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Research Corporation Annual Report 2006

America's first foundation for science advancement

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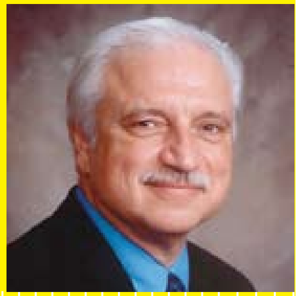
Research Corporation is a foundation for the advancement of science that provides catalytic and opportunistic funding for innovative scientific research and the development of academic scientists that will have a lasting impact on science and society.



PRESIDENT'S MESSAGE

Science in the United States is entering a crisis phase the likes of which none of us has seen before. In the coming decade we face the likelihood of losing our global lead in scientific research for the first time in more than half a century.

Two major trends contributing to this potential disaster — the departure of our post-World War II cohort of researchers, and the rapidly expanding numbers of science and engineering graduates coming out of India and China — are well under way.

A flat federal research budget for the past few years hasn't helped, either. Yet John Marburger, the current presidential science advisor, recently said it's unrealistic to expect dramatic increases in federal funding for the nation's research endeavors. As Research Corporation Board Member Brent Iverson warned at a U.S. Senate hearing earlier this year, flat federal funding means many bright young researchers will be forced out of science careers in the coming decade unless something is done.

Perhaps most troubling of all is the fact that the cost-cutting approach to business that has killed millions of American manufacturing jobs in favor of cheap, foreign labor is now beginning to find traction in our nation's basic and applied research laboratories.

These developments couldn't have come at a worse time. In today's world, where humanity's knowledge base continues to expand at a frenetic pace, the fruits of scientific research have never been more important to economic development and national security.

It's an immense problem, but one which has a very easily phrased — though not to be confused with "simple" — solution:

America must supercharge its commitment to science and to science education.

Military might and a strong financial sector take a great nation only so far — if innovation and intellectual growth are lacking, even the mightiest power will soon crumble. Only by turning out more and better science and engineering graduates, and by making science careers life-affirming choices, can the U.S. hope to remain first rate.

With that in mind, Research Corporation, America's first foundation for science advancement, offers the following article on a vitally important, though often overlooked, segment of science advancement in the U.S., namely the current state of our nation's undergraduate science education. You're about to discover what some of our most brilliant scientific minds and experienced educators say must be done to ensure the U.S. is second to none in this critical arena.

We thank science writer Randy Wedin for his extensive reporting on this issue, and we look forward to your response at www.rescorp.org. We invite the Research Corporation constituency to enter into an extensive discussion on how to open the doors to the future of research for a new generation of scientists.

I'll briefly note my own perspective on undergraduate science education after you've had time to read and consider Wedin's article.

James M. Gentile

Behind Door No. 2: A New Paradigm for Undergraduate Science Education

by Randy Wedin

OPENING A NEW DOOR

It's 11:55 a.m. on a crisp, autumn Monday at the University of Wisconsin, Madison. The lobby of the chemistry building is packed with nearly 200 students jostling, chatting and waiting to enter class. Soon the doors will swing open, students from the 11 a.m. lectures will flood out, pushing their way through the crowd, and these waiting students will stream in to find their seats for the 12:05 p.m. lectures.

Similar scenes are being played out in science buildings across the country, from Madison to Tucson, from Boston to Boulder and from Williamstown, Mass., to Winona, Minn. This year about half of the nation's 15 million undergraduate students will take science classes. Today's undergraduates are a diverse group of students, with about an equal number of females and males in the science classes. Underrepresented minorities — African-Americans, Hispanics and Native Americans — make up about 24 percent of the overall undergraduate population.

Among these 200 students crammed into the lobby of the UW-Madison chemistry building this morning are future scientists, legislators, lawyers, teachers, physicians, nurses, judges, business executives, screenwriters and videogame designers. In 10 or 20 years, these students will also be parents, consumers and voters.

Today, however, they are sharing tunes from their iPods, sipping strong coffee and discussing Saturday night's parties. And though they probably won't admit it, they're also worrying and wondering about what awaits them behind those classroom doors.

