APPENDIX A: Results of Strategic Outcome Goals

Program Highlights from the Fiscal Year 2008 Report of the Advisory Committee for GPRA Performance Assessment: *Discovery, Learning,* and *Research Infrastructure*[9]

Discovery

The Advisory Committee for GPRA Performance Assessment (AC/GPA) concluded on the basis of the highlights analyzed, that NSF has demonstrated significant achievement in meeting its goals in the area of Discovery. The 260 program highlights that were reviewed clearly demonstrate that NSF "fosters research that advances the frontiers of knowledge and helps in establishing our nation as a global leader in fundamental and transformational science and engineering." The Committee selected the following highlights as examples of significant achievements in the area of Discovery:

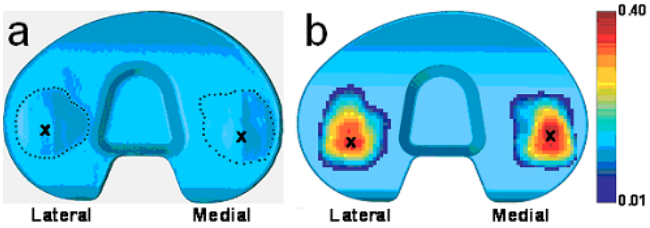
- ***Strengthen fundamental research across the full spectrum of science and engineering through support for NSF's fundamental or core disciplinary programs.***

It has been the conventional scientific wisdom for almost a century that magnetism in a given material opposes conventional superconductivity, such as that found in pure metals. Nobel laureates J. Bardeen, L.N. Cooper, and J.R. Schriefer showed that when superconductivity occurs the electrons in the metal form pairs. However, in unconventional superconductors, such as high temperature ones, where materials are on the verge of being magnetic, the electrons causing superconductivity take a different collective form than those in conventional superconductors, but the superconducting mechanism is not yet understood. A project titled **Magnetism Meets Superconductivity** *(Highlight 15821; Award Number 0710492)* is a collaborative effort between Zachary Fisk's group at University of California, Irvine and investigators at Los Alamos National Laboratory and Dresden University in Germany, and explores the boundary between superconductivity and magnetism. In crystals of one of these unconventional superconducting materials, consisting of a combination of cerium, cobalt, and indium, both superconductivity and magnetism have been discovered to coexist. This research is an example of fundamental and transformative research that could lead to a completely new understanding of the mechanisms causing superconductivity in high-temperature superconducting materials. $CeCoIn_5$, discovered in this NSF-funded research, has proven to be an ideal material for studying physics at the magnetic/superconducting boundary. These revolutionary findings are a direct result of support for Dr. Fisk that began with NSF-DMR 7504019, when he was a beginning investigator. Long-term NSF support of his research on fundamental condensed-matter physics has led to exciting, important results and to the field of highly correlated electron systems. This result could benefit many electrical applications areas such as power transmission and electronics.

Two other projects that "strengthen fundamental research across the full spectrum of science and engineering" are CAREER (Faculty Early Career Development Program) Awards. Program officers who highlighted these projects indicated that the projects were not only transformative in nature, but also promoted broadening participation, and had societal benefits as well. The first of these projects is titled: **The High Fidelity of Human Image Representation** *(Highlight 16657, Award Number 0546262).* Dr. Aude Oliva and her team in the Department of Brain and

[9] The *Report of the Advisory Committee for GPRA Performance Assessment, FY 2008* is available at http://www.nsf.gov/publications/pub_summ.jsp?ods_key=nsf08064.

Cognitive Sciences at MIT are currently exploring a novel avenue to explain the feat of human visual understanding, testing human capacity at remembering visual details for a given image. Her work has demonstrated that human visual memory can encode a massive amount of visual details that is an order of magnitude higher than previously believed. These results challenge assumptions about efficient image representations, which is highly relevant to cognitive psychology, neuroscience, and computer vision. This study potentially could lead to much higher-performance artificial vision systems as well as better understanding of human visual processes, which have potential applications to consumer technologies and homeland security and defense. The project affords significant opportunity to examine the ethical and safety dimensions of new technologies that may emerge.



The second CAREER Award selected for this criterion is titled: **Virtual Prototyping of Artificial Knees** *(Highlight 16684, Award Number 0239042)*. Dr. Benjamin Fregly, University of Florida, and his team are addressing a growing need for the aging American population. By one estimate, 40 million Americans will be affected by osteoarthritis in the year 2020. It is felt that this project could lead to an entirely new approach for designing knee replacements, and testing innovative designs using computer software rather than physical simulator machines. This work is unique because of its ability to predict long-term wear characteristics of knee replacement designs in a matter of minutes or hours using computer simulations. In terms of Broader Impacts, high school students from underrepresented groups have been involved in the knee research, through the University of Florida Summer Science Training Program. In addition, an orthopedic implant company has already enlisted the research team to participate in design of the next generation of knee replacements. Significant ethical and safety issues implicit in this study are ripe for further examination.

