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National Science Foundation, Directorate for Education and Human Resources

synergy

working together to revitalize science, mathematics, engineering, & technology education

Using Technology to Reform Teaching & Learning

Last spring, students at a half-dozen Maryland high schools collaborated over the Internet to identify the epicenter of a simulated earthquake. Each school, acting as an independent seismograph station, downloaded data devised to reflect its distance from an unknown earthquake site within the state. Armed only with their own geophysical data, no one school by itself had enough information to determine the hypothetical quake's center. But by exchanging and graphing the data among themselves, the students used the differences in time between the recorded shock waves at each of the six sites to triangulate the distances and successfully identify the fictitious epicenter.

This innovative experiment challenges dozens of young people, studying in separate locales linked through technology, to work together in

CONTINUED ON PAGE 3

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synergy

About Synergy

Synergy is a publication about programs of the National Science Foundation's Directorate for Education and Human Resources (EHR). Each ***Synergy*** issue highlights an EHR activity that demonstrates progress in reforming the teaching and learning of science, mathematics, engineering, or technology, from prekindergarten through career entry. The "synergy" derives from NSF working in partnership with organizations in all sectors of the economy, throughout the United States, to help foster the positive changes in education to which NSF is dedicated. The ingredients of these success stories are unchanging: access to quality science and mathematics education, high expectations for success, proven excellence of materials, and measurable gains in learning by all students.

In this Issue...

Synergy examines how technology can improve instruction and learning in science and mathematics. Exciting and dynamic forces of change are being unleashed across the nation wherever technology is being well-integrated into the curriculum. The EHR-sponsored projects described in this issue illustrate not only the range of ways technology can be used to improve learning, but also the host of learning settings that are benefited by its presence. Technology is greatly increasing students' ability to understand and learn complex material; it is inspiring revolutionary changes in classrooms, schools, and entire school systems.

COVER PHOTO BY WILLIAM MILLS•MONTGOMERY COUNTY PUBLIC SCHOOLS•MARYLAND

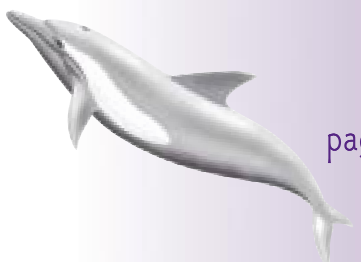
a shared learning activity. The project was designed by members of the ***Maryland Virtual High School of Science and Mathematics (MVHS)*** and funded by the National Science Foundation (NSF). Currently in progress at 15 Maryland high schools, the project is slated for expansion throughout Maryland, with participants envisioning its eventual replication in other areas of the United States.

> "Modeling activities have helped teachers and students to more critically consider relationships between theory and experimentation. They have raised the level of question-asking."

MVHS's primary goal, says Mary Ellen Verona, the project's principal investigator (PI), has been to enhance students' knowledge of science and the scientific process through the infusion of computational experiments into high school science curricula. Central to the concept is the establishment of "virtual" classrooms—groups of students united through communication technologies to share in research projects that have been collaboratively designed by the students and their instructors with the help of content experts.

The simulated earthquake experiment is but one of many virtual classroom endeavors designed by MVHS participants. Using real data, other projects have focused on the analysis of dissolved particulates in our drinking water; the measurement of carbon dioxide in the air we breathe; and the detection of pollutants in our streams and rivers. While the process of such experiments is fascinating to everyone involved, the improvement in quantitative skills of participating students has been especially gratifying. MVHS teacher, Don Shaffer, of North East High School, located near Baltimore, reports that his students who took part in the earthquake experiment "have taken a quantum leap in their abilities to problem-solve, perform simple computations accurately, work with maps and scales, and use computers—from spreadsheets and graphing programs, to sending e-mail and searching the Internet."

