New Challenges, New Strategies

Building Excellence in Undergraduate STEM Education

National Science Foundation
Transforming Undergraduate Education in Science, Technology, Engineering, and Mathematics (TUES)

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Formerly called the Course, Curriculum, and Laboratory Improvement (CCLI) Program

Contents

October 2009

Dear Friends of the Undergraduate STEM Community:

In the summer of 2008, the Directorate for Education and Human Resources at the National Science Foundation (NSF) sponsored the Principal Investigators' conference for the Course, Curriculum, and Laboratory Improvement (CCLI) Program. The conference highlighted the variety and innovation of projects supported through this program. CCLI reflects the mission and core values of NSF—research and education that is creative and visionary, enabling excellence in science, technology, engineering, and mathematics (STEM) undergraduate education.

This booklet reflects the spirit of the conference and the projects it showcased. While it was impossible to describe the more than 300 projects represented at the conference, we have tried to select a few representative projects in each of the categories funded by CCLI. These categories include curriculum development, implementing new instructional strategies, professional development, and assessment—all of which are necessary to develop an innovation and ensure that it can be sustained over time. Many CCLI projects also conduct research on the effectiveness of new learning materials and pedagogy to ensure that our community builds a strong research base for the STEM enterprise.

For more detailed information about projects funded as part of the CCLI Program, the accompanying CD includes the conference program, a map showing CCLI projects by state, abstracts for all CCLI projects, and the comprehensive Proceedings prepared after the 2004 CCLI conference.

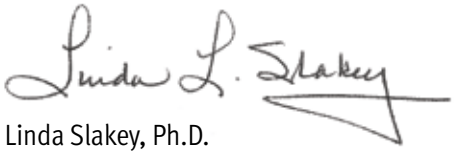
The title of the CCLI Progam was changed to Transforming Undergraduate Education in Science, Technology, Engineering, and Mathematics (TUES) to emphasize NSF's special interest in projects that have the potential to transform undergraduate STEM education.

For more details about the TUES Program and the CCLI awards, see the NSF website(http://nsf.gov/funding/pgm_summ.jsp?pims_id=5741&org=DUE&from=home).

We hope that the booklet and the CD encourage you to learn more about the NSF undergraduate program: its successes to date and its potential to further improve the quality of undergraduate STEM education.

Sincerely,

Wanda E. Ward, Ph.D.
Acting Assistant Director
Education and Human Resources Directorate
National Science Foundation



Linda Slakey, Ph.D.
Division Director
Division of Undergraduate Education
Education and Human Resources Directorate
National Science Foundation

October 2009

Dear Supporters of STEM:

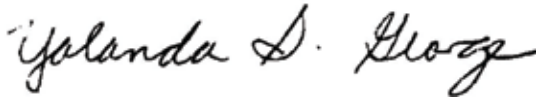
On behalf of the American Association for the Advancement of Science (AAAS), we are pleased to present this booklet, *New Challenges, New Strategies: Building Excellence in Undergraduate STEM Education* and the accompanying CD, to our colleagues at NSF and the larger STEM community, as well as to those interested in learning more about the importance of a strong science program in our undergraduate institutions. This booklet provides a snapshot of innovative projects funded by CCLI (now TUES) in the complementary areas of the development of learning materials and pedagogical strategies, professional development, and assessment. The CD includes the program from the conference, abstracts of all CCLI programs, and the Proceedings written after the 2004 CCLI conference. The AAAS CCLI Conference website (http://ccliconference.org/) is another source of information about this program.

As part of the mission of AAAS to *advance science engineering and innovation throughout the world for the benefit of all people,* AAAS is committed to providing high-quality resources for undergraduate education. This booklet and CD, whose purpose is to inform both the science education community and those committed to supporting its work, are part of that effort. Other outreach activities include a growing focus on education within the pages of *Science* magazine. These initiatives are designed specifically to highlight research as well as educational innovations, such as those initiated by NSF undergraduate programs.

We encourage you to look over these materials as a starting point in learning more about the undergraduate STEM education efforts. For those already engaged in undergraduate science, technology, engineering, and mathematics education, these projects can serve as models that could be adapted to meet the needs of students in your institutions.

Best regards,

Shirley M. Malcom
Director
AAAS, Education and Human Resources Programs



Yolanda S. George
Deputy Director
AAAS, Education and Human Resources Programs

About AAAS

The American Association for the Advancement of Science (AAAS) is the world's largest general scientific society, and publisher of the journal *Science* (www.sciencemag.org). AAAS was founded in 1848, and serves some 262 affiliated societies and academies of science, reaching 10 million individuals. *Science* has the largest paid circulation of any peer-reviewed general science journal in the world, with an estimated total readership of 1 million. The non-profit AAAS (www.aaas.org) is open to all and fulfills its mission to advance science and serve society through initiatives in science policy; international programs; science education; and more. For the latest research news, log onto EurekAlert!, www.eurekalert.org, the premier science-news Web site service of AAAS.

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About NSF

The National Science Foundation (NSF) is an independent federal agency created by Congress in 1950 "to promote the progress of science; to advance the national health, prosperity, and welfare; to secure the national defense..." With an annual budget of about $6.06 billion, NSF is the funding source for approximately 20 percent of all federally supported basic research conducted by America's colleges and universities. In many fields, such as mathematics, computer science, and the social sciences, NSF is the major source of federal backing. NSF fulfills its mission chiefly by issuing limited-term grants — currently about 10,000 new awards per year, with an average duration of three years — to fund specific research proposals that have been judged the most promising by a rigorous and objective merit-review system.