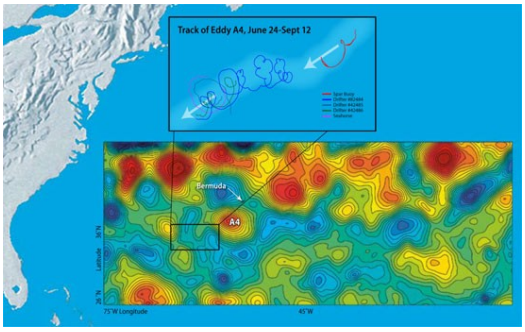
Cross-fertilization of ideas between disciplines can be transformative. Using control theory techniques originally developed for engineering applications, engineers are helping to transform medical treatment of cancer. The project **Control in Genetic Regulatory Networks: An Engineering Approach to Increase the Success Rate in Cancer Therapy** *(Highlight 15041, Award 0355227)* uses control theory from engineering to formulate the process of moving a cell from a diseased state to a disease-free state. The genetic regulatory networks were constructed from experimental data provided by collaborating biologists. The objective was to reduce the activity of certain genes at the tissue level by partitioning the probable outcomes of treatment strategies into good and bad regimes. The theoretically developed control algorithms performed significantly better in simulation studies than alternative approaches currently used. The project strengthens fundamental research in genomics using engineering analysis techniques of signal processing and control, and fosters discoveries whereby an engineering approach may transform medicine. In addition, this work promoted sufficient innovation to win a major follow-up grant from the W. M. Keck Foundation for validation experiments. Finally, it addresses the Strategic Plan goal of investigating the human and social dimensions of new knowledge and technology by transforming medical treatments in cancer.

- ***Foster discoveries that have the potential to transform disciplines or fields of science, engineering, or education research.***

Given the increasing frequency of tornadoes experienced today, new technologies to predict when and where tornadoes and other weather disturbances (floods, severe thunderstorms) will occur are

of obvious importance. The NSF Engineering Research Center for Collaborative Adaptive Sensing of the Atmosphere (CASA), located at the University of Massachusetts at Amherst, has developed a method of weather sensing that utilizes dense, low-cost radar networks that can sense the lower atmosphere, an important area that is under-sampled by today's technologies *(***New Radar Network Evaluated in National Weather Service Experimental Warning Program**, *Highlight 15599, Award 0313747)*. The finely grained observations of the lower atmosphere obtained by the CASA researchers allowed forecasters to see small meteorological structures that are close to the ground, such as mini-wind clusters that are embedded in larger storms. During the 2007 tornado season, CASA transmitted real-time data from its first prototype network in Oklahoma to National Weather Service forecasters for evaluation in the Experimental Warning Program. The Center's data will continue to be evaluated in the Experimental Warning Program during the 2008 tornado season. This research is multidisciplinary, requires a complex-systems approach, and involves collaboration between various universities and government agencies at many levels. The research is transformative because it will introduce a new dimension to weather forecasting and sensing, yielding capabilities that do not exist today. This highlight also represents broadening participation in that the faculty and students involved include many women and members of underrepresented minorities.

Interactions Between the Wind and Oceanic Eddies Stimulate Higher Biological Productivity In Subtropical Ocean Surface Waters *(Highlight 16578, Awards 0241310, 0241340, 0241023)* is a project led by Dr. Dennis McGillicuddy, Woods Hole Oceanographic Institution, with a team of collaborative investigators from eight different institutions. Oceanographers from these institutions have sampled two different types of eddies over a period of months using a sophisticated approach employing high-tech instrumentation to measure horizontal and vertical dispersion of several water properties. This research contributes to the fundamental knowledge about what factors control biogeochemical cycles and the conversion of carbon dioxide into biomass in the oceans. Their work has demonstrated that episodic eddy-driven upwelling may supply a significant fraction of the nutrients required to sustain primary productivity in the subtropical ocean. The results from this study are changing the view of how biological production and export of carbon to the deep ocean is taking place in the mid-ocean.

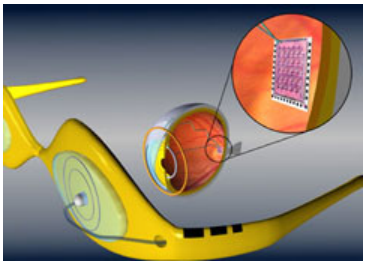


Fundamental research at the atomic level is still alive and well, and established wisdom continues to be challenged. A striking example of this is the preparation of "ultra-heavy" isotopes, magnesium-40 (normally Mg-24), aluminum-42, and aluminum-43 (normally Al-27). These extraordinarily heavy isotopes, created at the National Superconducting Cyclotron Laboratory at Michigan State University *(***Newly Created Forms of Magnesium and Oxygen**, *Highlight 16189, Award 0606007)*, defy established theory, which predicts that they should not be stable. The results emerged from careful detection with enhanced techniques that allowed observation of one in one billion particles, an experiment that could not have been carried out without a user facility of this unique type.

A project, **Beware What's Unaware: Deep Impact of Subtle Distractions**, undertaken by Takeo Watanabe, a cognitive neuroscientist at Boston University *(Highlight 15885, Award 0549036),* fosters discovery into the mechanisms of attention disorders by demonstrating how different regions of the brain interact. He found that participants had more difficulty suppressing subliminal, low-coherence stimuli (randomly moving dots on a computer screen) when trying to focus on a particular task. This was demonstrated by imaging a particular area of the brain, Middle Temporal, (MT), which perceives motion. The project also simultaneously imaged another area of the brain, the dorsolateral prefrontal cortex (DLPFC), which is responsible for inhibiting responses in the MT. They found that the DLPFC area did not activate when presented with low-coherence stimuli, thereby causing activity in the MT area. They also showed more activity in the MT area with low-coherence stimuli than with high-coherence (coordinated) stimuli. This project has implications for understanding attention disorders in humans (as this research shows that subtler distractions are harder for the brain to screen out) as well as understanding how different regions of the brain interact. It may result in more efficient workplace design. This meets the evaluation criteria of strengthening fundamental research (in understanding better how different regions of the brain interact) and fostering discoveries that could transform cognitive research on attention disorders. Finally, it addresses the Strategic Plan goal of investigating the human and social dimensions of new knowledge and technology.