In pursuing their goals, Mary Ellen Verona and her colleagues have witnessed several signs of intellectual growth among participating science students that bode well for their



ScienceWare…

Supported by an AAT grant, researchers at the University of Michigan have developed a suite of software tools—called *ScienceWare*—that supports middle and high school students in carrying out a wide variety of sophisticated scientific investigations entailing project planning, data gathering and analysis, visualizing and modeling data sets, and creating multimedia presentations. An especially stimulating *ScienceWare* module is Web-It, a program that automatically translates documents—reports, data models, and so forth—into a format that enables students to publish their findings on the Internet. The software, according to PI Elliot Soloway, provides the students with the "scaffolding" necessary to engage in increasingly complex tasks as their skills and understanding progressively mature.

Recently, 9th and 10th graders who used the software at Community High School in Ann Arbor, Michigan, scored 15 points higher than the national average on a 12th grade standardized science test. Moreover, says Soloway, "We have found that students' attitude toward science dramatically improved over a semester, compared with students taking a traditional class." He points out that the new National Science Education Standards call for "authentic science inquiry" as an essential component of the curriculum. Using *ScienceWare* to model and analyze complex systems and reason about causes and effects, says Soloway, "brings the tools and methods of professional scientists into the realm of understanding of high school students."

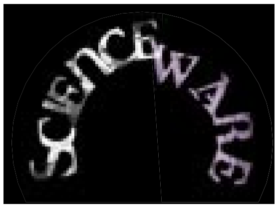
academic futures in general. For example, she says, "Implementation of successful collaborative science projects has brought about an understanding among students of a team approach to science, as well as a better understanding of problems in controlling variables while collecting data. And modeling activities have helped teachers and students to more critically consider relationships between theory and experimentation. They have raised the level of question-asking."

Furthermore, Verona notes, the MVHS project has become an effective tool for honing the pedagogical skills of participating teachers. She points out, for example, that an appreciation for the value of "Internetworking" has grown not only among students, but also among administrators and teachers, and that the cooperative process that shapes the experiments enables instructors to learn as well as teach. Linda Davis, a computer science and mathematics instructor at James M. Bennett High School in Salisbury, Maryland, agrees, saying: "Working with this group of kids has been one of the most interesting and rewarding experiences of my teaching career. We all teach one another."

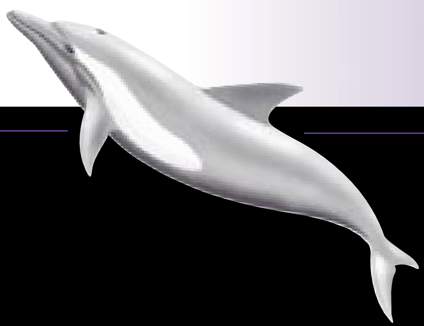
Above all, Verona believes, the project has helped participating students learn to "think for themselves." "In many situations," she says, "students were in the habit of uncritically accepting information obtained from so-called authorities, such as textbooks and teachers. Now, students are understanding that the information we have about many natural phenomena is incomplete and sometimes contradictory—that authorities often disagree. This is important to the public, since the United States needs a citizenry that questions how scientists project such things as environmental effects or epidemic outbreaks."

Risk-Taking Research

During the past two decades, NSF has supported the Maryland project and hundreds of other innovative efforts throughout the country designed to explore the potential of new learning technologies and ways to incorporate them with maximum impact into every area of our educational system. Leading this effort is NSF's Directorate for Education and Human Resources (EHR), the branch of the Foundation specifically charged with promoting science and mathematics education in the United States, from prekindergarten through college. Since 1984, EHR has funded risk-taking research on technology and cognition in science and mathematics and, in partnership with other NSF directorates, has participated in a variety of undertakings designed to advance understanding in such areas as mathematical thinking, human-computer interaction, intelligent systems, and information technology infrastructure.