NSF's goals—discovery, learning, research, infrastructure and stewardship—provide an integrated strategy to advance the frontiers of knowledge, cultivate a world-class, broadly inclusive science and engineering workforce and expand the scientific literacy of all citizens, build the nation's research capability through investments in advanced instrumentation and facilities, and support excellence in science and engineering research and education through a capable and responsive organization.

Introduction

Without change there is no innovation, creativity, or incentive for improvement. Those who initiate change will have a better opportunity to manage the change that is inevitable.

—William Pollard
CEO, ServiceMaster

Americans face a dizzying array of problems. An economy in crisis, the costs of health care putting it beyond the reach of millions of people, and clear signs of global climate change are just a few of the large-agenda items. For these reasons, it is crucial that we cultivate a highly skilled generation of scientists and engineers—along with scientifically literate citizens who can engage in debates about biotechnology and nanotechnology research, alternative energy sources, and other science-related topics that have a direct impact on society and the quality of life. Since everyone must be ready to confront the challenges of the 21st century, it is essential that we support innovation in undergraduate science, technology, engineering, and mathematics (STEM) education.

The overall goal of the National Science Foundation's (NSF) Transforming Undergraduate Education in Science, Technology, Engineering, and Mathematics (TUES) Program (formerly called the Course, Curriculum, and Laboratory Improvement [CCLI] Program) is to meet these challenges head-on. Housed in the Division of Undergraduate Education (DUE), TUES (formerly CCLI) focuses on improving and, in some cases, transforming undergraduate STEM education through innovation and new methods of problem solving. The projects that it supports are instrumental in creating, adapting, and disseminating learning materials and teaching strategies that reflect the latest developments in the STEM disciplines and incorporate current research about teaching and learning.

NSF undergraduate programming provides all institutions—from community colleges to large research facilities—with the support necessary to experiment with innovative and creative approaches to teaching and with ways to disseminate large-scale, more established projects. In addition, nonprofit organizations, professional societies, universities, and colleges that are collaborating on a project also are encouraged to come forward with their own proposals. In turn, NSF strives to ensure that its supported projects make state-of-the-art learning opportunities available to all students—men and women of all racial and ethnic groups. Last year, under the auspices of CCLI, NSF provided 67.5 million dollars for 262 new initiatives on 203 campuses nationwide. Currently, there are about 950 active projects.

Program Mirrors Learning Theory

Over the past decade, researchers have made tremendous strides in their understanding of how people learn. It is now clear that, for most people, learning requires active engagement and that new knowledge is gained through hands-on, inquiry-based investigations. In addition, learning often is more meaningful when students are able to relate it to their own personal experiences and make lateral connections to other knowledge areas. Finally, learning is collaborative. It takes place within a community of students and faculty, in which everyone is committed to providing a safe place for students to gain confidence and succeed in learning science content and skills.

The National Academies' book *How Students Learn* spells out the four key elements that need to be in place in order to create an environment conducive to learning.[1]

Learner-centered: Learning begins from the experience, knowledge, interest, and motivation that learners bring to the setting. In addition, learners are active participants in the process. To engage students, it is important to provide new information that can be used to build upon or challenge their intuitive ideas. Often the most effective way to do this is by presenting students with real-world problems that can be solved using the tools of science.

Knowledge-centered: Problems can only be solved if students have a solid knowledge base from which they can draw. Educators have long struggled to find the best way to present that new knowledge. Developing strategies that enable people to absorb and internalize new information and apply it to a range of different situations is an important goal of all educational institutions.

Community-centered: Learning is usually more effective when it occurs within a community, where people can exchange ideas and receive feedback from other interested participants. In this way, learning becomes a collaborative process, with participants gaining insights, knowledge, and perspectives from the standpoint of their peers.

Assessment to support learning: In order for the quality of learning to improve, there must be mechanisms in place to determine just how effective the teaching strategies are. Assessment is the means to accomplish this. Information gained from a variety of assessment instruments can be used to measure what learning has occurred—or hasn't occurred—and what can be done to take that learning to a higher level.

[1] National Research Council. (2000). *How People Learn: Brain, Mind, Experience, and School* (expanded ed.). Committee on Developments in the Science of Learning. J.D. Bransford, A.L. Brown, and R.R. Cocking (eds.). Washington, DC: National Academy Press.

Translating Learning Theory into Practice

To encourage projects that achieve these four learning goals, TUES (formerly CCLI) recognizes the necessity of a multi-pronged approach. For learners to be engaged, the *curriculum materials* must encourage inquiry and active investigation. Faculty must be prepared to put *new instructional strategies* in place to help spark students' interest and motivate them. Often this process requires the teaching staff to participate in targeted *professional development* workshops and programs. Increased faculty expertise and added experience help *build learning communities* within individual classes and departments.

Faculty must be prepared to put *new instructional strategies* in place to help spark students' interest and motivate them.

In many STEM disciplines, carefully designed laboratory courses with powerful *modern equipment,* including high-end research instruments, are important components of learning. Through hands-on experience in the laboratory, students enhance their knowledge base by conducting their own research. New educational technologies also provide tools that can be used to promote more effective teaching and learning.

As a way to determine whether learning goals have been achieved, *evaluation and assessment* are integral components of each NSF-funded project. Through evaluation, principal investigators can see what learning goals have been realized and what additional work needs to be done. In this way, projects are continually refined.