What kind of class will it be? Will they have to memorize lots of facts and equations? Will it be relevant to their daily lives? Will the lectures be boring, incomprehensible or fascinating? Will the tests be hard? What will happen in the labs? Will the professor be friendly, arrogant or funny? Will the teaching assistants be helpful?

For too many years, the door has opened onto a science classroom that's stultifying — where students memorize facts, fail to learn underlying concepts and lose interest in science. Let's call that Door No. 1.

In a steadily increasing number of institutions, however, the door is opening onto a learning environment that's stimulating — where students engage and interact with the subject, where they learn the concepts and context of science, and where they experience the beauty and power of science. Let's call that Door No. 2.

This article, based on interviews with more than 20 leaders in the world of undergraduate science education, peeks behind the closed doors of the classroom. It outlines why so many classrooms are stuck in the old paradigm of Door No. 1, while also offering suggestions on how to create classrooms that exemplify the new paradigm of Door No. 2.

BEHIND DOOR NO. 1: A Broken System for Undergraduate Science Education

The problems with undergraduate science education are not new. In two books published nearly 20 years ago by Research Corporation (*They're Not Dumb, They're Different: Stalking the Second Tier*, 1990, and *Revitalizing Undergraduate Science: Why Some Things Work and Most Don't*, 1992), Sheila Tobias documented the situation. And in the last generation, since the 1983 release of the landmark report "A Nation at Risk," hundreds of reports on American science and mathematics education have been released. These reports examined the subject from every perspective and across all sectors of the education community, from pre-K to post-doc. (Tobias wrote, in 1990, that reports were being issued at the rate of about one a week, with some 300 appearing between 1983 and 1990. The rate of report writing seems to have held steady in the years since then.)

The most recent reports continue to document the problems. For example, the influential 2006 report from the National Academies, "Rising above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future," included this strong warning linking educational shortcomings and economic competitiveness:

> Having reviewed the trends in the United States and abroad, the committee is deeply concerned that the scientific and technical building blocks of our economic leadership are eroding at a time when many other nations are gathering strength. … Although many people assume that the United States will always be a world leader in science and technology, this may not continue to be the case inasmuch as great minds and ideas exist throughout the world. We fear the abruptness with which a lead in science and technology can be lost and the difficulty of recovering a lead once lost — if indeed it can be regained at all.

Also in 2006, the National Science Board (NSB) appointed a commission to revisit the subject of STEM (science, technology, engineering, and mathematics) education, one generation after the 1983 NSB report, "Educating Americans for the 21st Century." The new Commission on 21st Century Education in Science, Technology, Engineering and Mathematics has a charge to "make recommendations to the Nation through the Board for a bold new action plan to address the Nation's needs, with recommendations for specific mechanisms to implement an effective, realistic, affordable and politically acceptable long-term approach to the well-known problems and opportunities of U.S. pre-K-16 STEM education." A final report from this commission is expected in late 2007.

The data, anecdotes and conclusions found in these many reports are illuminating — and disturbing. Here are **five** of the **problems** identified in these reports:

Student Attrition: Many students enter college with an interest in science and engineering but decide to switch to other fields. According to annual statistics reported by the National Science Foundation (NSF), approximately one-third of all incoming freshmen have traditionally considered majoring in science or engineering. However, half of all students who begin in the physical or biological sciences drop out of those fields by their senior year (compared with a 30 percent dropout rate in the humanities and social sciences). The attrition rates are even higher for underrepresented minorities.

Shirley Malcom, co-chair of the NSB commission and head of education and human resources programs for the American Association for the Advancement of Science (AAAS), says, "You have many students who come into the university planning to major in science or engineering. And then, all of a sudden, you look up … and they're not there anymore! You have people who were talented, interested and excited when they came in. Where did they go? Are people leaving or are they being pushed out?"