Two EHR programs have embodied this commitment. In 1984, ***Applications of Advanced Technologies (AAT)*** was launched to support the research and development of innovative technologies that further the learning and teaching of science and mathematics. It has focused on altering what is taught as the result of the technology's ability to represent and manipulate concepts and scientific and mathematical information. The achievements of the Maryland Virtual High School—an AAT-sponsored endeavor—is a striking example of the program's



Union City Online…

A remarkable transformation has taken place in the Union City, New Jersey, school system, under a project called *Union City Online: An Architecture for Networking and Reform.* This ambitious effort is supported by NIE in partnership with a number of civic organizations and business enterprises, most notably Bell Atlantic-New Jersey. Less than a decade ago, the city's school system—serving the most densely populated urban area in the United States—was in danger of being taken over by the state owing to its impoverished, ill-equipped schools, low-performing students, and alarmingly high student dropout rates and absenteeism. A massive effort was launched to remedy the bleak situation through systemwide reform, with the seeding of technology playing a key role in the attempt to improve academic performance and curb the soaring transience of its predominantly Latino student population. During the past six years, approximately 1,500 computers have been installed in the district — a 5-to-1 ratio of students to computers. Each of the district's 11 schools has a lab with approximately 25 student machines networked through Ethernet; and more than 50 percent of the district's classrooms have at least one computer.

Today, the technology-enriched students of Union City are scoring higher than the state average. Moreover, the school system is now experiencing significant declines in absenteeism, a steady rise in the number of students transferring into its schools, and a marked decline in the number transferring out. The NIE-supported effort is building on this climate of innovation by contributing to the creation of an extensive networking infrastructure that will make Union City the most comprehensively "wired" urban school district in the United States. Computers are being

success. Then in 1993, ***Networking Infrastructure for Education (NIE)*** was established by EHR in conjunction with NSF's Directorate for Computer and Information Science and Engineering (CISE). NIE's mission has centered on hastening the use of computer and communications technologies in schools to reform science and mathematics education by bringing individual areas of technological and educational expertise together, seeking ways to scale-up advances, and exploring methods of facilitating their widespread implementation. Among notable NIE-supported efforts is a project called ***New Jersey Networking Infrastructure for Education,*** through which 500 state schools have been networked as part of a statewide initiative to empower teachers and to enhance student learning.

Both programs—administered by EHR's Division of Research, Evaluation and Communication—were conceived on the premise that, if society is to continue to benefit from the rapid expansion of new knowledge, improvements are needed in the process of using this ever-growing volume of knowledge. Better ways must be devised to expand human capacity to deal with the increased information; to expand the power of human reasoning to cope with the increasing complexity of science; to develop ways to compensate for human limitations; and to enhance the ability of humans to convert data into information, information into knowledge, and knowledge into practice.

Although AAT and NIE were designed to have impact on a national scale, many projects began by targeting states, cities, rural areas, or even individual schools and classrooms. Both programs address long-range opportunities rather than short-term problems. Their projects further systemic reform in science and mathematics education on a national scale and reflect EHR's goal of helping all students learn complex science and mathematics content.

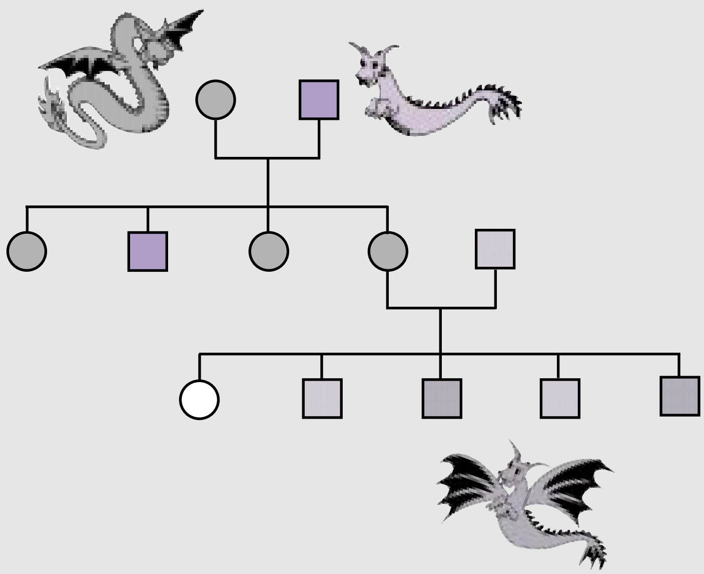
With the help of an NIE grant, an extraordinary project is developing in Denver, Colorado. Although only a small fraction of the overall research on the integration of technology and education focuses on the elementary level, the impact of distance education and interactive networks on K-4 learning and teaching is precisely the emphasis of the Denver project. In addition to demonstrating that very young children can adapt to the use of sophisticated computing and communications devices in the classroom, the researchers have implemented their distance delivery projects in Spanish as well as English, thereby serving the school's large Latino population. Moreover, since the grant funds had to be shared by a variety of teachers, with correspondingly varied interests, the project's goal of transforming pedagogical methods and curriculum at the school was enriched by faculty-wide collaboration.