TUES-Funded Categories

With an understanding that effective learning means supporting development in all four areas—learner, knowledge, community, and assessment—TUES, as did CCLI, funds projects in the following categories:

- Creating Learning Materials and Strategies
- Conducting Research on Undergraduate STEM Education
- Implementing New Instructional Strategies
- Developing Faculty Expertise
- Assessing and Evaluating Student Achievement

Viewed together, projects funded from each category represent what elements need to be in place to ensure that all undergraduate institutions have the opportunity to create the best possible environment to foster student learning in the STEM disciplines.

Types and Levels of Funding

NSF-funded undergraduate projects that vary in terms of *scale, scope,* and *stage. Scale* refers to the number of institutions, faculty, and students impacted by the project. *Scope* refers to the range of project components involved, with some focusing on one component and others cutting across many. *Stage* refers to the place of the project along a continuum, from early conceptual development through dissemination of a mature project with a strong research base.

The combination of scale, scope, and stage is reflected in the project type and the level of funding it receives. Below is a brief description of the three types of projects described in the Solicitation (NSF 10-544).

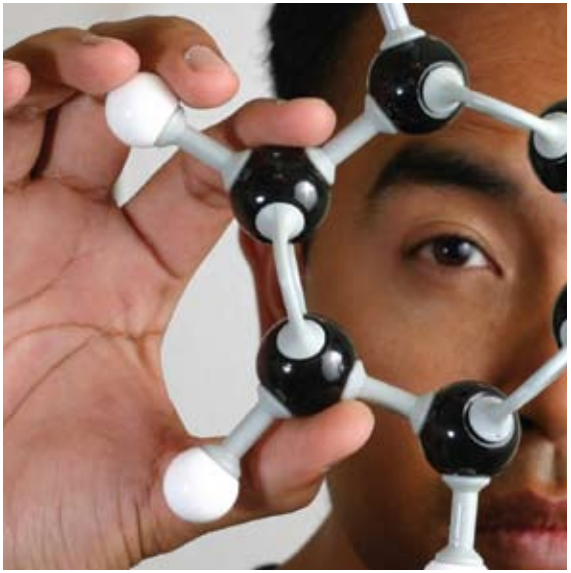
Type 1 Projects (formerly Phase 1 CCLI) have a total budget of up to $200,000 ($250,000 when four-year colleges and universities collaborate with two-year colleges) over a two- to three-year period. They include a range of pilot projects, such as developing a new type of instructional material, integrating current science and pedagogy into teacher preparation programs, and developing a new instrument to assess students' knowledge about a particular discipline or the mastery of key science processes.

Type 2 Projects (formerly Phase 2 CCLI) top out at $600,000 for two to four years. These projects typically address more than one project category or focus on a single category on a scale that goes well beyond a single institution. Examples include a sequence of courses that integrates a conceptual or pedagogical approach at several institutions; a large-scale partnership between community colleges and four-year universities and colleges; or the development of an Internet-based professional development program that is available to whomever chooses to access it.

Type 3 Projects (formerly Phase 3 CCLI) budgets are not to exceed $5,000,000 over five years and are intended to support large-scale efforts. These include the regional or national dissemination of proven materials or pedagogies; the creation of a self-sustaining model for professional development; or a large-scale assessment project that involves multiple institutions, with the goal of developing a database reflecting student knowledge in one of the four STEM disciplines.

TUES Central Resource Projects budgets may not exceed $3,000,000. These projects assume responsibility for leadership and implementation of activities that sustain the TUES community as it works to transform undergraduate STEM education. TUES Central Resource projects will work to increase the capabilities of and communications among the STEM education community and to increase and document the impact of TUES projects. Projects can include large and small meetings, publications, and research and evaluation studies.

An Overview of CCLI Projects



In 2008, more than 300 CCLI-funded exemplary projects were showcased at a conference in Washington, DC. The conference was an opportunity for grant recipients to share their work, exchange ideas, and learn from one other.

The following section describes 17 projects among those highlighted at the conference. Although each project has been placed in one of the five categories described earlier, many projects cut across categories. For example, an innovative curriculum project may also include new instructional strategies as well as an evaluation and assessment component. Some of these are beginning, small-scale curriculum or faculty development projects, while others are large-scale, multi-institution undertakings, many of which evolved from earlier, small-scale efforts.

For more information about the CCLI conference, see:
http://ccliconference.org

Creating Learning Materials and Strategies

Coastal Carolina University: Process-Oriented Guided Inquiry Learning in Context (POGIL-IC)

Effective learning is enhanced by innovative curriculum materials, which pique students' interest and engage them in learning. POGIL, or process-oriented guided inquiry learning, is effective in engaging students becauses of its carefully structured activities, which focus on the processes of learning. The POGIL-in-context (POGIL-IC) project takes this concept a step further. It challenges students to apply their understanding to a new situation. These advanced activities present students with real-world problems that can be solved only by using their knowledge of chemistry.

Building on work begun in the 1990s, John Goodwin, Professor of Chemistry at Coastal Carolina University (Conway, SC), received a Phase 1 CCLI curriculum development grant to develop the new POGIL-IC pedagogy and create a set of classroom activities. Collaborating with Professors David Hanson at Stony Brook, Thomas Gilbert at Northeastern, and Darlene Slusher from Coastal Carolina, Goodwin held a series of four workshops in 2007 and 2008. He received input from more than 50 chemistry faculty from high schools, community colleges, four-year colleges, and research universities.