- ***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.***

More than 25 million people around the globe, including six million in the United States, are visually affected by genetic retinal diseases. Researchers are working to help patients blinded by Retinitis Pigmentosa; the work involves development of a second generation prosthetic implant (ARGUS II) that will enhance the vision of individuals who have lost sight *(***USC Research May Help Patients Blinded by Retinitis Pigmentosa**, *Highlight 15664; Award 0310723).* The new implant was developed by Dr. Mark Humayun's research team at the University of Southern California and Second Sight Medical Products Inc. The ARGUS II consists of a tiny camera and transmitter mounted on eyeglasses, an implanted receiver, and an electrode-studded array that is secured to the retina with a microstack the width of a human hair. A wireless microprocessor and battery pack powers the entire device. Six patients were implanted with earlier prototypes in 2002, and can now perceive light, distinguish between objects, and detect motion. The new implant contains nearly four times as many electrodes as the original (60 vs. 16), each of which is independently controllable, allowing patients to process higher-resolution images. Researchers hope the ARGUS II will be available in a few years and are currently enrolling subjects in clinical trials.



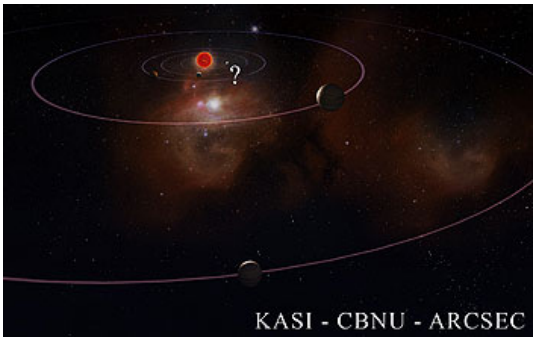
This work is transformational in that it represents breakthroughs in microelectronics, image processing, and bio-engineering, which are likely to lead to radically new prosthetic technologies in other areas beside the retina. By 2020, some 50 million patients who have lost their sight due to genetic eye diseases that affect the retina are projected possibly to be able to regain some of their sight using a new retinal implant. The research also satisfies the NSF Strategic Plan's emphasis on broadening participation in that a number of key members of the research team are women. Finally, it demonstrates one of the investment priorities of the Strategic Plan goal of investigating human and social dimensions of new knowledge and technology by developing products to give some level of sight to patients suffering from Retinitis Pigmentosa.

Bendable Concrete for Safe, Durable, and Sustainable Infrastructure *(Highlight 15376, Awards 0223971, 0329416, 0700219)* is a project by investigators at the University of Michigan who have designed a new type of concrete that maintains all the advantages of current concrete but adds ductility, allowing it to bend under stress without fracture. The new type of concrete has 300-500 times the tensile ductility of normal concrete; it can be bent without fracturing when overloaded. The material also exhibits self-healing properties, which further enhances its durability. The work may establish the United States as the global leader in "designer" cement-based composites. It also embodies collaboration among several sectors: government, industry, and academic partners. It has potential consequences in the design of sustainable structures resistant to earthquakes and weather events. This research also exemplifies the NSF Strategic Plan goal of integrating research on ethics, and safety considerations.

- ***Promote international collaboration among U.S. investigators and partners in other countries and regions.***

Research and Education Experiences for Students to Examine Earthquake Hazard Mitigation Utilizing the Network for Earthquake Engineering Simulation (NEES) is an excellent example of international collaboration *(Highlight 16728, Award 0526590).* Professor Richard Christenson and graduate and undergraduate students traveled to Thailand and Japan to conduct research in innovative ways to reduce structural damage arising from natural hazards, such as earthquakes. The visits and collaborative research in the two countries are enabling partnership building between United States, Thai, and Japanese institutions, and scientists who are engaged in the study of ways to create better designed buildings that can withstand strong forces during earthquakes and tsunamis, thus enhancing public safety.

The societal urgency of understanding impacts of global warming on sea level rise requires establishment of innovative observations and partnerships. In the project, **Sea Level Rise from Polar Ice Sheets: Societal Relevance and Broader Impacts** *(Highlight 14730, Awards 0122520, 0407827, 0424589),* the Center for Remote Sensing of Ice Sheets (CReSIS) serves to join forces between U.S. universities (U. Kansas, Ohio State, Penn State, U. Maine, Elizabeth City State University, and Haskell Indian Nations University) and international collaborators from Denmark, Norway, Australia, the United Kingdom, and Iceland, and the Topeka K-12 school district. This team is transforming science and engineering fields by using satellite-based sensing of the earth with UAV (Unmanned Aerial Vehicle) and traditional airborne-based radar, along with seismic and other measurements with data products, modeling, and analysis to improve on current estimates of sea level rise resulting from global warming. The Nobel-Prize-winning IPCC (Intergovernmental Panel on Climate Change) 2007 estimates, which may underpredict the rate of future sea level rise, are based on traditional modeling of the ice sheets, which ignore rapid changes that may occur due to recently observed mechanisms of bed lubrication and ice shelf stability effects. CReSIS is integrating discovery and learning via classroom activities developed for K-12 education, which are free and available to all via their website (https://www.cresis.ku.edu/), along with the Summer School for Teachers and PolarTrec, which increase classroom knowledge of climate change. This project has genuine partnerships with minority-serving institutions, which play integral roles in the discoveries and reporting of results. Finally, this work investigates human and social dimensions of new knowledge and technology by integrating discovery (better modeling of sea level rise due to the integration of various observations and data sets) and learning using K-12 classroom activities.



Going from the subatomic to the cosmological, astronomers collaborating from 11 universities have observed a new solar system analogous to ours but smaller in size that contains planets similar to Jupiter and Saturn (**Newly Found Solar System has Jupiter/Saturn Pair Similar to Ours, just scaled down**, *Highlight 16275, Awards 0206189, 0452758, 0708890)*. The system was detected by "gravitational microlensing," in which light from another star is magnified by the passing of another body—in this case, the star detected—in front of it. Observations from the 11 different ground-based telescopes provided the sensitivity to observe the planets. The small size of the solar system compared to other exosystems suggests that solar systems like ours may not be rare. The work is an excellent example of an international collaboration, including participation of amateur astronomers.

