
APPENDIX: ADDITIONAL EXAMPLES ILLUSTRATING OUTCOMES OF NSF INVESTMENTS

Outcomes relevant to: Discoveries at and across the frontier of science and engineering

- **Robotics:** NSF awards have enabled fundamental new discoveries while promoting collaboration across traditional disciplines. Developments in high performance computing applied to use of robotics in surgery, impacts the simulation, planning and execution of surgery. Use of virtual reality techniques and robotic mechanisms improve the ability of surgeons to perform small-scale micromanipulation tasks.
- **Testing Astronomy's Theories:** Computational methods lead to new discoveries. Of special note was a simulation of the collision of two black holes, important for understanding Einstein's theory of general relativity and how gravitational waves behave.
- **Polar Research:**
 - An international drilling project into the sea floor at Cape Roberts, Antarctica provided evidence of previously unknown large volcanic eruptions in the Ross Sea, and yielded a large number of new species of microfossils, providing important information about how Antarctica evolved into the large stable ice mass we know today. One drilling project drilled 625 meters into the sea floor and recovered core for 95% of the hole, finding many cycles of glacial advance and retreat between about 20 and 35 million years ago.
 - Researchers discovered that during this decade tundra soils have become a source of greenhouse emissions, especially during winter, rather than serving as a depository for greenhouse gases.

-
- **Understanding the Human Brain:** Scientists attempting to understand the human brain have developed computer models called neural networks, which attempt to simulate the computational power of the nervous system. For every human action –vision, memory, or language- the brain enlists dynamic interacting populations of nerve cells to perform the task. New approaches use a nonlinear neural network combined with computer simulations that mimic the way humans solve problems, not like a digital computer, but by memorizing facts, simplifying, and estimating answers. Progress in these areas has contributed to the design of “smart” machines and other forms of artificial intelligence.
 - **Life in Extreme Environments:** Recent discoveries have revealed bacteria living in corroded and leaking tanks containing highly radioactive waste at the Department of Energy Savannah River Site. It was previously assumed that microbial growth was not possible in such an environment of high radioactivity, heat, and alkaline pH. In future work, the investigators propose to culture, identify, and investigate properties of the microbes discovered. This discovery and study has immediate and substantial significance for the safe, long-term storage of radioactive wastes, and may yield important insight into fundamental mechanisms that allow organisms to adapt to extreme environments.
 - **Advances in Nanoscience and Engineering:** A new type of atomic force microscope recently developed will enable direct writing on surfaces at nanometer scale resolution – more than 1 billion times smaller than an inch. This method promises to be a tool for nanoelectronics, molecular electronics, and biological applications. In nanoscience and engineering research, nanometer-sized metallic dots linked by conducting organic molecules have been synthesized toward the path of molecular electronics. Nanomagnets in large arrays and nanocapacitors have been fabricated to dramatically improve information storage systems. Nano-scale magnetic probes are also being developed to measure properties of particles important for device technology and techniques for DNA sequencing.

A young investigator in collaboration with industry and European scientists is making important progress in understanding the fundamental interactions at the nanoscale level between nanoparticle fillers and molecular chains use in making plastics. Understanding these nano-composites and how they work is important for producing new high-strength, low-cost materials, which are likely to find use in applications such as automotive parts, refrigerator liners, business, medical, and consumer equipment housings; recreational vehicles, appliances, pipes and fittings for building and construction industry.

- **Molecular Motors:** NSF supported researchers have developed models of a remarkable variety of molecular motors, the microscopic engines that drive most intracellular motions. Using mathematical and computational models and incorporating experimental data from many laboratories, they have been able to predict motor behaviors at a level that can distinguish between competing theories of how the underlying biological mechanisms work. The predictions in turn have been the impulse for further experiments by others – an example of the interplay between theory, computation, and experiment. The project provides web-accessible data, simulations, and visualizations that are easy for biologists to access and compare to ongoing experiments.
- **Global Change Studies of Glacial Rebound :** Projects using the Global Positioning System to measure vertical crust motion in Antarctica hold the promise of being key to calculating ice mass changes over the past several thousand years. Two competing approaches to the measurement use high tech methods to resolve this difficult but scientifically important problem – How much ice has the Antarctic ice sheet system lost since the last glacial maximum? Initial results are promising, but will require several years to complete a set of measurements to compare with predictions.
- **A High Risk Collaboration** linking academic engineering research with industry investigated a novel method for reducing volatile organic compound emissions in green sand metal castings. The result is successfully being demonstrated at the production level. The process reclaims much of the sand used in the metal casting process, which is a major waste-stream expense and it reduces undesired emissions.



