# 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:***

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Professor of Physics and Astronomy
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Population Council

**Ed Getty**
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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

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- 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.

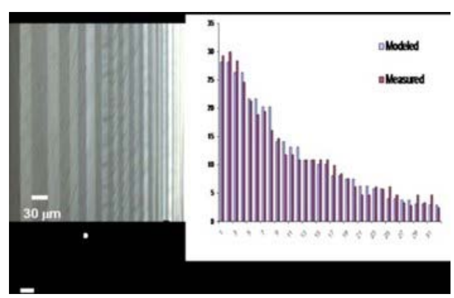
The first live feed video images from deep in the ocean have been received from the Eye-in-the-Sea (EITS), an instrument designed to provide uninterrupted and unobtrusive observation of life in the deep-sea for the first time. (***First Live Feed Video Images Received from Eye-in-the-Sea (EITS) Deep 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).

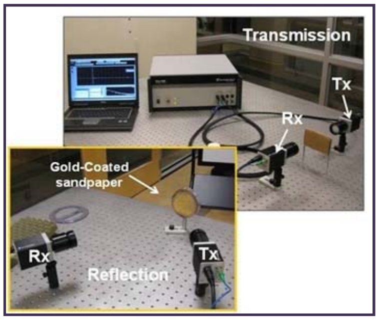
**NSF investments enable discoveries on very small spatial and temporal scales:**

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.

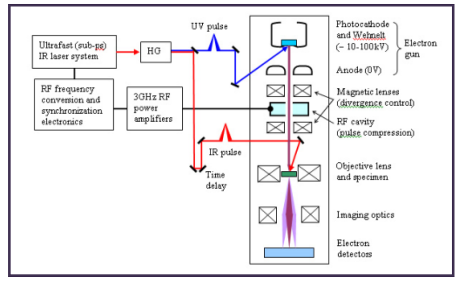


Gradient films with thicker, micrometer-scale layers are currently under investigation for membrane and controlled-release applications.




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