Research stimulated by the devastation caused by tsunamis has revealed possible origins for their profound impact. Japanese and U.S. scientists *(***"Ultrasound" of Earth's Crust Reveals Inner Workings of a Tsunami Factory**, *Highlight 16358, Award 0451790)* examining the seafloor near the southwest coast of Japan, where tsunamis are particularly prevalent, have found a major fault line that can trigger serious earthquakes, which are known to occur in that region. Core drilling also reveals that the fault line appears to have shifted landward over time, and has become shallower and steeper, conditions that are ideal for tsunamis. These multidisciplinary results, carried out through an international partnership, contribute to developing ways for living sustainably on Earth.

Learning

The Advisory Committee for GPRA Performance Assessment (AC/GPA) concluded on the basis of the highlights analyzed, that NSF has demonstrated significant achievement in meeting its goals in the area of Learning. The 159 program highlights that were reviewed clearly demonstrate that NSF "cultivates a world-class, broadly inclusive science and engineering workforce, and expands the scientific literacy of all citizens." The Committee selected the following highlights as examples of significant achievements in the area of Learning.

A significant number of projects contributed to creating a pre-school to postdoctoral STEM pathway that engages learners across all levels of schooling, involving learners in hands-on science, broadening participation, and increasing scientific literacy across age groups and backgrounds. Two examples are particularly telling of the cross-cutting nature of some of the initiatives in the portfolio.

Vast Facility in Appalachia Brings Students, Researchers Together (*Highlight ID 16111, Award 0520928)* describes a facility in Appalachia that studies cosmic ray sources. The project engages high school and college students in scientific research and outreach activities to members of the community. The location of the facility is unique, providing first-time access to advanced instrumentation for populations without a robust tradition of scientific research: students are given opportunities to make genuine and exciting discoveries. In sum, this project integrates successfully education, research, and societal benefit.

Another example is given in **New Flight Simulator Environment Engages Students in Interdisciplinary Research at Historic Tuskegee University** (*Highlight ID 15039, Award 0411464*), which describes a multidisciplinary, collaborative effort at Tuskegee Institute. The Flight Simulator Environment brings together aerospace engineers and psychologists in a quest to understand ways in which pilots make decisions during flight. Research on the topic was conducted by twelve Tuskegee students, and their work has great potential for societal impact, especially in the area of public safety.

In addition to these all-encompassing examples of excellence, the Subgroup also has identified projects that speak specifically to K-12 education, undergraduate education through postdoctoral level, and public understanding of STEM and lifelong learning.

K-12 Education

The portfolio of highlights provides many examples of work that engages learners across all levels of schooling and prepares K-12 teachers to create and deliver meaningful STEM curricula. The enrichment of K-12 students through research experiences is an important theme found in the highlights. The work summarized in **Scientists and Students Online: An Oceanographic Expedition to the Indian Ocean** (*Highlight ID 16357,* Award 0652315) exemplifies integration of pre-college students in a cutting edge research project through real-time tracking of an oceanographic expedition to the Indian Ocean. This ingenious use of the web resulted in increasing numbers of students tracking and participating in learning activities connected with the expedition. **COSMOS Students Become Rocket Scientists** (*Highlight ID 16417, Award 0602286*) describes a summer residential program at the University of California, San Diego (UCSD) that brings together high school students, undergraduates, graduate students, postdoctoral fellows, and faculty at UCSD with a focus on rockets.

The development of teachers is also an important feature of the portfolio. A Robert Noyce Scholarship program summarized in **Noyce Scholars Prepared to Teach in High-Need Schools** (*Highlight ID 14873, Awards 9852170, 0733849*) addresses the need to attract and retain the next generation of STEM professionals. The program has recruited 63 new math and science teachers to teach in high-need school districts in California, and 65 percent of the scholars have been drawn from underrepresented populations. In another similar example, **Vanderbilt University Biomedical Engineering Research Experience for Teachers** (*Highlight ID 15384, Award 0338092*), 44 teachers participated in a 24-day summer program with academic year follow-up. They completed a research project in a biomedical engineering laboratory, designed instructional units based on that research experience, and implemented them in their high school classrooms.

Project SEEDBed (Stimulating Enthusiasm, Exploration, and Discovery through Biotechnology Education), *(Highlight ID 14893, Award 0602744*) engages students and teachers from middle and high schools in summer academies at community colleges designed to increase knowledge, stimulate interest in biotechnology among students and teachers, and encourage students to pursue further study, possibly leading to careers as biotechnicians. Teachers are provided with "footlockers" to take back to their classrooms, with all of the equipment necessary to conduct

new laboratory activities. Evaluation data indicate significant impact on both students and teachers.

In the project described in **Bringing an Atomic Force Microscope to School** (*Highlight ID 16213*, *Award 0653346*) high school teachers learn science through serious engagement with University of Wisconsin-Milwaukee faculty, with the science of CD-ROMs and DVDs as the focus. The effective and exciting use of technology in instruction is accomplished through classroom visits by UWM faculty who bring an Atomic Force Microscope to high schools as part of their instruction on the inner workings of CD-ROMs and DVDs. Broadening participation occurs through involvement of high school teachers.