Poor Teaching: In their 1997 book, *Talking About Leaving: Why Undergraduates Leave the Sciences*, **Elaine Seymour** and **Nancy Hewitt**, from the University of Colorado, offer a number of reasons for attrition. However, the chief complaint — cited by 83 percent of respondents (including students who finished with majors in science, math and engineering) — was "poor teaching."

A number of experts interviewed for this article mentioned that introductory science classes are too often used as a way of weeding out students instead of cultivating them. Interviewees recounted a classic scene on the first day of class, when the teacher would say, "Look at the student to the left of you and the student to the right of you. By next semester one of them will be gone."

According to Malcom, the problem is not just poor teaching and poor course planning, but it's also the attitude of too many faculty that "if you can't make it, it's because you didn't know enough, you didn't try enough, and you aren't good enough." Malcom argues instead for teachers to ask themselves, "How did I fail to give you what you needed to understand?"

Learning Shortfalls: Research about teaching and learning reveals some surprising and disturbing results. **Jack Wilson**, a physicist and now president of the University of Massachusetts System, says, "When people started doing pre- and post-testing [to measure student knowledge before and after taking a course], they were shocked and staggered to learn that students weren't learning."

The traditional lecture format, a staple of introductory science classes for generations, actually fails miserably as a technique for encouraging student learning. Careful measurements reveal that students learn significantly less in a traditional lecture format (where they learn less than 30 percent of the important concepts) than in a setting with active engagement (where they learn about 65 percent of the important concepts).

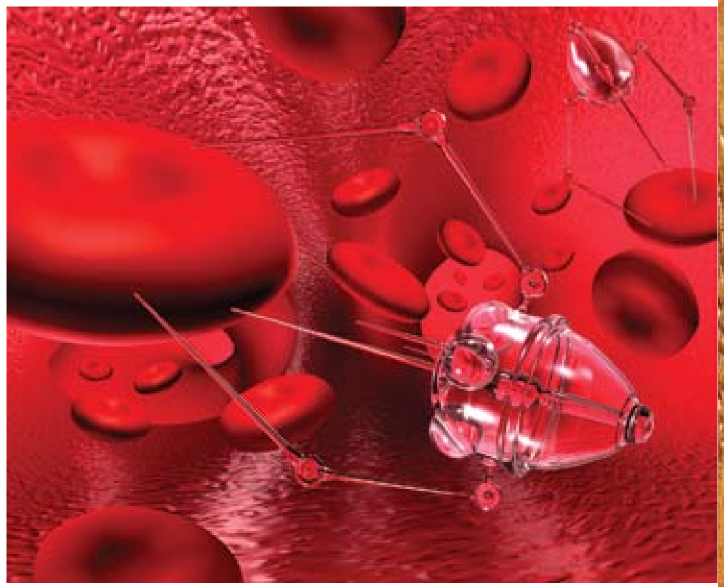
In another type of study, researchers measured whether students' beliefs about science resemble those of a "novice" or an "expert." (For example, a "novice" believes scientific knowledge is unrelated to the world and is handed down by authority, while an "expert" believes scientific knowledge is established by experiment and describes nature.) After taking an introductory course in chemistry or physics, most students were found to have fewer expert-like beliefs about science than before taking the course. Nobel laureate **Carl Wieman**, physicist and science educator, finds these results particularly troubling. Wieman observes there's a lot of nervous laughter in the audience when he describes this study to his colleagues during presentations about science education.

Wieman continues, "I argue that what you want in an education is to have someone understand science more like an expert. They're obviously not going to be a complete expert, but that's the direction you want to move them. The alternative is that science education is memorizing jargon and not much else. And that's obviously not of any use. Science education for anyone — whether they're going to be a scientist, a plumber or a lawyer — is really the ability to think about the subject and the world more like an expert scientist."

Corporate Panic: The 21st century economy relies heavily on science and technology, and business leaders are deeply concerned the United States is losing its competitiveness in an increasingly international marketplace. Nobel laureate **Leon Lederman**, who co-chairs the NSB commission with Malcom, believes the voices of business leaders are helping raise public awareness of the issue. Lederman says, "CEOs from major corporations are sounding notes of panic. They've outsourced everyone except their wives and children. We've survived on immigration, but Alan Greenspan has said that immigration will not keep us going."