A typical POGIL-IC activity presents a problem such as the following: What volume of gasoline is required for one combustion cycle in one cylinder of the Dodge Viper? To answer this question, students need to have an understanding of gas laws, partial pressures, stoichiometry, and liquid density. While guidance can be provided by an instructor, the new POGIL-IC materials provide printed help pages at varying levels that serve as the guided inquiry essential to the POGIL pedagogy, but with an added emphasis on higher-level problem-solving skills.

Goodwin and other educators believe that the POGIL-IC activities encourage students to become actively involved in their learning. Contextual problems are included with the POGIL-IC activities to build students' confidence as they apply their understanding of chemistry to new problems, even those outside the traditional chemistry class.

Like any innovation, POGIL-IC has its challenges. Faculty members used to the lecture approach have had to adjust to their new role in the classroom. Facilitating a problem-solving activity is more labor-intensive than presenting a lecture. Nonetheless, Goodwin is committed to this style of teaching. "The old school approach—lecturing and giving tests—

resulted in high attrition and low satisfaction," he explains. "Although students find the POGIL-IC activities difficult, they appreciate the challenge and find the group work productive."

Michigan State University: Problem Solving in Biology

Students in introductory biology classes often are overwhelmed as they try to make sense of a large vocabulary of new terms and complex biological ideas. To address these challenges, Assistant Professor Joyce Parker of Michigan State University (East Lansing, MI) collaborated with Lansing Community College on a NSF CCLI Phase 1 project, which is designed to help students truly understand biological processes happening at different scales, such as digestion in the human body and respiration in the cell. Often, too, students have difficulty understanding what happens during energy transfers. To remedy these problems, faculty aligned lectures, homework, and tests, emphasizing a few basic principles to help students understand patterns in the processes studied.

During a lecture, instructors use "clickers," handheld devices that allow students to respond to the instructor's questions while, at the same time, the responses are being collected and processed for the professor. As a result, professors can see students' responses on a computer screen almost instantaneously, giving them important information about whether students understand the main concepts. If students are struggling with a particular idea, the professor can respond with additional explanations and examples. Homework reinforces key ideas; in some instances, the homework is online so that students can check their answers and see for themselves how they are progressing.

"We're trying to see whether students are reflecting on their own thinking," explains Parker. "If they're learning about cellular respiration, we want them to understand what matter is going in, what matter is going out, what drives it, and how it is regulated."

The bioscience programs at both institutions are trying out these approaches with about 500 students. During the final year of the grant, Parker and her colleagues will be collecting data to compare with their baseline information. One particular subpopulation of interest is future science teachers. "With many of our biology majors going into teaching," Parker says, "we are hoping to break this cycle of rote learning and have them come out of college with more understanding of the underlying processes of biology."

If students are struggling with a particular idea, the professor can respond with additional explanations and examples.

Syracuse University: Preparing Students for the 21st Century Workforce

Since 9/11, Americans have become aware of the threat of terrorism on our soil, in our planes, and now, in cyberspace. We have to be vigilant and prepared, and some college curricula reflect this concern. Syracuse University (Syracuse, NY) has received a Phase 2 grant to develop computer security labs.

The labs are designed to give students numerous opportunities to learn by doing. The first type of labs focuses on "learning by breaking"; students learn how hackers use systems' vulnerabilities to get into computer systems and what kind of protection is most effective. The second type of labs focuses on "learning by exploring"; students are given a "guided tour" within security systems, during which they learn security principles. These labs lay the groundwork for the next step: building a security system. Working in groups, students develop strong security systems to protect cyberspace.

Kevin Du, Associate Professor in the Department of Electrical Engineering & Computer Science, has been building these labs since 2002 and has compiled an instructors' manual for other faculty members. The manual provides tips on how to maximize the curriculum's effectiveness. Du also has gone to conferences to display these materials as part of a dissemination effort. As a result, the labs are now being used in ten other universities.

"Computer security courses are growing nationwide," says Du. "This is a skill we have to teach, and, in doing so, we help create the workforce for the 21st century."

Rochester Institute of Technology (RIT): Enhancing the Engineering Technology Curriculum

In the engineering field, a new area of interest has emerged that is also needed for the next generation of workers: reliability knowledge and skills. This involves building equipment such as cell phones that are still "reliable" after being dropped multiple times. This kind of expertise, in high demand by the electronics packaging industry, is being taught in an electronics packaging lab developed at RIT (Rochester, NY). The course is supported by a Phase 2 grant.

"Courses such as these are usually focused at the graduate level," notes Manian Ramkumar, Professor and Director of the Center for Electronics Manufacturing and Assembly. "But we wanted to teach this topic to our undergraduates to help them get jobs right out of school."

Early signs indicate that they're on the right track. Although only about 25 undergraduates have taken the course each year, they have shown evidence of improved understanding of electronics. Their senior capstone projects have improved, and many have gone on to get jobs in this field. "Our main idea was to build up the workforce," adds Ramkumar. "There is a large need for engineers trained in this area."

Conducting Research on Undergraduate STEM Education

In the past, it has been difficult to conduct controlled experiments on the effectiveness of new educational curricula or learning strategies. Despite the challenges inherent in this effort, some researchers are designing research studies that measure the impact of new ideas in the same way they would design a scientific experiment.

University of Mississippi: Making a "Case" for Case Studies

Tamar Goulet, Associate Professor of Biology at the University of Mississippi (Oxford, MS), has completed a compelling study. She compared learning in biology courses for non-majors under three conditions—students in a traditional lecture hall, lectures with the use of clickers, and lectures with the use of both clickers and case studies.