linked in classrooms, libraries, computer rooms, teachers' homes, and—to support the already increasing involvement of Union City parents in their children's education—in homes and public libraries as well. The project, reports PI Margaret Honey, also is cultivating the necessary human infrastructure through extensive teacher, student, parent, and administrator training. A broad agenda of activities includes the support of teachers in integrating Internet resources into their curricula and provides for the dissemination of project outcomes for application at state and national levels.

Using Technology to Reform Teaching & Learning…

GenScope. . .

Supported by AAT, researchers at Bolt Beranek and Newman Inc., a Cambridge, Massachusetts, software development firm, have been investigating the use of innovative educational technology for improving the teaching of genetics to middle school and high school students. "Genetics is a particularly difficult topic to teach," says PI Paul Horwitz, "because it involves complex interrelationships of processes that occur at different levels. To make matters worse, many of these processes are not directly observable because they take place too quickly or slowly, or on a scale that is too small or too large." Central to this exploration has been the creation of *GenScope,* a software program that uses fictitious dragons as a basis for manipulating genetics at six levels of description dealing with, respectively, molecules, chromosomes, cells, organisms, pedigrees, and populations.



Another NSF-funded venture is helping Native Americans connect to the Internet for educational activities offered by five tribally controlled community colleges in North Dakota. Meanwhile, at Cornell University in Ithaca, New York, NIE is supporting the analysis, from an economic perspective, of case studies of the Foundation's Statewide Systemic Initiatives for educational reform in New Jersey, Virginia, and Vermont. This program focuses on the implementation of technology—and the impact of that implementation—on education in those three states. And in Memphis, Tennessee, grant recipients are examining the use of networking as a means of delivering previously unavailable educational resources to the community by connecting universities, K-12 schools, a city housing project, senior citizens groups, libraries, and a medical school.

Pedagogical Implications

Recognizing the clear need for the incorporation of advanced technology into classrooms, Dr. Nora H. Sabelli,

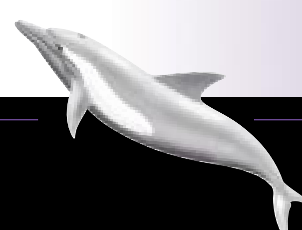
director of EHR's technology initiatives, asserts that "As the affordability of powerful microcomputers and network connectivity increases, educators become responsible for exploring the profound pedagogical implications of the changes brought about by technology on the practice of science and engineering. One nontrivial reason for this exploration is that, properly used, technology can help make science more understandable and attractive to the increasingly large numbers of students and future citizens now lost to its joys… Research and experimentation are needed to help understand how technology can achieve in education the same paradigmatic changes it has introduced in the practice of science, mathematics, and engineering. These changes are defining the workplace that all students will join."

In 1995, NSF articulated a statement of principles on the subject of technology in the classroom in a document issued jointly with the U.S. Department of Education. The appropriate use of technology, the document noted, can be effective in improving teaching and instruction;

> "Technology can help make science more understandable and attractive to the increasingly large numbers of students and future citizens now lost to its joys."

Each level contains representations of the important biological processes appropriate to that level, as well as tools that enable students to "plug in" a variety of genetic scenarios and witness their impact on the fictitious creatures.

Horwitz and his colleagues have used *GenScope* at several urban and suburban schools in the Boston area, with both elementary- and secondary-level students. In one school, 5th graders are now solving genetics problems usually reserved for high school sophomores. But the most dramatic results, according to Horwitz, have been with the urban schools. The *GenScope* team presented the project to inner-city students, gave them challenging puzzles, and left them alone to solve them. Over the course of a few weeks, they watched these students become enthusiastic learners and take pride in their intellectual abilities.