Outcomes Relevant to Connections Between Discoveries and their use in Service to Society

- **From University Lab to Industry Practice:** A university engineer approached by industry to help improve manufacturing quality and reduce time to market has developed an open platform for machine tool control using standard software and hardware. NSF support through a series of awards led to more flexible and open controllers for machine tools; development of the first open architecture machine tools; and development of sensors, controllers, and other tools. These results have been picked up by government labs conducting research in these areas and may stand to benefit from these new tools. These tools allow for faster production, more flexibility, and more opportunity for on-machine inspection and quality control.
- **Innovative Bioengineering Advances:** An NSF supported bioengineer has been recognized by the National Academy of Engineering, the National Academy of Sciences, and the Institute of Medicine, for his accomplishments in the area of bioengineering based on his work on copolymers as matrices for the growth of tissues. This work has led to technology that has spawned an entire field of study and has developed into an industry aimed at cultivating human skin for diabetic skin ulcerations. The Food and Drug Administration has approved the use of the human skin produced through this technique. In yet another area, the same researcher has developed methods to use polymers to deliver drugs, for use in new treatments for some forms of brain cancer. The plastic coated drug is implanted as a small wafer at the time of surgery, and slowly releases a highly toxic drug directly to the tumor site.
- **Plant Genome Research:** In it's ninth year, NSF, the Department of Energy, and the US Department of Agriculture along with international collaborators, are nearing the completion of a project aimed at the first complete genome sequence of a plant. Using Arabidopsis as a model organism for studies of the biology of plants, knowledge generated from its genome sequence is readily applicable to all other plants. With about 80% of the genome sequence completed, the study has already contributed to new discoveries and potential applications to plant-based industries.

- **Knowledge and Distributed Intelligence:** NSF supported research groups have created a Web-based toolkit and research network that links collection databases distributed across 6 museums. Expected to expand to 40 institutions, this powerful database architecture allows investigators to tap millions of records of natural history specimens.

- **Increasing Profits:** NSF supported researchers have studied steel finishing lines owned by 21 American companies and three in Japan, to identify specific combinations of human resource practices associated with employee productivity and product quality. They have found quantitative evidence that one specific combination of quality management practices and participatory human resource management practices boosts these outcomes by between 7.5% and 13%. Only 10% of U.S. steel finishing lines use the high-performance system, although it is responsible for about a \$1.5 million in monthly profit in the firms that use it.

- **Communicating Research Results:** NSF funding supported the design, implementation, and incorporation of innovative tools for the electronic communication of research results. The electronic archives are now available to the entire physics and mathematics fields and to sectors of the biology and economics communities. The archive is an enormously successful endeavor that has speeded technical developments in many areas of research. It offers an electronic publishing platform for unrefereed publications that supplements the normal peer-reviewed publications. In August 1999 alone, there were nearly 600,000 connections to the archive alone.

- **Understanding Natural Environmental Processes:**
 - **Climate Dynamics:** NSF support for research in geography and regional science has produced a number of related advances in the understanding of natural environmental processes. For example, climate change frequently has not been gradual; rather, shifts from glacial to post-glacial environments apparently have taken only decades, not centuries as previously thought. Other evidence suggests that droughts as extensive as the Dust Bowl in the 1930s are more common than previously believed. Researchers have discovered connections between forest-fire occurrence in Argentina and El Nino-related atmospheric dynamics. Studies of historical hurricane landfall probabilities along the Gulf Coast have generated enormous media attention.

-
- **Global Change:** Research on policies dealing with global change is expanding, with obvious prospective benefits for abating the social costs of dealing with global warming. Recent results on the efficiency of alternative forms of emissions abatement are making contributions to long-term policy, as well as a better understanding of how rich and poor countries differ in their approach to handling environmental problems.

 - **Advancing Information Technology:**
 - NSF supported projects rapidly utilized in other sectors and demonstrating value to society include activities involving the early development of WWW search tools: Webcrawler (which is now Excite), Lycos, Infoseek, and the Library of Congress “Thomas” system for searching.

 - **Better Materials:** NSF-supported researchers have gained a fundamental understanding of a new class of ultra-high-strength cement based materials that have a fracture strength 50 times that of conventional concrete. Using NSF findings, a foreign industry built the body of a new solar car which received awards for its outstanding achievement as an earth-friendly, low-energy material. In a rally held in Japan, the low weight car averaged a speed of nearly 28 miles per hour over a distance of more than 300 miles. Italian industry is commercializing the material for use as cladding panels.