Throughout many institutions nationwide, case studies have become increasingly popular as a learning strategy. They are real-world scenarios that pose a complex question for students to resolve. Many case studies use the technique of progressive disclosure, by which pieces of the puzzle are added over time. "The television show *House* is an example of a case study developed through progressive disclosure," Goulet explains.

After comparing the three learning scenarios, Goulet reported that students using case studies felt more involved with their learning. Goulet also found that more students in the case study section were able to pull up their grade from a D or an F to a B or a C. Overall, the take-home message is that large, introductory biology classes that use a combination of case studies and clickers result in improved attendance, increased student satisfaction, and in some instances, improved grades.

Research studies such as this one are important to the undergraduate community. They provide the research base needed to substantiate observations and anecdotal findings reported from the field. As a result, more instructors will have confidence that a new learning strategy will be effective with their students.

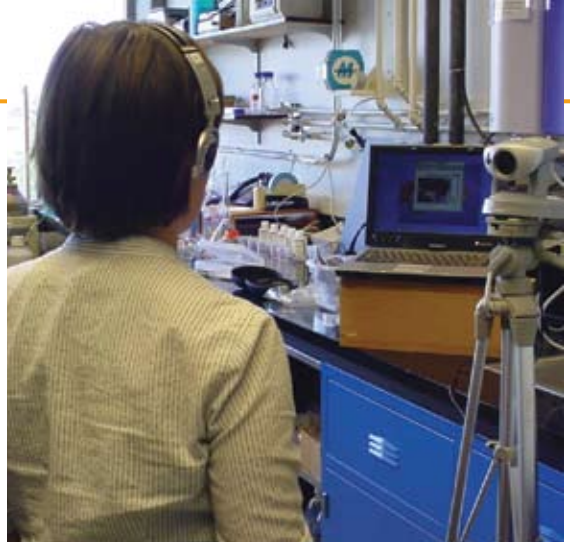
Implementing New Instructional Strategies

Refining *how* students are taught represents a significant part of the work that CCLI supports. In the STEM disciplines, often changes in pedagogy go hand in hand with greater access to state-of-the-art scientific instruments. Technology, too, is playing an essential role in reshaping the science classroom of the 21st century. These and other innovations, including providing students with more opportunities to go out into the community, are highlighted in the next section.

Opening the Doors to Research: Greater Access to Scientific Instruments

Columbia College (Columbia, SC) Chemistry Professor Julia Baker was concerned that her students at this women's institution did not have access to research-grade instruments. Using funds from a Phase 1 CCLI grant, the college was able to purchase a nuclear magnetic resonance instrument, a tool that all science majors should know how to use and that makes independent research projects possible. "Students can work on discovery-based problems, which allows them to try to solve a problem whose answer is not known in advance," explains Baker. "This is not cookbook science."

Currently, students in general chemistry, organic chemistry, and a new course called instrumental analysis have access to the instrumentation. Based on completed evaluations, about half of the first-year students in introductory chemistry indicate



that using the machine for scientific investigation has increased their interest in chemistry. About 52% of all students are now interested in doing undergraduate research, and 73% report that they enjoy the problem-based labs that incorporate the instrumentation.

"For a small college like ours, grants like CCLI are the only way we could afford to purchase instruments," says Baker. "And we make sure our undergraduates have opportunities to use them, which improves the overall quality of the experience students have here." In this way, Columbia College also is helping to develop the next generation of female scientists and leaders.

Western Washington University: Creating a Virtual Network of Instruments

Buying scientific instruments is one way to provide students with the opportunity to work with state-of-the-art equipment. But technology now offers another option—sharing equipment remotely over the Internet to create a virtual laboratory that is available to any educational institution.

For the past three years, Western Washington University (Bellingham, WA) has been using its Phase 2 CCLI grant to build such a system, which is called the Integrated Laboratory Network, or ILN. The ILN is an e-learning initiative designed to provide anytime/anyplace access to scientific instrumentation and supporting curricular materials using Web-based resources. The network has many components, including an open-source Web site of labs and links submitted by different "cyber-enabled" institutions, such as Loyola University, Purdue, and the Massachusetts Institute of Technology (MIT), as well as videoconferencing software to share data and solve problems.

How can students access instruments thousands of miles away? The answer lies in the fact that most scientific instruments are controlled by computer. After preparing lab samples at their own university and sending them to Western Washington University, students can remotely operate, and watch in real time, Western's advanced scientific instruments, ranging from atomic absorption spectrometers to scanning electron microscopes (SEM). To date, 12 academic institutions, including high schools, community colleges, and a university in Puerto Rico, have taken advantage of this opportunity.

Putting together the ILN is an extremely complex task, involving interactions with faculty and IT staff at numerous institutions. Much trial and error has been involved, as well as confronting resistance from some faculty members.

"The first barrier we faced was from the IT departments at some universities and colleges," says Devon Cancilla, Director and Associate Professor of Scientific Technical Services. "They were nervous about opening up their firewalls to so many new users because of the possibility of infecting their network with viruses. And professors were nervous about having students use such expensive, high-tech instruments."

"Web 2.0 technologies have given way to Science 2.0..."

On top of those issues, Cancilla found that many traditional labs are not designed around the use of instruments, either because the institutions did not have access to them or the time available in a typical three-hour lab did not allow them to be used. But having 24/7 access to instruments is changing the way labs are being designed. In disciplines ranging from chemistry, environmental science, and marine biology, students are discovering the excitement of conducting science online—an excitement enhanced by their ability to analyze samples that they have prepared themselves.