Knowledge Integration Environment…

An AAT-sponsored project at the University of California, Berkeley, is using the Internet as a means to instill in students a lifelong love of science and scientific research. The project, *Knowledge Integration Environment (KIE),* combines scientific content, pedagogical supports for teachers, and software to form a powerful instructional framework. Augmented with Internet resources, the project guides students in developing a cohesive, linked, and integrated understanding of scientific phenomena, from the nature of light to the evolution of dinosaurs. Under the leadership of PI Marcia Linn, the project team works with teachers in northern California middle school classrooms. Their efforts are based on evidence that students contend best with novel information

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expanding and enriching learning opportunities; supporting systemic educational reform; linking schools and learning sites to the broader society; and providing equal access to educational opportunities.

Information technologies can provide tools that enable all learners, regardless of location and socioeconomic status, to access resources, information, experts, mentors, and colleagues. These technologies enable the integration of abstract and hands-on learning in the classroom, providing students with access to research methods previously available only to scientists and other professionals. Moreover, with technologically enhanced linkages between home and school, parents can become more actively involved in the education of their children and decisionmaking in their schools. At the same time, advanced communications tools can elevate the skills of teachers, allowing them instantaneous access, for example, to the latest developments in science

NSF Technology Initiatives

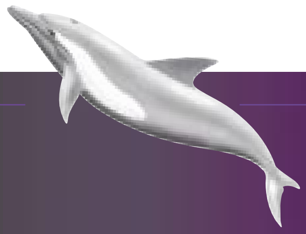
1984	1993	1996	1996	1997
Applications of Advanced Technologies (AAT)	Networking Infrastructure for Education (NIE)	Research in Education, Policy, and Practice (REPP)	Collaborative Research on Learning Technologies (CRLT)	Learning and Intelligent Systems (LIS)

and mathematics research, the education standards, instructional strategies, and a host of other information that will enhance their effectiveness.

Today, owing significantly to ambitious, innovative projects supported by the Foundation, we are witnessing a transformation in the way teachers teach and students learn. This change is at least as dramatic as the technology-spawned changes that are affecting every level and area of society at large. Experts in information technology are now cooperating with education experts to better understand how children learn and to develop appropriate new pedagogical techniques; computers are being used in new and exciting ways; children are learning more efficiently by interacting with software that corresponds to their individual paces and capabilities; and young students previously limited to the resources of their school library now have access to stores of knowledge in institutions throughout the world.

by adding new ideas to their existing repertoire of scientific knowledge. *KIE* learners develop scientific ideas from personal experience, school instruction, Internet exploration, and other activities. The project's software then guides the students in investigating those ideas and seeking a cohesive understanding of them.

KIE software includes a World Wide Web-based student discussion tool called SpeakEasy; a networked database of science information; tools for organizing evidence and constructing arguments; and a variety of other management and help tools. Using the software and related classroom activities, learners emulate such science practices as comparing theories, critiquing arguments, and designing problem solutions. Individual students, families, and school groups use *KIE* for personal as well as class activities. Teachers use the environment to add activities in new domains. And science experts participate as liaisons to develop Internet materials for the students.



WhaleNet . . .

Right whales, blue whales, seals, dolphins, and countless other creatures of the deep stand to benefit from the vigilant work of marine biologists at Boston's Wheelock and Simmons Colleges, whose efforts to tag, track, and monitor the travels and habits of such marine mammals are dedicated to their long-term survival. Benefiting also, are hundreds of thousands of young people in the United States and elsewhere around the world whose interest in science is being stimulated daily by their virtual participation in this ambitious conservation project, called *WhaleNet.* The project, carried out with support from NIE, was launched as a means of establishing a nationwide interactive education resource and research network. Today, *WhaleNet* involves communication and collaboration among students, scientists, and research organizations worldwide.