A number of highlights summarize important work that teaches science in cultural context. **BPC-DP: New Voices and New Visions for Engaging Native Americans in Computer Science** (*Highlight ID 16501*, *Awards 0539982, 0540484*) describes a highly innovative pilot project that integrates Native American culture and experience with computer science. High school and college level students use computing to illustrate and display Native American art and culture to wider publics. By using the computer in culturally affirming ways, students are attracted to computer science and hopefully STEM work in general. The project should result in increasing the participation of Native Americans in computer science. It also illustrates the effective use of the computational sciences as a window for learning about arts and culture, as well as the use of arts and culture as a vehicle for attracting students to computer science. The project, if successful, should be highly replicable across regions and cultures.

WolfQuest: Learning Science through Game Play (*Highlight ID 15717*, *Award 0610427*) is a project that brings wolf behavior and ecology to life through exciting game play and intense social interactions for youth who are not normally attentive to ecological concepts and conservation issues. The WolfQuest game (www.wolfquest.com) represents a new model for informal science learning with practical, cultural, and ethical values embedded in the game's

design. With an engaging online forum for learner-generated content, including art, stories, photos, and videos, WolfQuest has created a safe and engaging arena for youth. Removing the formal barriers typically found between scientists and the public, youth can talk directly with the world's leading wolf researchers as scientist role models. Striving to create new forms of science learning, in WolfQuest learners must engage experientially in authentic scientific problem solving using their reasoning skills to figure out complex scenarios regarding wolves and wolf survival without any external guidance. Because of its unique learning strategies, WolfQuest will aggregate data on learners' science content acquisition, attitudinal change, game engagement, and will ultimately yield new guidelines on effective practices for the future development of science education games and appropriate methodologies for evaluating game-based learning.

Undergraduate Education through Postdoctoral Level

A number of highlights described alternative pedagogical approaches to undergraduate science education. For example, a project summarized in **From Sausages to Skateboards** (*Highlight ID 15221*, *Award 0431756*), measured the impact of teaching real-life applications in undergraduate mechanical engineering courses. The research demonstrated that the use of applications had a

positive impact on final course grades only when the whole course was applications based. Students in the application-based course had significantly higher final course grades than comparison students matched by instructor and course who did not receive application-based teaching or when only two or three applications were used during a course.

In a similar vein, **An Infrastructure for Designing and Conducting Remote Laboratories** *(Highlight ID 16031, Award 0326309*), describes a project consisting of an online laboratory environment that supports experiments based on multi-player computer game engines. This project aims to conceive, design, implement, test, and assess various online laboratory resources for undergraduate engineering and science education based on the use of advanced information technologies and of the rapidly expanding cyberinfrastructure. These online laboratory resources include remote experiments, virtual experiments, and virtual learning environments. Cyberinfrastructure-enabled educational tools such as this online laboratory environment show strong potential for initiating a dramatic shift in the general educational paradigm where the interactions between learners and educational resources as well as between

The portfolio has many examples of programs aimed at populations of students currently underrepresented in STEM disciplines (*Highlight IDs 14876, 15287, 15299, 15304, 15345, 15350, and 15389*). However insufficient data are provided to assess fully the outcomes and broader impacts of these initiatives. That having been said, some examples do stand out. A program at a university in Texas (**Undergraduates Discover the Thrill of Research**, *Highlight ID 15007*, *Award 0344221*) emphasized learning through discovery rather than by development of specific technical skills. The approach demonstrated success with inquiry-based exposure to scientific research, and the pilot group of 16 students won first place in a college-wide competition. In addition, two students from the group received awards for research presentations at the Louis Stokes Alliances for Minority Participation Program . Likewise, **Flying High in Louisiana** (*Highlight ID 16198*, *Award 0653423*), describes a curriculum revolving around small balloon science experiments and flight. These activities are designed to attract students from underrepresented groups into STEM programs and develop partnerships between Louisiana State University and local minority serving institutions. The students develop and conduct science experiments involving physics and thermodynamics. They create, launch, and bring to earth balloon vehicles. The project involves minority youth in creative experiments, exposing them to physics and the process of scientific research.

Project Pathways (**Community College Students Discover Rare Mushroom in Texas**, *Highlight ID 15403, Award 0525536*) is a community college research project that has increased the number of students who obtained associate degrees or transferred to baccalaureate programs in science, technology, engineering, and mathematics (STEM) disciplines. Eastfield College students participate in research projects with various agencies. Some students were placed with U.S. National Park Service researchers and others in collecting data for the All Taxa Biodiversity Inventory of the Big Thicket. These data are used for national strategic planning related to a host of environmental issues. Additionally, the students collect data for their own research projects in biological areas of their choosing including botany, entomology, mycology, and ichthyology. The expedition to the Big Thicket enabled genuine scientific discoveries by students at the community college. Eastfield College is primarily a Hispanic serving institution. The students participating in Project Pathways are mostly first generation college students, women, African -

American, Hispanic, or students with disabilities. The program often provides these students with critical first experiences in STEM. This project also illustrates how community colleges enhance infrastructure with major scientific instrumentation to integrate research and innovative teaching that advances discovery and scientific understanding for early undergraduates.

A very good model for global engagement of STEM students is NanoJapan (**Rice University PIRE Program Feated as Best Practice in International Education**, *Highlight ID 15598, Award 0530220*), a program of 12-week research internships in Japan for undergraduate engineering majors that has been awarded the 2008 Andrew Heiskell award for innovation in study abroad by the Institute for International Education. The NanoJapan program sends a diverse group of sixteen first and second year engineering majors from U.S. universities to leading edge nanotechnology laboratories throughout Japan to work with Japanese teams on research projects related to carbon nanotube fabrication. NanoJapan serves as a model for increasing study abroad and for participation of students in science and engineering fields. NanoJapan allows students to gain both experiences. Internships with world-class researchers in state-of-the-art facilities allow students to enhance engineering and research skills while building the cultural understanding, adaptability, and networks necessary to succeed in the global marketplace. This program has strong potential benefits in workforce development. In addition, the exposure of budding engineers to world-class nanotechnology expertise and facilities in Japan can be expected to enhance research and industrial engineering in the United States as participants advance in their careers.