Not only is remote instrumentation replacing "abysmal" labs—where students were not using any kind of instrumentation—with access to state-of-the-art technology, students also are becoming part of a broad community of scientists. Web 2.0 technologies have given way to Science 2.0, where true collaborations are possible," explains Cancilla. "Students are able to experience science the way it is really done."

A Four-University Collaboration: Multiple Uses of Technology

Remote instrumentation is just one innovative use of technology in higher education that's changing the way students are learning. Four universities—the University of Virginia (UVA, Charlottesville, VA), Purdue University (West Lafayette, IN), the University of Akron (Akron, OH), and Smith College (Northampton, MA)—are using a Phase 2 CCLI grant to collaborate on a project for engineering students that makes use of podcasts, blogs, and wikis. Edward Berger, Associate Dean for Undergraduate Programs and Associate Professor in the Department of Mechanical and Aerospace Engineering of the School of Engineering and Applied Science at UVA, made the first foray into Web 2.0 by creating podcasts of lectures. From there, the next step was to develop video problem-solving sets that could be accessed to help with homework assignments and to review difficult concepts.

"Students can't get enough of them," reports Berger. "The technology allows them to control what learning materials they use and when they use them, and that's very empowering."

Students also can exert control by exchanging ideas and information through each course's blog. In particular, Purdue's use of the course blog is exemplary. Students can join in on the conversation, adding threads, posting their original questions to a wider audience, and linking to outside resources. Students also have the option of creating their own wikis and communicating directly with one another without a faculty facilitator.

In the remaining year of the grant, the team is working with the School of Education at UVA to develop assessment instruments that can correlate improvements in student performance with the use of these Web 2.0 technologies. Although there is strong anecdotal evidence that supports how much students like these approaches, the hope is to build a more solid evidence base. "The real hook is that this material can be repurposed and distributed to just about anyone—people returning to the field after a hiatus, online degree programs, community colleges, and high schools," Berger points out. "Online education has tremendous potential."

The American Meteorological Society: Reaching Out to Minority Institutions

Technology also can be used to reach out to underrepresented populations. For several years, with the help of a Phase 2 CCLI grant, the American Meteorological Society (AMS, Washington, DC) has been developing online courses focusing on weather

and ocean studies and targeting them to federally designated minority-serving institutions (MSI).

The benefits of these courses are that they take students into the real world, where they have access to weather maps, satellite images, and other data. Although any undergraduate institution can use these materials, MSIs can choose to participate in one-week workshops focusing on the weather course to gain tips on how to teach with these tools. AMS has been giving the faculty workshop once a year over a six-year period, with a total of 145 faculty members attending. The workshop on ocean studies has been offered for three years, and 75 faculty members have participated.

A measure of the success of a project is whether it survives after one or two years. AMS has found that 75% of all institutions that began using these courses sustain them after the funding ends. Although much of the information is anecdotal, faculty report that students sought out additional learning opportunities after taking these courses.

"Our intent with these courses was to promote greater diversity in the geosciences," says James A. Brey, Director, Education Program, at the American Meteorological Society. "We were behind, but now the numbers are improving. And we're also excited that many of the minority students who become interested in the geosciences become K-12 teachers."

Ithaca College: Changing the Setting to Fit the Student

One of the key contributions of learning theory is recognizing the importance of a student-centered learning environment. Most students in undergraduate education have difficulty learning in a lecture hall, where they are passive recipients of information. Research has confirmed that engaging students in their own learning is much more effective. The question is, how can this be done? Building on work done at North Carolina State, Ithaca College (Ithaca, NY) is re-designing its physics classrooms to accommodate how students really learn through SCALE-UP (Student-Centered Active Learning Environment for Undergraduate Programs). Michael Rogers, Assistant Professor of Physics, is leading the effort to bring studio physics to Ithaca College. Ithaca's Phase 1 CCLI grant is contributing to this effort.

Instead of attending a lecture a couple of days a week and a separate lab on another day, a SCALE-UP classroom has 11 tables with room for 9 students at each one. Students are given a problem to solve or an experiment to perform, which they complete by collaborating with their peers. If the students get stuck on a problem the professor is available to answer questions and provide guidance. In this way, a seamless learning environment is created.

The team also is comparing this innovative teaching approach with the traditional lecture format for two other courses: a general education astronomy course and an algebra-based physics course. Even though the research is not yet complete, Ithaca has taken the step of moving all introductory physics courses out of the lecture hall and into this new learning environment. "Our school is committed to this approach," says Rogers.

Purdue University: Learning in the Community

Sometimes the real world trumps school as the best place to learn. Purdue University (West Lafayette, IN) has created a service-learning program called EPICS (Engineering Projects in Community Service) for engineering students that is now being disseminated through a Phase 3 CCLI grant.

The idea is simple. Students can partner with schools, government agencies, or nonprofits to help them meet their design and engineering needs. For example, suppose a local high school needed a traffic study done. Instead of hiring a team of engineers, students can be brought in to do the job. Working with the school and the community, the students can develop a design concept, collaborate with the team, and work through issues and concerns to complete the design. Students gain valuable work experience, and the school saves money—a win-win for everyone. Alternatively, students can work on environmental projects such as designing "green" buildings or developing an efficient energy system for newly constructed houses. Students receive academic credit for their work, as well as an opportunity to acquire engineering and design knowledge "on the job."