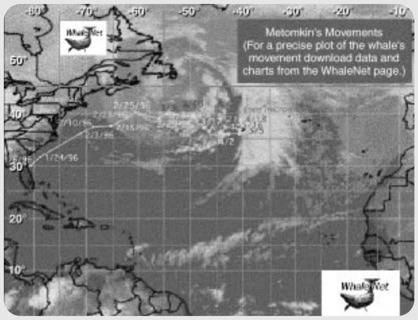
Future Directions

The extensive variety of projects supported by EHR over the years has dramatically enriched our understanding of the nature of learning, and we have also learned a great deal about how emerging computer and communications technologies may be most effectively exploited in science and mathematics education for all students, from prekindergarten through workforce entry and beyond. However, the gains achieved by these programs—significant as they have been—form but the basis for further exploration, a foundation for the ongoing pursuit of still newer knowledge. As EHR's Nora Sabelli puts it, "Only two or three years ago, technology was not a high priority. Now the spotlight is on technology in science and mathematics education. It is leading the way, and as the environment changes, NSF must be responsive and change its focus accordingly."

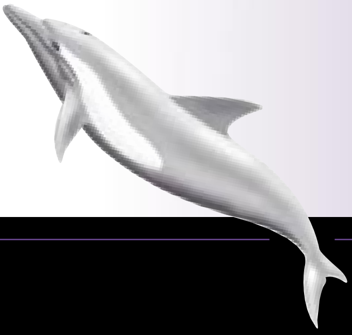
Thus, in keeping with its role as a catalytic agent for progress toward the enrichment of the nation's science and mathematics education, NSF is moving forward in building on the lessons learned from its programs. Today, NSF is repositioning itself with new and even more ambitious programs designed to explore the learning process and the use of technology-based infrastructures as a tool for sustainable education reform. As AAT and NIE are phased out, new initiatives already are in place to propel the acquired knowledge of the past onto higher, more refined levels of understanding. Two newly launched programs express NSF's goal of generating innovative research that shapes practices for increasing student learning in science and mathematics:

- ***Learning and Intelligent Systems (LIS).*** This program builds on research into learning and intelligent systems previously drawn from a wide variety of traditionally separate scientific disciplines. It uses the combined expertise of EHR and five discipline-specific NSF directorates covering the entire range of scientific, engineering, and information science fields. The initiative challenges interdisciplinary teams of researchers to address

The conservation effort is tailored to enhance students' education and interest in science, develop their critical thinking skills, and improve their problem-solving capabilities. Students participate in real-time interdisciplinary research by accessing data collected from the field and using electronic media to converse with working researchers. The use of communications technologies allows learners to collaborate with each other and with scientists and others around the world, thereby increasing exponentially their access to resources at minimal cost.



According to PI Michael Williamson, *WhaleNet's* popularity among students and educators has grown "phenomenally" during the past year. At last count, its web site was being accessed as frequently as 40,000 times a day by young "whale watchers" in more than 70 countries throughout the world.



with complex environments and with each other. An integral component of the LIS initiative is the *Collaborative Research on Learning Technologies (CRLT)* program. Its specific mission is to enrich the understanding of learning and to foster the application of

such matters as the ways learning and intelligent behavior occur in human and artificial systems and the kinds of knowledge that each system characteristically produces. It also focuses on ways to enhance human learning ability through methods and technologies—accessible to learners of all ages, backgrounds, and expectations—that integrate biological cognitive, linguistic, social, and educational concepts with interactive, collaborative, and multisensory technologies. The program will encourage collaborative studies in such diverse fields as artificial intelligence, cognitive development, cultural anthropology, education, neural science, and sociology. Accordingly, the ultimate goal is to stimulate the creation of learning systems, tools, and methods that can truly revolutionize how humans deal

technologies in all facets of education, both formal and informal.

• ***Research in Education, Policy, and Practice (REPP).*** This new EHR program seeks to increase the knowledge and resources devoted to science, mathematics, engineering, and technology learning and teaching throughout the life cycle of individual learners. However, it focuses on several aggregate areas of educational performance—classrooms, schools, and campuses; districts and consortia; states; regions; and the United States in an international context. As an instrument for furthering systemic reform in science and mathematics education through the effective incorporation of technology into pedagogical theory and practice, the REPP initiative addresses such themes as how tools that link individuals and institutions dispersed in space and across cultures can be used to teach and learn the changing content of science and mathematics; how the evolving capacity of computers and other technologies enables teachers to individualize instruction and students to engage in the processes of experimentation, understanding, and application of their newly acquired skills and content knowledge; and how high-performance computing and communications empower the effectiveness of educational administrators, policymakers, and researchers.