Ron Bullock, chairman and CEO of Bison Gear and Engineering and a member of the NSB commission, points out that the demographics of the coming decades will present serious problems for our workforce. "For the past 20 years," he says, "businesses have relied on a 44 percent growth of the native-born workforce to provide a supply of new workers. That growth is over, and the native-born workforce will grow by zero percent over the next 20 years." As an additional problem, the level of educational attainment is "stagnant at best, and it may be in decline." At the very time when a skilled workforce is required to support innovation, the United States, for the first time in decades, no longer leads the world in the rate of college completion.

With estimates of up to a third of all STEM practitioners and half of all STEM teachers retiring in the next 10 years, Bullock states the challenge bluntly: "The Chinese are coming; the boomers are going. We're all facing this demographic shift. At the same time, we're creating additional new jobs, above and beyond the ones that need to be replaced as a result of retirement. We really have our work cut out for us going forward."



Science Illiteracy: Undergraduate science education must serve at least three purposes. First, it trains the scientists of the future. Second, it provides the foundation of information and knowledge required by many 21st century professions, from manufacturing to marketing to medicine. And finally, it provides all citizens and consumers with a foundation of science literacy.

As citizens and consumers, Americans are faced with many personal and societal issues that require scientific understanding, critical thinking and creative problem-solving skills. And yet the evidence is overwhelming that public literacy about science is appalling. "Science and Engineering Indicators 2006" (SEI 2006), a comprehensive document published every two years by the NSF, gives several examples:

- Less than half the American population accepts the theory of evolution.
- Most people have never heard of nanotechnology.
- Belief in various forms of pseudoscience is common in both the United States and other countries.

Perhaps most disturbing is the lack of progress in science literacy as we move into the 21st century. SEI 2006 concludes, "Science knowledge in the United States is not improving. Survey respondents' abilities to answer most questions about science have remained essentially unchanged since the 1990s."

BEHIND DOOR NO. 2: A New Paradigm for Undergraduate Science Education

"It's time for a new paradigm for science education," says **Nicholas Turro**, professor of chemistry at Columbia University and recipient of an NSF Director's Award for Distinguished Teaching Scholars. "Instead of trying to teach all the details of science, it's time to start teaching the practice of science."

Turro places the choice faced by science educators in a broad historical context. "During the early part of the 20th century, law schools, starting with Harvard Law School, introduced the case study method. They decided that instead of teaching all the details of the law, they would teach the practice of law. Case study methods are also used extensively in the teaching of business and medicine."

With this change of perspective, the central role of the student becomes clear. Turro continues, "It's not the transfer of information that's important, it's the assimilation of information. And assimilation takes place in the mind of the student."

Teaching students the practice and process of science involves transforming many elements of the traditional lecture-based, fact-based approach. The transformation touches all aspects of education — from content and curriculum, to pedagogy and assessment, to faculty training and development.

The new paradigm for science education brings the intellectual challenge of science, as practiced by research scientists, into the classrooms and the daily lives of students and teachers.

Researcher and educator Wieman describes it this way: "I approach teaching exactly the way I approach scientific research. I have clear goals. I have clear measurements. I figure out what the past research says and what the guiding principles are. I guide what I do by that, and I measure if it works. And if it doesn't work, I try something different until it does."

Wieman's example is worth noting, because his achievements in research and teaching are of the highest order. On the research side, he won the Nobel Prize in Physics in 2001, along with **Eric Cornell** and **Wolfgang Ketterle**, for creating a new state of matter — the Bose-Einstein condensate. On the teaching side, he was honored as Professor of the Year in 2004 by the Carnegie Foundation for the Advancement of Teaching and the Council for Advancement and Support of Education.

However, you don't have to be a Nobel laureate to embrace and practice a new paradigm. Across the country there are many outstanding examples of science education being practiced by individuals, departments and institutions. This article mentions a few of them, and many more can be found by exploring some of the websites and resources outlined in the bibliography.

