CHAPTER 5
LEARNING AND WORKFORCE DEVELOPMENT (2006-2010)

I. Cyberinfrastructure and Learning

Cyberinfrastructure moves us beyond the old-school model of teachers/students and classrooms/labs. Ubiquitous learning environments now will encompass classrooms, laboratories, libraries, galleries, museums, zoos, workplaces, homes and many other locations. Under this transformation, well-established components of education—pre-school, K-12 and post-secondary—become highly leveraged elements of a more open learning world where people learn as a routine part of life, throughout their lives.

Cyberinfrastructure is enabling powerful opportunities: i) to collaborate, ii) to model and visualize complex scientific and engineering concepts, iii) to create and discover scientific and educational resources for use in a variety of settings, both formal and informal, iv) to assess learning gains, and v) to personalize learning environments. These changes both demand and support a new level of technical competence in the science and engineering workforce and in our citizenry at large. Imagine an interdisciplinary course in the design and construction of large public works projects, attracting student-faculty teams from different engineering disciplines, urban planning, environmental science, and economics; and from around the globe. To develop their understanding, the students combine relatively small self-contained digital simulations that capture both simple behavior and geometry to model more complex scientific and engineering phenomena. Modules share inputs and outputs and otherwise interoperate. These "building blocks" maintain sensitivity across multiple scales of phenomena. For example, component models of transportation subsystems from one site combine with structural and geotechnical models from other collections to simulate dynamic loading within a complex bridge and tunnel environment. Computational models from faculty research efforts are used to generate numerical data sets for comparison with data from physical observations of real transportation systems obtained from various (international) locations via access to remote instrumentation. Furthermore, learners explore influences on air quality and tap into the expertise of practicing environmental scientists through either real-time or asynchronous communication. This networked learning environment increases the impact and accessibility of all resources by allowing students to search for and discover content, to assemble curricular and learning modules from component pieces in a flexible manner, and to communicate and collaborate with others, leading to a deep change in the relationship between students and knowledge. Indeed, students experience the profound changes in the practice of science and engineering and the nature of inquiry that cyberinfrastructure provokes.

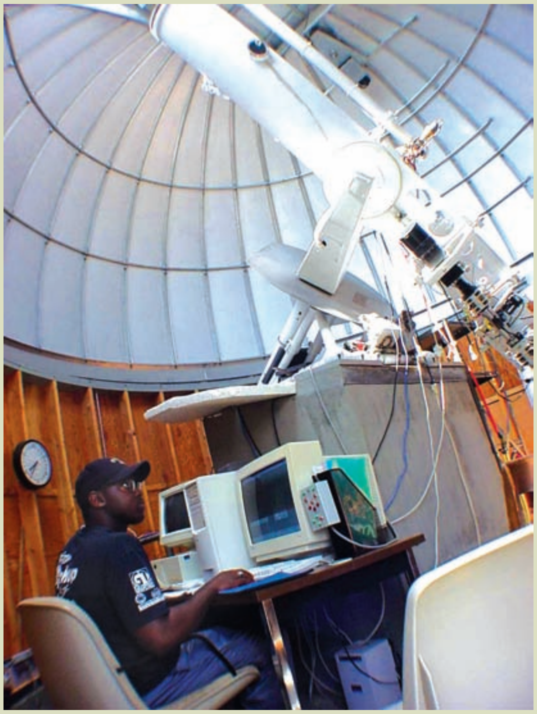
II. Building Capacity for Creation and Use of Cyberinfrastructure

To realize these radical changes in the processes of learning and discovery, networked resources also demand a new level of technical competence from the nation's workforce and citizenry. Indeed, NSF envisions a spectrum of new learning needs and activities demanded by individuals, from future researchers, to members of the technical cyberinfrastructure workforce, to the citizen at large.