To inform other institutions about EPICS, the project holds an annual conference. About 19 institutions have adopted the model, and many others have expressed interest. As part of the national dissemination grant, William Oakes, Director of the EPICS Program and Associate Professor of Engineering Education, and his team point newcomers to grant opportunities such as the CCLI program and help them apply the EPICS model to the unique needs of their institutions.

"The time is right to make a fundamental change in the engineering curriculum," says Oakes. "Although it's hard to do, we find that if each school has a 'champion' who is passionate about education, the innovation can be adopted. For students, it is an opportunity to do design so that they really understand all of its complexities."

Developing Faculty Expertise

Across STEM disciplines, leaders in professional development for undergraduate faculty members have similar goals. They are working to implement the following changes:

- Establish a community where collaboration and the sharing of ideas, problems, and solutions are common practice. Often this can be accomplished by creating a Web site that houses recent information about professional development activities, essays on relevant topics, and suggested lessons, labs, and activities.
- Encourage faculty to use teaching strategies that engage students in their own learning. To realize this goal, instructors are encouraged to move beyond the lecture format and to experiment with other, more engaging methods.
- Cultivate leaders within STEM departments who can champion the desired changes and gain support for them within the department and throughout the school.
- Work with professional societies to coordinate meetings and workshops and to support the desired changes.

The following section illustrates how different CCLI projects are developing strategies to realize these goals.

Science Education Resource Center (SERC): Community Building in the Geosciences

In the geosciences, Cathy Manduca, Director of SERC at Carleton College (Northfield, MN); Heather Macdonald, Chancellor Professor of Geology, College of William and Mary (Williamsburg, VA); David Mogk, Professor of Geology, Montana State University (Bozeman, MT); and Barbara Tewksbury, Professor of Geosciences, Hamilton College (Clinton, NY) are the leaders of a Phase 3 CCLI collaborative project that emphasizes community building and the sharing of ideas.

Each year, the project offers six or more multi-day workshops that focus on current topics in content and pedagogy related to the geosciences, as well as strategies for succeeding in an academic career in the discipline.

"The signature feature of the project has been building the Web site, which includes materials from the workshops, such as teaching activities, essays, and ideas for interactive experiences," explains Manduca. "We are trying to build a culture of sharing, where teachers automatically go to the Web site to see what their colleagues are doing."

Thus far, the project has held 40 professional development workshops, reaching more than 1,500 faculty, post-docs, and graduate students from all the disciplines in the geosciences. Evaluation data have shown that participants have been receptive to the project, and it has led to an improvement in teaching.

But the work is far from over. "We've done really well making a big reach into the geosciences community," says Manduca. "We've had good participation from other institutions, and we've brought women and minorities into the mix. With collaborations working so well, we're ready to do more."

A Three-University Collaboration: Innovative Approaches to Chemistry

A collaborative project similar to the one at Carleton College is underway in chemistry. Since 2001, the Center for Workshops in the Chemical Sciences (CWCS) has been offering workshops to faculty from two- and four-year institutions plus comprehensive universities, as well as post-docs and graduate students. The purpose is to improve instruction and learning in the chemical sciences primarily at the undergraduate level by running workshops on engaging topics related to chemistry and innovative ways to teach them. Topics include introduction to forensics and advanced forensics, chemistry of art, and molecular genetics. Between 10 and 20 people participate in each workshop.

Facilitated by Georgia State University (Atlanta, GA), Georgia Institute of Technology (Atlanta, GA), and Williams College (Williamstown, MA), this Phase 3 collaborative CCLI project has attracted 1,141 participants representing 715 institutions from 48 states plus Guam, Puerto Rico, and Washington, DC.

"We help people assess their chemistry program . . . to ensure that the program's impact will continue over an extended period of time."

Evaluations estimate that 450,000 students have benefited from CWCS activities.

With the workshop component well underway, CWCS is in the process of forming a Community of Scholars, made up of former and current workshop participants, organizers, instructors, and others interested in the effort. "We are trying to raise the profile of the project," says Jerry Smith, Associate Professor of Biophysical Chemistry at Georgia State and CWCS Director. "We help people assess their chemistry program and write grant proposals. Our goal is to ensure that the program's impact will continue over an extended period of time."

Project Kaleidoscope: Supporting Leadership Development

To promote institutional efforts to build and sustain robust undergraduate STEM learning environments, Project Kaleidoscope (PKAL), a long-term NSF-funded program based in Washington DC, used support from a Phase 3 CCLI award to design and implement a "STEM leadership development" curriculum. Over a three-year period, PKAL has coordinated a series of workshops and national meetings with teams from participating institutions to explore steps in creating a vision for change, developing strategies for implementing that vision, and determining mechanisms through which leadership teams take long-term responsibility for advancing and achieving systemic transformation.

A major outcome of this project was identifying essential factors that need to be in place for change to be initiated and sustained, including a clear vision, a leadership team ("change agents") empowered to move toward that vision, and a community and infrastructure supportive of the work of these change agents. Another outcome was a renewed sense of the value of communities of practice—colleges and universities sharing lessons learned and best practices in addressing common challenges facing STEM leaders. But perhaps most important of all was the realization of the need to focus on student learning at all stages of the process of transformation.

Building collaborating communities of colleges and universities is now central to the work of PKAL, which is engaged with consortia and systems in Connecticut and Minnesota and has informal associations in Georgia and Oregon. PKAL is partnering with SERC (discussed on page 23) in building these collaborating communities.