MOVING FROM DOOR NO. 1 TO DOOR NO. 2 — Barriers

INERTIA AND CONSERVATISM   THE TENURE RAT RACE   LACK OF MEASUREMENT   POOR COMMUNICATION

Although more teachers and students want to spend their time behind Door No. 2, the transition from one way of teaching to another is not easy. Here are four of the most difficult barriers that stand in the way of change:

1) INERTIA AND CONSERVATISM — both individual and departmental — mitigate against science education reform.

When **Sir Isaac Newton** described the concept of inertia in his first law of motion, he could have been talking about the world of undergraduate science education: The system of science education that's been in place for generations tends to stay in place.

John Moore, editor of the Journal of Chemical Education and a chemistry professor at UW-Madison, says, "There's a lot of inertia in the system. A lot of people who have been teaching for a long time tend to be conservative about both content and pedagogy. They aren't as amenable to change as they might be."

Passionate educator **Bruce Alberts**, former president of the National Academy of Sciences and a biologist at the University of California, San Francisco, says, "You've got to shake people up, because we're very comfortable. Once you have your lecture notes and you've taught Biology 101 four times, why should you change anything? It's easy to just keep teaching in the same way."

Young faculty members face so many demands on their time and attention that they also find it difficult to change the system. As **Jo Handelsman**, microbiology professor at UW-Madison, says, "Changing one's approach to teaching takes time. Using the traditional method doesn't."

The AAAS's Malcom says, "You've got to expect that people will fight it. Why should they change? This is not easy. It's easy to do what we always did. It's not easy to all of a sudden say, 'I never really learned how to teach. I never learned how students learn. I never learned the different strategies that students who have different styles of learning might need in order to be successful in these classes.' "

William Wood, editor of CBE: Life Sciences Education and a biology professor at the University of Colorado, Boulder, says that it's not just a lack of time and interest. "Most scientists at big research universities aren't aware of what's been going on in educational research and cognitive psychology, and they're surprised to see evidence that the lecture system we've used for so long doesn't work very well in terms of student learning. They tend to say, 'I came up through the lecture system and I did fine. All my colleagues did, too, and they're all successful academics. So what's the problem?' I think it's ironic, particularly for biologists, to draw that conclusion, because it's just a process of selection. People in academia have been selected by the environment to which they were exposed. It doesn't mean the environment is optimal. It just means that they were able to survive in it."

Even if individual teachers want to change, the structure of the system makes it challenging. For example, the system for passing along knowledge to the next generation — a structure built out of specific curricula, textbooks and requirements for a major — is organized and controlled by discipline-based departments. And yet today's science is increasingly interdisciplinary.

When **Darcy Kelley**, a neurobiology professor at Columbia University, suggested a new approach for introducing science to undergraduates — an approach that would cut across many disciplines — she ran into opposition from each department. She says, "There's a real guild mentality. I encountered enormous resistance. One famous professor said the change would happen 'over my dead body.' Fortunately, I was able to find at least one professor in each department willing to try something different."

Even the students themselves are a source of inertia. Several interviewees observed that new pedagogical approaches should be introduced first at the introductory levels, because juniors and seniors, who have already established their study habits and classroom strategies, are more opposed to — and vocal about — any attempts to introduce change.

UMass's Wilson summed it up this way: "The major obstacle to science education reform is our history and past practices. We've been doing it a certain way, and we've accustomed ourselves to thinking it's the right way. We have created in science education the equivalent of the 'Russian employment contract.' There used to be a joke in Russia — 'They pretend to pay us; we pretend to work. Nobody asks too many questions; everyone is happy.' Well, we've created an education system where we pretend to teach them; they pretend to learn. Nobody asks too many questions; everybody is happy."

2) THE TENURE RAT RACE at research universities strongly rewards research, not teaching.

In the last half of the 20th century, the American system of scientific research became the strongest in the world. With generous support from government, industry and private foundations, America's research universities built an imposing infrastructure of people, facilities and administrative organizations. However, it came at a cost to undergraduate education.