As cyberinfrastructure tools grow more accessible, students at the secondary school and undergraduate levels increasingly use them in their learning endeavors, in many cases serving as early adopters of emergent cyberinfrastructure. Already, these tools facilitate communication across disciplinary, organizational, and international and cultural barriers, and their use is characteristic of the new globally-engaged researcher. Moreover, the new tools and functionality of cyberinfrastruc-

Weather recording equipment used in Jornada Range studies is part of the LTER Network, involving more than 1800 scientists and students at 26 different sites investigating ecological processes over long temporal and broad spatial scales. These researchers in southern New Mexico are studying the causes and consequences of desertification.

ture are transforming the very nature of scientific inquiry and scholarship. New methods to observe and to acquire data, manipulate it, and represent it, challenge the traditional discipline-based graduate curricula. Increasingly the tools of cyberinfrastructure must be incorporated within the context of interdisciplinary research. Indeed, these tools and approaches are helping to make possible new methods of inquiry that allow understanding in one area of science to promote insight in another, thus defining new interdisciplinary areas of research reflecting the complex nature of modern science and engineering problems. Furthermore, as data are increasingly "born digital," the ephemeral nature of data sources themselves raises new dimensions on the issues of preservation and stewardship.



Undergraduate students participate in research projects in solar and space physics using remote and local facilities such as the Prairie View Solar Observatory.

To employ the tools and capabilities of cyberinfrastructure-enabled learning environments effectively, teachers and faculty must also have continued professional development opportunities. For example, teachers and faculty must learn to use new assessment techniques and practices enabled by cyberinfrastructure, including the tailoring of feedback to the individual, and the creation of personalized portfolios of student learning that capture a record of conceptual learning gains over time. Undergraduate curricula must also be reinvented to exploit emerging cyberinfrastructure capabilities. The full engagement of students is vitally important since they are in a special position to inspire future students with the excitement and understanding of cyberinfrastructure-enabled scientific inquiry and learning.

Ongoing attention must be paid to the education of the professionals who will support, deploy, develop, and design current and emerging cyberinfrastructure. For example, the increased emphasis on "data rich" scientific inquiry has revealed serious needs for "digital data management" or data curation professionals. Such careers may involve the development of new, hybrid degree programs that marry the study of library science with a scientific discipline. Similarly, the power that visualization and other presentation technologies bring to the interpretation of data may call for specialized career opportunities that pair the graphic arts with a science or engineering discipline.

Cyberinfrastucture's impact on the conduct of business demands that members of the workforce have the capability at least to refresh if not also retool their skills. In some cases the maintenance of formal professional certifications to practice is a driver, and in other cases the need for continual workplace learning is driven by pressures to remain competitive and/or relevant to a sector's needs. Adequate cyberinfrastructure must be present to support such intentional workforce development.

Cyberinfrastructure extends the impact of science to citizens at large by enhancing communication about scientific inquiry and outcomes to the lay public. Such informal learning opportunities answer numerous needs, including those of parents involved with their children's schooling and adults involved with community development needs that have scientific dimensions. Moreover, cyberinfrastructure enables lifelong learning opportunities as it supports the direct involvement by citizens in distributed scientific inquiry such as contributing to the digital sky survey.

III. Using Cyberinfrastructure to Enhance Learning

Just as cyberinfrastructure changes the needs and roles of the individual learner, NSF also envisions it changing the organizational enterprise of learning. Two intertwined assumptions underlie this vision. First, "online" will be the dominant operating mode for individuals, characterizing how individuals interact with educational resources and complementing how they interact with each other. Second, ubiquitous (or pervasive) CI will extend awareness of our physical and social environment, with embedded smart sensors and "device to device" communication becoming the norm. Moreover, the shift from wired to wireless will untether the learner from fixed formal educational settings and enable "on demand/on location" learning whether at home, in the field, in the laboratory, or at the worksite, locally or across the globe.

These conditions permit new learning organizations to form, raising in turn new research questions about the creation, operation, and persistence of communities of practice and learning. In such cyberlearning networks people will connect to learn with each other, even as they learn to connect with each other, to exploit increasingly shared knowledge and engage in participatory inquiry. Cyberinfrastructure is also a driving movement to more open educational resources, for example, the growing Open Courseware project now includes over a hundred international universities.

The JASON Project uses cyberinfrastructure to connect middle school students with great explorers and great events to inspire and motivate them to learn science.

To support this vision of (massively) networked learning, cyberinfrastructure must be adaptive and agile – in short, a dynamic ecosystem that supports interactive, participatory modes of learning and inquiry, and that can respond flexibly to the infusion of new technology.

IV. The Next Five Years: Learning About and With Cyberinfrastructure

NSF's five-year goals are as follows:

- To foster the broad deployment and utilization of Cyberinfrastructure-enabled learning and research environments.
- To support the development of new skills and professions needed for full realization of CI-enabled opportunities.
- To promote broad participation of underserved groups, communities and institutions, both as creators and users of CI.
- To stimulate new developments and continual improvements of cyberinfrastructure-enabled learning and research environments.
- To facilitate cyberinfrastructure-enabled lifelong learning opportunities ranging from the enhancement of public understanding of science to meeting the needs of the workforce seeking continuing professional development.