Assessing and Evaluating Student Achievement

Assessment is used in a variety of ways. For example, one purpose is to determine project outcomes, while another is to determine which aspects of a course or program are promoting student learning and which are not. Often the way data are collected is by asking students what content they know or skills they have before taking a course (pre-test), and then asking them the same questions at the end of the course (post-test). Learning gains are measured by looking at the differences between the two sets of scores or responses.

There are many different kinds of assessment instruments, and each has been developed to measure a specific kind of learning. The following section describes three examples of state-of-the-art tools designed to assess the quality of student learning.

University of Wisconsin-Madison: Student Assessment of Learning Gains (SALG)

First created in the late 1990s, the SALG instrument focuses exclusively on the degree to which a course has enabled student learning. In particular, the SALG asks students to assess and report on their own learning, and on the degree to which specific aspects of the course have contributed to that learning. A detailed questionnaire asks students about these issues. SALG can be used by any discipline and can be given multiple times during a semester or school year. Responses also can be compared to a baseline instrument given at the beginning of the semester.

Housed at the University of Wisconsin-Madison

(Madison, WI) and managed by a multi-university development team, SALG is using its Phase 2 CCLI grant to further refine this instrument and to make it highly Web accessible. For example, there are online options for users to customize the SALG to meet their unique needs. Work also is underway to develop versions of the SALG Web site that can be used for department-wide evaluation programs as well as for evaluators of innovative STEM education programs. Ultimately the team envisions the SALG being used in support of institution-wide faculty development and accreditation.

To date, about 1,600 instructors have used the SALG instrument. In the future, Robert Mathieu, Professor and Chair, Department of Astronomy, and Director, Center for the Integration of Research, Teaching and Learning, expects that SALG will comprise a large portfolio of assessment tools. "SALG has the potential to deepen our understanding of student learning, leading to changes in the way instructors teach," says Mathieu.

Tennessee Tech University: Critical Thinking Assessment Test (CAT)

At Tennessee Tech University (Cookeville, TN), Barry Stein, Professor of Psychology, is managing a Phase 3 CCLI grant. The grant is focusing on regional "train the trainer" workshops on how to implement and score the CAT instrument, a test designed to measure critical thinking skills and the ability to solve real-world problems. The purpose of these workshops is to cultivate a larger cadre of faculty members from other institutions who can use and score the test effectively and disseminate it within their regions.

The test can be used in a variety of ways. It can be administered to freshmen when they start college and then to seniors, before they graduate. Or it can be used to measure learning for a particular course. By seeing students' weaknesses firsthand, faculty members discover what particular learning issues need to be addressed.

Interest in this instrument has been high. Representatives from over 35 institutions have participated in these workshops, and over 7,000 tests have been distributed nationwide. State universities and private institutions—some of which had never assessed student outcomes before—are now using the CAT.

"In a world that is changing fast, this instrument assesses what students need to know, helping to ensure that the right skills are taught."

"What sets this test apart is that it is trying to assess skills, not broad retention of factual information," explains Stein. "In a world that is changing fast, this instrument assesses what students need to know, helping to ensure that the right skills are taught."

Clemson University and UCLA: Tracking How Students Solve Problems

With so much attention being paid to problem solving, it would be helpful to understand how students approach complex problems and the steps they take in solving them. A unique assessment system called IMMEX (Interactive Multimedia Exercises) developed at the University of California, Los Angeles (UCLA) can do just that, and it is being implemented and studied through a collaboration with Clemson University (Clemson, SC). Clemson and UCLA received a Phase 2 CCLI grant for this project.

Melanie Cooper, Alumni Distinguished Professor of Chemistry from Clemson and Interim Chair, Department of Engineering and Science Education, has used IMMEX in general and organic chemistry classes; Ron Stevens, Professor of Microbiology, Immunology, and Molecular Genetics, conducts the analysis of the assessment system.

The team has developed problems focusing on chemical analysis, structure, function, and energy. After working with over 4,000 students, Cooper and Stevens have made some interesting discoveries. For example, in many cases, students use the same strategies as they attempt to solve problems, and often they do not improve over time by practice alone.

But the good news is that relatively simple interventions do make a difference. "For example, working in groups is very effective, and the gains made carry over even when students work alone on subsequent problems," says Cooper. Other effective interventions that have produced significant improvements in student problem-solving strategies and abilities include concept mapping, distance collaborations, and problem-based laboratory activities.

Cooper also notes that while many college students can think abstractly, some are still concrete thinkers. "Pairing a concrete thinker with an abstract thinker helps everyone improve."

Concluding Remarks

NSF-funded undergraduate programs are a major force for change and innovation in undergraduate STEM education. Through projects encompassing all aspects of instruction—learning materials, teaching strategies, professional development, and evaluation and assessment—TUES (formerly CCLI) is fostering model programs that can be replicated at institutions nationwide. These projects bring recent advances within a discipline and the latest thinking about how students learn into the undergraduate curriculum, and they all include a robust built-in evaluation component to help investigators continually refine and improve their projects. Many of these projects introduce new technologies, using them to the best educational benefit. In addition, scientifically sound research projects are solidifying the foundation of evidence for new strategies, ensuring that they can be used with confidence.

TUES (formerly CCLI) is soliciting proposals from the higher education community, encouraging faculty members to stretch their thinking to develop the most effective, student-centered approaches to teaching and learning. The ultimate goal is to transform the higher education system so that all students graduating from college are scientifically literate, prepared to debate the complex and challenging issues of our time. For those students who choose to become scientists, their experiences in college should prepare them for the highly competitive workplace of the 21st century.

For more information about the CCLI Conference and projects, see: http://ccliconference.org.
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