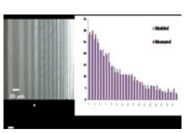
Page 39: Graduate STEM Fellows lead teams in intertidal data collection, Hawaii
Credit: University of Hawaii, Manoa GK12



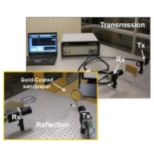
Page 42: JOIDES Resolution at the ship yard in Singapore right before it leaves for sea trials.
Credit: Consortium for Ocean Leadership

Page 42: Image from the Eye-in-the-Sea (EITS) showing a Tanner Crab (*Chionoecetes tanneri*), Slender Sea Pen (*Funiculina sp.)* and Deepsea Sole (*Embassichthyes bathybius*) near the electronic jellyfish, an electronic device that imatates a jellyfish's bioluminescent display to lure large, active predators into view.
Credit: Edie Widder, Harbor Branch Oceanographic Institution, Inc.

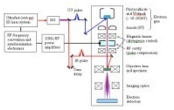
Page 43: Deployment of equipment on Mount Erebus on Ross Island, Antartica.
Credit: Philip R. Kyle, Richard C. Aster, Department of Earth and Environmental Science, New Mexico Institute of Mining and Technology



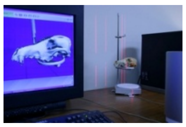
Page 43: The left side shows a high-magnification photograph in an electron microscope across the thickness of a film consisting of 32 individual layers of two different polymers alternating one-by-one. The right side shows a graph of the thicknesses of these layers from left to right and demonstrates the smooth gradation in thickness from layer to layer.
Credit: Professor Anne Hiltner, Case Western Reserve University



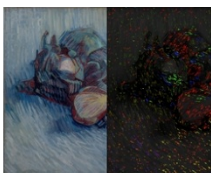
Page 44: The left side shows a high-magnification photograph in an electron microscope across the thickness of a film consisting of 32 individual layers of two different polymers alternating one-by-one. The right side shows a graph of the thicknesses of these layers from left to right and demonstrates the smooth gradation in thickness from layer to layer.
Credit: Professor Anne Hiltner, Case Western Reserve University



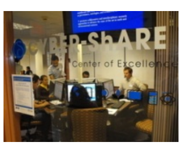
Page 45: Design schematic of the ultrafast electron microscope operated in transmssion mode. A harmonic generator (HG) produces the ultraviolet (UV) drive laser pulse for the electron gun and the residual time-delayed infrared (IR) laser pulse is used to perturb the sample. A magnetic lenses and a 3GHz radio frequency (RF) cavity prepare the photo-generated electron pulse to probe the specimen's transient response.
Credit: W. Andreas Schroeder, University of Illinois at Chicago



Page 46: The first step in the virtualization process: a red fox (Vulpes vulpes) skull is being laser scanned, with the unprocessed output visible on the computer monitor.
Credit: Robert Schlader, Idaho Virtualization Laboratory



Page 46: A computerized technique developed by Penn State researchers attempts to find brushstrokes from digital images of oil paintings. A number of features, such as length, width, shape, and orientation, are calculated from the isolated brushstrokes. The inter-brushstroke characteristics and overall statistics on a painting are also analyzed and compared with those extracted from authentic paintings. Left: "Red Cabbage and Onions" by Vincent van Gogh; Right: Automatically identified brushstrokes, with colors indicating different orientations of the brushstrokes. (Courtesy of the Van Gogh Museum in Amsterdam and James Z. Wang's Research Group at Penn State)
Credit: Courtesy of the Van Gogh Museum in Amsterdam and James Z. Wang's Research Group at Penn State



Page 48: Hands-on activity at the Fall 2008 workshop on using TeraGrid and Cyber-ShARE's high-performance computing resources.
Credit: Ann Gates, University of Texas at El Paso

Page 48: Map of the National Nanotechnology Infrastructure Network user facilities that provide researchers open access to resources, instrumentation and expertise in all domains of nanoscale science, engineering, and technology.
Credit: National Science Foundation

Page 50: These robots are part of the multi-robot testbed and include a custom suite of sensing, computing and communication equipment. Experiments using these robots range from demonstrating control systems that move the robots in formation to a spoken dialogue interface that allows a single operator to command the robots through normal speech.
Credit: Dr. Christopher Kitts & Mr. Ignacio Mas, Santa Clara University