The following principles will guide the agency's FY 2006 through FY 2010 investments:

- Equitable and broad access to state-of-the-art networked resources is essential.
- To achieve widespread use of cyberinfrastructure by science and engineering researchers, educators, and learners, efficient methods must exist to find, access and use cyberinfrastructure resources, tools, and services as well as the educational materials associated with them.
- The privacy, social, cultural, ethical and ownership issues associated with increasing use of cyberinfrastructure for learning, research and scholarship must be addressed.
- Learning and workforce development opportunities contribute to cyberinfrastructure developments.
- Cyberinfrastructure developments will lead to new learning models necessary for lifelong

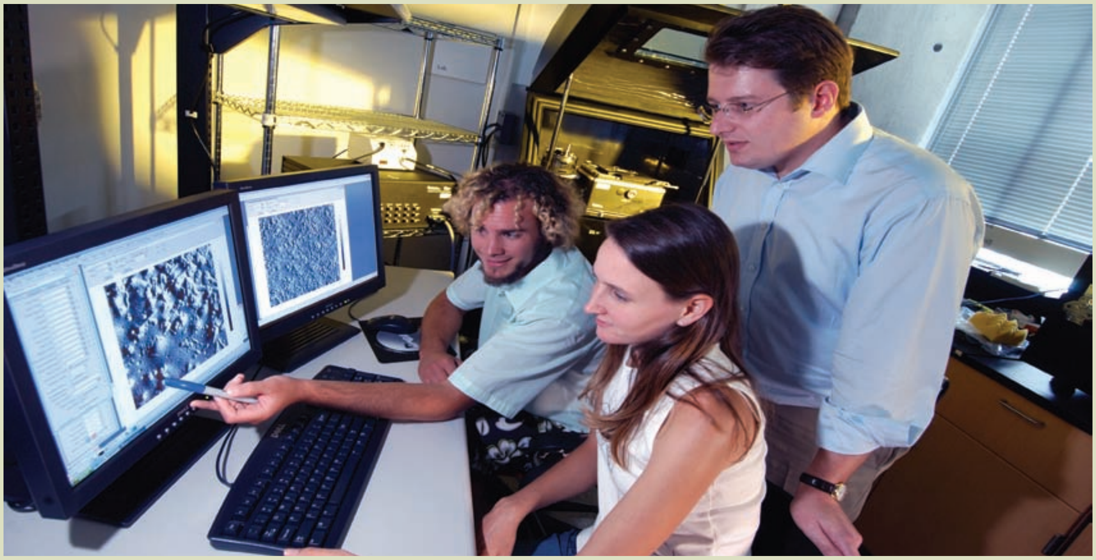
learning in the distributed and networked learning environment.

- Leveraging cyberinfrastructure LWD activities and investments within NSF and by other agencies – national and international – are essential for enabling 21st century science and engineering.
- Scientists and engineers must be prepared to collaborate across disciplinary, institutional, geopolitical and cultural boundaries using cyberinfrastructure-mediated tools.

Current and future generations of scientists, engineers and educators will utilize cyberinfrastructure-enabled learning and research environments for their formal and informal educational training, research projects, career development and lifelong learning. Therefore, NSF will develop and implement strategies for their deployment and utilization. To do so, NSF will stimulate awareness of cyberinfrastructure-enabled learning and research environments for scientists, engineers and educators; enhance usability and adaptability of cyberinfrastructure-enabled learning and research environments for current and future generations of scientists, engineers and educators both nationally and internationally; promote new approaches to and integration of cyberinfrastructure-enabled learning and research environments for educational and research usage nationally and internationally; and foster incorporation of solutions for addressing privacy, ethical and social issues in cyberinfrastructure-enabled learning and research environments.

It is very likely that new disciplines will develop as a natural outgrowth of the advances in cyberinfrastructure. NSF will be an enabler in developing the workforce in these newly-formed disciplines. These disciplines could be as important as the relatively new disciplines of computer science, mathematical biology, genomics, environmental sciences and astrophysics are today. NSF will support mechanisms for development of new cyberinfrastructure-related curricula at all levels; stimulate partnerships – domestic and international – between and among academic institutions and industrial cyberinfrastructure-professionals, and support the wide dissemination of "best practices" in cyberinfrastructure workforce development.