Also noteworthy are the Pan American Advanced Studies Institutes (PASIs), which are jointly funded by the Department of Energy and the NSF (**Better (and More Sustainable) Living with Green Chemistry**, *Highlight ID 15261*, *Awards 0221274, 0617357*). A Sustainability and Green Chemistry PASI, organized by Dr. Mary Kirchoff of the American Chemical Society, was held in Mexico City, Mexico. Fifty-five graduate and postdoctoral students, nine local participants, and fourteen faculty members representing chemistry, pharmacy, biotechnology, packaging, genetics, nanotechnology, and chemical, civil, environmental, and geo-environmental engineering participated in interdisciplinary activities and research to advance their knowledge of green chemistry and green engineering. Participants received educational materials and project ideas that could be implemented at their home university and within their local community. This project is an exemplar of interagency collaboration, global engagement, broadening science and engineering knowledge for sustaining the earth, and education extending to the postdoctoral level.

Public Understanding of STEM and Lifelong Learning

The portfolio is rich in examples of projects that enhance public understanding of science and engineering. Here we focus on three particularly innovative programs that cut across age groups. CYBERCHASE (**NSF-Funded CYBERCHASE Wins Emmy,** *Highlight ID 14955*, *Award 0638962*) is a ground-breaking multi-platform children's program on PBS KIDS GO! that shows the connection between mathematics and the invention process. The content spans the 3rd-5th grade standards of the National Council of Mathematics. The program has been awarded a daytime Emmy and reaches nearly five million viewers each week. It has recorded more than 1.7 billion page views for CYBERCHASE Online (http://pbskids.org/cyberchase/). Importantly, research shows that viewers take away the mathematics content of the episodes they watch and visitors spend more than an hour at the site on the average visit.

The Coalition on the Public Understanding of Science – COPUS (*Highlight ID 15556*, *Award 0628790*) is organizing the Year of Science 2009, a national year-long celebration of science to engage the public in science and improve public understanding about the nature and processes of science. COPUS is a growing network with over 180 registered participants that include professional societies, government agencies, business, universities, museums and informal science centers representing all major science disciplines. The network has an active web site with information about the organization, national events, resources, and new participant registration. The database allows the public to search for COPUS related activities based on type, location, discipline, and target audience. To better coordinate COPUS activities, the network participants are organizing in regional and thematic hubs that will facilitate the interaction among network participants with common goals.

sLowlife: A Traveling Exhibit of Plant Science and Art (*Highlight ID 15586, Awards 0080783, 0416741, 0531641*) is a novel multi-media educational/art installation including video, live plants, photographic prints, and interactive environments, originally designed by plant biologist Dr. Roger Hangarter in collaboration with an artist, Dennis Deharte. The exhibit highlights the research of Dr. Hangarter and is designed to convey to a public audience that plants are complex living beings and not just the ornamental inanimate objects many people assume. By combining time-lapse movies with artistic elements that demonstrate various plant movements and growth responses, the exhibit accurately and effectively combines science and art in a way that provides scientists and non-scientists with a novel way of learning some basic plant biology and an appreciation of the dynamics of plant growth and movement. Contemporary research approaches, including a striking presentation of a genetic screen for tropism mutants in Arabidopsis, use of microarrays to understand plant growth, use of green fluorescent protein (GFP) to visualize the cytoskeleton, and views of chloroplast movement are mixed with classic experimental and educational demonstrations. With written commentary kept to a minimum, the visual impact of plants and experimental data dominates the experience in this novel exhibit.

Research Infrastructure

The Advisory Committee for GPRA Performance Assessment (AC/GPA) concluded on the basis of the highlights analyzed, that NSF has demonstrated significant achievement in meeting its goals in the area of Research Infrastructure. The 115 program highlights that were reviewed clearly demonstrate that NSF "builds the nation's research capability through critical investments in advanced instrumentation, facilities, cyberinfrastructure and experimental tools."

Research Infrastructure encompasses the entire scope and scale of science, mathematics, technology, and education, enabling the conduct of leading-edge research while educating the next generation and future generations of scientists and engineers. Imagine funding the discovery and development of probes that can detect the most singularly quantifiable constituents of the nucleus of an atom or production of an educational video that describes the "life" of a single electron that travels around any nucleus. Research infrastructure has evolved to a point where scientists and engineers can develop and use instrumentation and probes to study phenomena that are smaller than a single strand of hair. At the other end of the spectrum, research infrastructure supports construction, maintenance, and upgrades for telescopes that explore galaxies "far, far away," where distance is measured in millions of light years. While grade school children are using desk top computers and digital hand-held games that have more computing power than mainframe computers of a generation ago, researchers advancing the frontiers of cyberinfrastructure are developing hardware that together with software and communication systems enables petascale computing power. That's one million billion [10^{15}] operations per second – virtually an incomprehensible much less imaginable number if the results weren't there

to be reckoned with. For example, a million billion seconds would work out to be 32 million years.