 - **Students Doing Hands-on Research:** An NSF supported project allows students to view on-line actual astronomical images and to extract information from them in the same way professional astronomers do. Teaching thousands of students the basic principles of astronomy, it has enabled students to take part in the discovery of a supernova and an asteroid.

 - **Take Another Look** - an exhibit disseminated to nine sites that has reached 1.5 million visitors. Its purpose is to develop powers of observation in children and adults, with the target audience being parents, teachers, and children ages 2-10. One interesting finding demonstrated that parents were three times more likely to explain science to boys than to girls, while families were using interactive exhibits. The findings have been widely disseminated through articles and presentations to encourage further development.



Examples of Outcomes Relevant to A Diverse, Globally-oriented Workforce of Scientists and Engineers

- Collaborative teacher preparation programs enrolled nearly 74,000 undergraduates and post-baccalaureate students (58% females; 30% underrepresented groups) in courses supported by the NSF program.
- More than 60,000 teachers were part of local school reform projects from 1995 to 1999 that NSF supported. Seventeen percent were African American or Hispanic.
- In an NSF-supported educational program, institutions conferred more than 20,000 degrees to underrepresented minorities in science and engineering in 1998, representing sustained progress toward the program goal of doubling minority baccalaureate degree recipients in the program.
- **Careers in Marine Science:** An NSF funded project is a national effort to provide research experience and mentoring for minority students in ocean sciences. The participant group has been diverse, consisting of 70 percent African-Americans, 21 percent Hispanic-Americans, 3 percent Pacific Islanders, and 6 percent Native Americans. Students from more than 100 different institutions have participated in the past ten years, with 31 different colleges and universities in the 1999 program alone.
- **NSF-supported Research Experiences for Undergraduates:** NSF invests in many efforts to bring young students closer to actual research experiences. One of the largest efforts in the Foundation for one field of science involves support for 55 sites in 36 states, at which about 600 students are supported each summer. Typically half the participants are female, and over sixteen percent are from underrepresented groups. In a similar program for another field of science, over 1,200 undergraduates receive hands-on experience each year. Some of these efforts provide unique international experiences for students. Many of the participants are recognized as co-authors on papers resulting from their involvement. Such programs introduce students at an early stage in their career to important approaches and concepts outside their traditional experiences.

- **International Partnerships:**

- NSF funds are used to support many international collaborations. One involving three European partners is trying to repress zebra mussels, which pose a huge environmental threat to the Great Lakes and possibly the Chesapeake Bay. These tiny mussels, which clog valves on ships, power plants, and water supplies, originated in Belarus, Ukraine, and Russia, where the research projects are collecting data on their habitats and life cycle. This information is helping to develop methods of controlling these extremely costly infestations. Without a coordinated international approach, this progress would not be possible.
- At an NSF supported international research site for undergraduates in Tanzania, U.S. undergraduates learn fundamentals of biological and geological processes related to tropical lakes. Their research and the associated education relates to global change processes, including early warning signs of freshwater ecological change.



Examples of Outcomes Relevant to Improved Achievement in Mathematics and Science Skills Needed by all Americans

- **Instructional Materials Developed with NSF Support:** Of 12 middle school mathematics textbooks subjected to rigorous analysis by the American Association for the Advancement of Science, only the 4 supported by NSF received high ratings.
- **Gains in K-12 Student Performance Reported:** In Puerto Rico national and international mathematics and science assessments administered in grades 4, 8, and 11 show overall that students performance in mathematics and science was significantly higher at those high schools with students exposed to the NSF supported activities, compared to the performance of high schools whose students had not had such exposure.
- The 1998 Connecticut Mastery Test results confirmed continuing improvement in student mathematics performance from 1993 to 1998 in that state: in grade 4, the percentage of students meeting performance goals improved from 53% to 61%; grade 6 student performance increased from 44% meeting goals to 53%; and grade 8 growth moved from 46% meeting goals to 56%.
- Detroit students showed significant gains in the percentage of students performing at the highest level in science and mathematics on the Michigan Educational Assessment Program between 1994 and 1998: (1) grade 5 science – an increase from 18% to 33%; (2) grade 7 mathematics – an increase from 16% to 33%; and (3) grade 4 mathematics – an increase from 33% to 65%.