Cyberinfrastructure has the potential to enable a larger and more diverse set of individuals and institutions to participate in science and engineering education, research and innovation. To realize this potential, NSF will strategically design and implement programs that recognize the needs of those who might not have the means to utilize CI in science and engineering research and education. To do so, NSF will identify and address barriers to utilization of cyberinfrastructure tools and

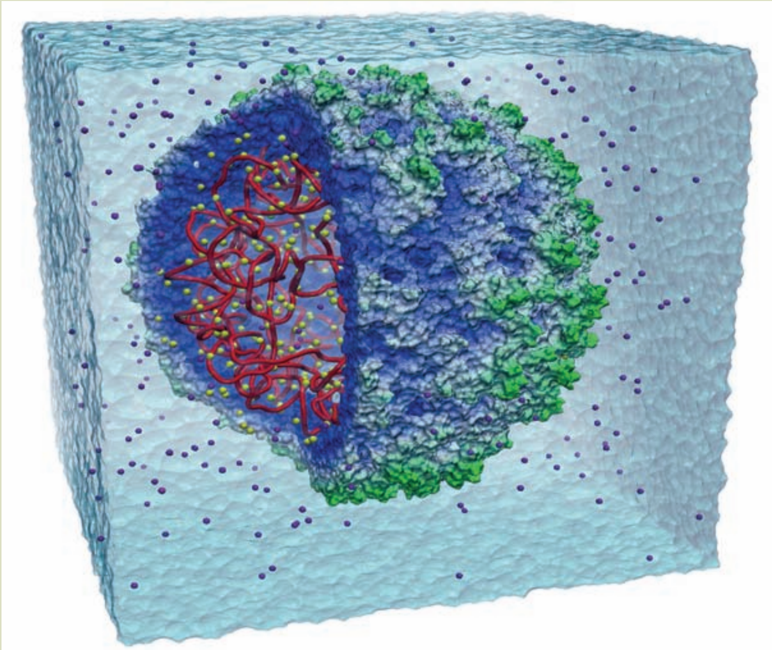


Georgia Institute of Technology and NRL researchers have developed improved methods for directly writing nanometer-scale patterns onto a variety of surfaces. Atomic force microscopy generated images are used to analyze nanometer-scale structures.

resources; promote the training of faculty, particularly those in minority-serving institutions, predominantly undergraduate institutions and community colleges; and encourage programs to integrate innovative methods of teaching and learning using cybertools (particularly in inner-city, rural and remote classrooms), including taking advantage of international networked resources to prepare a globally engaged workforce.

In the dynamic environment of cyberinfrastructure-enabled learning and research, NSF will facilitate new developments as well as continuous improvements of the currently available tools and services, including those for education and training. NSF will support research that increases understanding of how students, teachers, scientists and engineers work and learn in a cyberinfrastructure rich environment, for example, interactive gaming, simulation and modeling (as opposed to conventional instruction methods). The agency will support the development of methods to embed relevant data collection and analysis tools in cyberinfrastructure-based environments in order to assess, for example, satisfaction, usability, utility, productivity, etc., as well as the development of specific means for tracking student progress in content-based cyberinfrastructure learning; promote the development of technological solutions for addressing privacy, ethical and social issues in cyberinfrastructure-enabled learning and research environments; and stimulate both domestic and international partnerships to identify best practices in cyberinfrastructure enabled learning and research environments.

Lifelong learning, through both formal and informal mechanisms, will be an essential part of the workforce of a cyberinfrastructure-enabled society. NSF can play a crucial role by promoting and sustaining programs that exploit existing resources and encourage creation of new resources in order to continually improve the science literacy of society in general and of the science and engineering workforce in particular. NSF will support mechanisms for professionals to continuously update their cyberinfrastructure skills and competencies; catalyze the development of new lifelong learning networked resources; promote new knowledge communities and networks that take advantage of cyberinfrastructure to provide new learning experiences; support programs that bridge pre- and post-professional (lifelong) learning; and encourage programs that promote public awareness of, and literacy in, cyberinfrastructure.



A visualization of the changing structure of the satellite tobacco mosaic virus is produced on the NCSA Cobalt System by calculating how each of the one million atoms interacted with each other every femtosecond.