The significance of the Research Infrastructure goal is easier to grasp if one thinks of these investments as the critical facilities, tools, and resources that breach the boundaries of yesterday's research and educational programs and enable new and more challenging questions to be answered while enriching educational experiences for graduate students and postdoctoral scholars. NSF's Research Infrastructure investments are on the seas with ships carrying equipment and investigators to and from the Antarctic, and under the seas with submarines that explore the seabed. They are on virtually every continent with telescopes, particle detectors, and cyberinfrastructure collaborations. In addition to petascale computing tools, NSF also supports the preparation of searchable digital libraries and enormous databases that offer better teaching aids for K-12 teachers and students, or facilitate storm prediction or atmospheric modeling for the most challenging research questions. Predominantly undergraduate institutions benefit from Research Infrastructure investments in advanced instrumentation and programs that offer targeted research experiences for high school and college students to attract and train American students in STEM disciplines. Research-intensive institutions and special subject centers receive funding from NSF to develop new research tools and to apply unique research capabilities targeted to practical purposes that will benefit the public. NSF's Research Infrastructure portfolio also includes the collection and analysis of data related to STEM for public information and national science policy analysis; NSF's Science and Engineering Indicators 2008, the foremost compendium of quantitative STEM data, is regarded internationally as the gold standard of such reports. The flavor and vast impact of some of these extraordinary "enablers" in each of the programmatic areas is highlighted below. The Committee selected the following highlights as examples of significant achievements in the area of Research Infrastructure.

Major Multi-User Research Facilities

NSF's major multi-user facilities primarily benefit scientific inquiry while providing opportunities for integrating education and research. How safe is a modern-day operating hospital room in a moderate to severe earthquake? An investigator from the University of Nevada-Reno (**Hospital Room Shook Up in First Seismic Experiment of Its Kind**, *Highlight 14938*, *Awards 0721399 and 0402490*) used the Structural Engineering and Earthquake Simulation Laboratory at the University of Buffalo to explore the impact of shaking on nonstructural elements such as portable equipment, wall-mounted EKGs, ceilings, pipes, and internal walls in a model hospital room. Their findings will help hospitals to anticipate the impact and plan accordingly for the safety of patients and hospital personnel. Researchers at Stanford University (**Holding the San Andreas Fault in our Hands**, *Highlight 14818*, *Award 0323938*) have been amassing data from samples bored into the San Andreas Fault, the most notorious earthquake zone in the United States. Scientists are using these samples to better understand episodic tremors and slips – the little fault line activities that accumulate strain slowly along the Fault plates. For the West Coast residents who live with the San Andreas Fault as a neighbor, improved understanding of fault behavior is practical research with tremendous potential public

"**When Planets Collide**" sounds like a Star Wars movie plot or a GameBoy title. But this is the report of exciting observations by a team from UCLA and the Spitzer Science Center from NSF's Gemini Observatory, which supports telescopes in Hawaii and Chile for observing from both the Northern and Southern hemispheres (*Highlight 15617, Award 0525280*). Astronomers have found the first clear evidence of planet formation through observation of young stony planets which appear to have formed from a collision around one of the stars in the Pleiades clusters. Northern winter sky watchers recognize the Pleiades as one of the most brilliant star clusters.

Instrumentation

A group of engineers at the National High Magnetic Field Laboratory at Florida State University (**Novel Technique to Study the Structure of Proteins**, *Highlight 16236*, *Award 0084173)* have developed a novel probe that will permit the use of nuclear magnetic resonance (NMR) for the study of proteins that don't dissolve in water. These new tools are opening up a new frontier in protein structure determination.

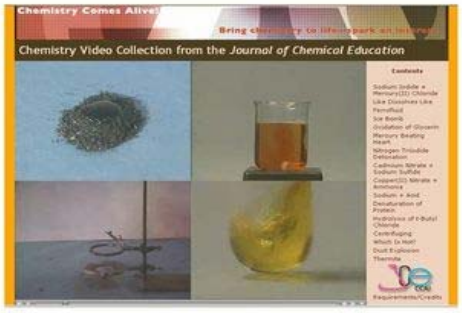
Development of an In-Line Cylinder Bore Inspection System (*Highlight 15077*, *Award 0723669*) features an In-line Cylinder Bore Inspection System. This Small Business Innovation Research (SBIR) award to Industrial Optical Measurement Systems supported transformative research that replaces inefficient human visual inspection of cylinders of engine blocks with an automated total inspection of cylinder bore surface finish at the speed of a production line. This novel probe pushes automation and efficiency up a notch in the highly competitive automotive market with a potential to stem the market share loss of domestic producers.

In the midst of all this sophistication, there is also room in the NSF portfolio to explore good old-fashioned slime. For many youngsters, a little "play" with worms could be the pathway to a scientific career. The Nebraska State Museum teamed with a local academic lab to lead some middle schoolers for a romp through parasitology (**The Worms Crawl In, The Worms Crawl Out!**, *Highlight 15805*, *Award 0646356*). What's not to like about cuddly worms, a fair portion of yuck, lots of curiosity, an admirable "ick" factor, worm humor, and learning. This project demonstrates that attracting young people into scientific careers may begin with a real lab experience on a college campus. These students found out the getting a 'hands-on" worm experience was better than just watching "CSI." NSF continues these enriched experiences for potential STEM careers through programs at minority and primarily undergraduate institutions providing sophisticated research instrumentation and summer research participation programs to allow students to preview scientific and technical opportunities.

Cyberinfrastructure

NSF's leadership in high performance co mputing is gene rating com puting capacities and capabilities t hat approach petascal e ranges. Solving problem s at a scal e that was uni maginable and be yond our reach just a few y ears ago is now within rea ch. NSF' s invest ments h elp anticipate an d resolve the real proble ms and ch allenges of petasc ale computing: storage, manipulation, and m ining of m assive am ounts of data that rely o n co mplex hardware architectures, networking of parallel computing power, and heroic software solutions.