Although these new initiatives may be diverse in their specific objectives, management, and modes of operation, they are consistent in expressing EHR's vision of the vital role that research and technology must play in the modern school systems, colleges, and classrooms.

For the foreseeable future, the proliferation of newer, ever more powerful computing equipment, communications tools, scientific instrumentation, and countless other technologies and processes will increasingly influence all aspects of our professional and personal lives. Technology will continue to change the ways in which we work, think, and spend our leisure time—and every citizen must be prepared to cope with the dramatic transformation characterizing our entry into the 21st century.

NSF and its EHR directorate, striving to elevate knowledge and skills in all fields of science, mathematics, engineering, and technology, are committed to the task of equipping today's students for professionally productive and personally fulfilling lives in the challenging world of tomorrow.

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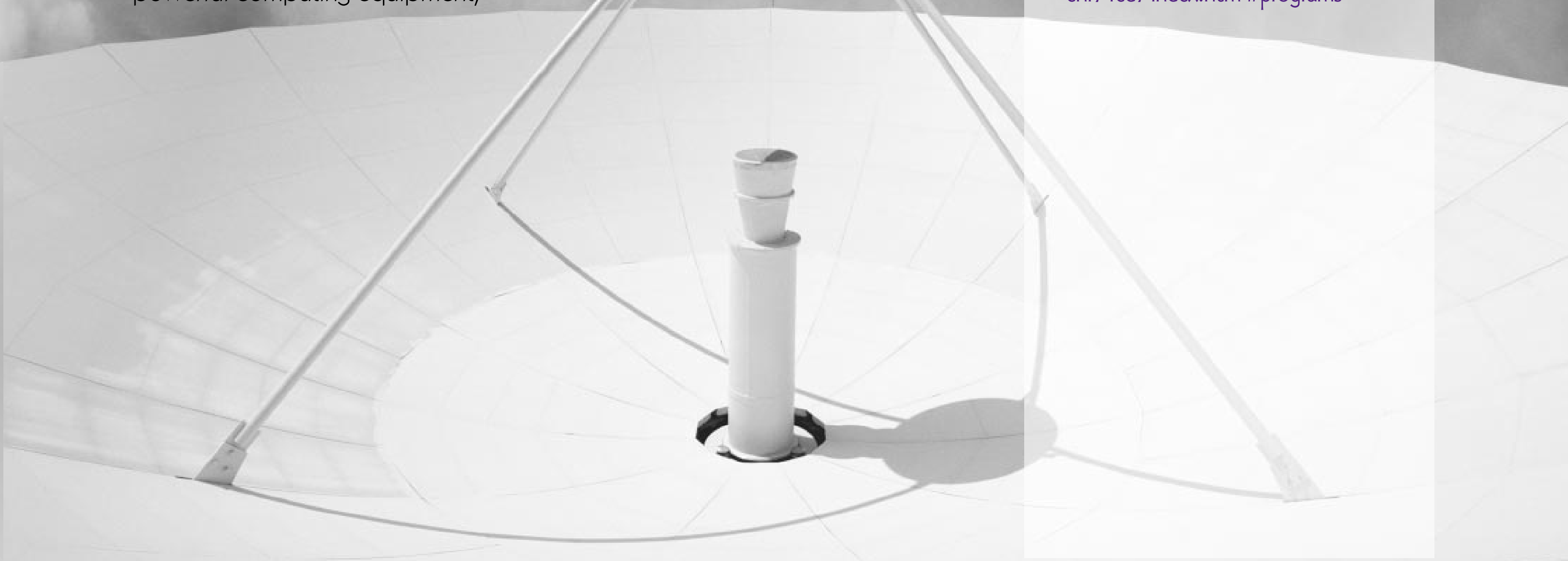
For more information on these programs, please contact NSF's Division of Research, Evaluation and Communication at 703•306•1650. Summaries of funded projects can be found on the World Wide Web at http://www.ehr.nsf.gov/ehr/red/index.htm#programs



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