Computer Recognizes Facial Expressions Better Than Humans Can (*Highlight 16396*, *Awards 0454233 and 0627822*) describes how res earchers at t he University of Buffalo and University of California, San Diego have developed the Com puter Expression Recognition Toolbox that can be used by social scientists, education researchers, cogniti ve neuroscientists, and vision resear chers. A particularl y inter esting finding from their expe riments w as that automated classifiers were able to diffe rentiate real pain from fake pain significantly better than inexperienced human subjects. Computers were able to detect driver drowsiness with more than 98% accuracy, perhaps telling us that co mputers can recognize facial expressions better than humans can. Research in these areas will also provide critical in formation for co mputer science and engineering efforts to make computers and r obots that interact effectively with hum ans and understand nonverbal behavior.



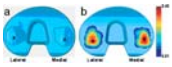
Digital libraries offer delightful educational "shopping t rips" for teacher s and budding scientists. With **Chemistry Comes Alive**, (*Highlight 14835, Awards 0632303, 0632247 and 0632269*), a collaborative project between the University of Wisconsin and the Am erican Chemical Society , the curious c an observe dangerous chem ical reactions and le arn about demonstrations or experim ents that rivet the attention of young students. Dramatic footage and supplemental educational materi als make this a wonderfull y at tractive and easily accessible resource. This project addresses both the Resea rch Infrastructure and Learning goals by providing teachers and stu dents the opportunity to view a diverse array of chemical reactions that demonstrate concepts in chemistry.

Recent advances in computational linguistics enabled by NSF funding have produced the Sanskrit digital librar y (**International Digital Sanskrit Library Integration**, *Highlight 16177*, *Awards 0535207 and 0535038*). This resource challenged t he m ost sophisticated co mputer scientists – because robust techniques involvi ng recognition factors, selectio n, and mapping rules made this venture a veritable romp in computational linguistics. The digital Sanskrit tool and infrastructure provide an internationally accessible tool that will re place outmoded grammars, reference bo oks, and other printer materials that will facilitate and broaden participation in linguistics research.

NSF's interest in accu mulating m assive data bases spans disparate fields, from aggregations of huge v olumes of astrono mical observations to atm ospheric hist ories that pr omote challenging modeling an d si mulation rese arch. Climate modeling has direct releva nce for global climate change resear ch and policy issues leading to factual, inform ed decision making. **Creation of a new satellite-based hurricane database** (*Highlight 15823*, *Award 0614812*) describes the development of the URSAT dataset which contai ns 170,000 storm-centered satellite observations in over 2,000 storms wo rldwide. Research ers at the University of Wisconsin and NOAA' s

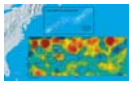
National Climatic Data Center ha ve developed the f irst global ho mogeneous record of trop ical cyclone intensity estimates from 1978-2006. Hurricanes and tropical storms have a major impact on U.S. and global econom y; this database may provide better insight into how increasing temperatures could affect the intensity of hurricanes and cyclones.

Photo Information and Credits



Page A-2 – Comparison of experimental (a) and simulated (b) wear regions for a total knee replacement design after 5 million cycles of walking performed in a knee simulator machine. X's indicate locations of maximum wear. Dotted lines in (a) indicate boundaries of experimental wear regions. Color bar in (b) indicates depth in millimeters of simulated wear regions.
Credit: B.J. Fregly, University of Florida

Page A-3 – Damage from an EF1 tornado. CASA graduate student Patrick Marsh (University of Oklahoma) conducted a damage survey to verify the EF1 tornado identified in CASA data.
Credit: CASA



Page A-3– Data from satellite altimeters (lower inset), which measure sea surface heights, show depressions (blue) and bumps (red) that mark cold- and warm-water eddies in the ocean on June 17, 2005. Researchers tracked the southwestward motion of eddy A4 (light-blue in the upper inset) by ship from June 24 to Sept. 12. They released several drifters and a buoy (colored tracks) to capture the swirling motion of the eddy's currents.
Credit: This figure was drafted by Jim Canavan and provided as a courtesy by Dennis McGillicuddy, WHOI, and the Colorado Center for Astrodynamics Research.

Page A-4 – The retinal prosthesis consists of a camera and transmitter mounted in eyeglasses, an implanted receiver, and a microelectrode array attached to the retina.
Credit: Biomimetic MicroElectronic Systems Engineering Research Center (BMES)

Page A-6 – c
The two planets were
revealed when the star they orbit crossed in front of a more distant star as seen from Earth. For a two-week period from late March through April 2006, the nearer star magnified the light shining from the farther star. Their finding suggests that our galaxy hosts many star systems like our own.
Credit: Korea Astronomy and Space Science Institute (KASI), Chungbuk National University (CBNU), and Astrophysical Research Center for the Structure and Evolution of the Cosmos (ARCSEC)

Page A-7 – View of the Flight Simulator Environment setup at Tuskegee University
Credit: Tuskegee University

Page A-7 – Two SEEDBEd high school students use micropipettes to move enzyme digested DNA into an electrophoresis gel.
Credit: Cindy Barton, Tulsa Community College

Page A-8– Virtual wolves on the prowl.
Credit: Grant Spickelmier, Minnesota Zoo

Page A-9 – Middle school teachers building models of fullerenes (above) and running an experiment.
Credit: Andrew Greenberg, University of Wisconsin, Madison

Page A-10 – The Emmy-Award winning CYBERCHASE team, featuring Jackie, Inez, Matt, and Digit.
Credit: Sandra Sheppard

Page A-13 – Artist's rendering of what the environment around HD 23514 might look like as two Earth-sized bodies collide.
Credit: Gemini Observatory/Lynette Cook

Page A-13– Student practice combing for ectoparasites.
Credit: Dr. Scott Gardner, University of Nebraska

Page A-14 - Chemistry Comes Alive! website received the 2006 Pirelli *Internet*ional Award "for the effectiveness of this collection of multimedia tools that are designed to enhance chemistry education in schools and universities".
Credit: Journal of Chemical Education Software, a publication of the Division of Chemical Education, Inc. of the American Chemical Society