Bassam Shakhashiri, chemistry professor at UW-Madison and former assistant director for science and engineering education at the NSF, says, "The federal government and the private foundations have been very successful in capturing the intellect and the emotional involvement of scientists to do research… and the outcome has been valuable for society. The faculty themselves are narrowly and sharply focused (as they should be) on their research programs. However, they should put that in a bigger context and find more effective ways

to engage undergraduates. The most important part is developing an attitude on the part of the faculty that shows they care for the students and the future these students have — whether or not they are going to be science majors."

Jeanne Narum, director of Project Kaleidoscope, networks extensively with scientists across the country involved in science education reform. Reporting on what she's seen and heard from this network, she says, "Institutional policies still recognize and reward research excellence more than teaching excellence. It's all right if you do teaching reform on the side, but you're going to get evaluated, tenured and promoted based on the research dollars and the indirect costs that you bring in."

UCSF's Alberts says, "Unfortunately, what happens now is that too many people are rewarded by the outside grants that they get, and there aren't many grants for doing the important things in education."

When a young scientist joins the faculty at a research university, he or she must make decisions about how to prioritize time and energy. The "rules" that reward research over teaching may be unwritten, but they are unmistakable at most research institutions. **Nate Lewis**, chemistry professor at the California Institute of Technology, says, "People respond to those ground rules. They see those signals and have to play within those rules."

Being a good teacher won't help young professors win tenure; it might even hurt their chances. **James H. Stith**, vice president of the Physics Resources Center for the American Institute of Physics (AIP), says, "In physics, you used to hear that an outstanding teaching award was the kiss of death for a young professor."

AAAS's Malcom says, "Think about the psychology of it. If you don't do your job, you will not be punished. And if you do it, you will not be rewarded — and you may even be punished. You'll be punished because people will look and say, 'It's obvious that as much time, energy and effort that this person is putting into teaching, they aren't putting enough time, energy and effort into research.'"

The priority of research over teaching is most clear at research universities. At primarily undergraduate institutions, such as liberal arts colleges, comprehensive regional universities and two-year colleges, the focus on teaching is stronger. Lewis says, "There's a lot of great stuff going on at the smaller schools — the Swarthmores, Carletons, Williamses and Kenyon colleges. They have much closer and sustained interaction with undergraduate students than you would typically see at a much bigger state school or research university."

Malcom agrees, observing, "There are many institutions where the reward system isn't built on research — the liberal arts colleges, the women's institutions, the minority-serving institutions, the historically black colleges."

However, faculty at these primarily undergraduate institutions were themselves trained as graduate students and post-docs at research universities. Therefore, the culture, values and unwritten rules found at the prestigious research universities tend to point the direction that others will follow. Scientists, like other people, respond to their culture and colleagues. Malcom puts the challenge this way: "Can they stand up against the constant framing of what a career needs to look like?"

3) LACK OF MEASUREMENT of teaching effectiveness and student learning.

While doing their scientific research — whether in particle physics, protein folding or cell signaling — scientists follow a well-established process. They propose hypotheses, design rigorous experiments, collect and analyze data and compare results with others. Then they adjust accordingly and start the process over again. When they enter the classroom to do their teaching, however, this process is usually forgotten or ignored.

Too often, instead, teachers base their choices about content and pedagogy on their own experiences as students and their beliefs about teaching and learning. **Eric Mazur**, a physicist at Harvard University, says, "Every day, I see colleagues abandon all pretense of the scientific method. As scientists, we have very naïve beliefs about learning and seeing. We have lots to learn from cognitive psychology."

Teachers also base their choices on intuition and anecdote. But as Columbia's Turro points out, "The plural of anecdote is not data."

The type of experimental design and data that physicists, chemists and molecular biologists associate with the scientific process is not easily available when it comes to measuring learning. **Mary Kirchhoff**, director of education at the American Chemical Society (ACS), says, "It's extraordinarily difficult to get good metrics, because there are so many variables."

Peter Bruns, vice president for grants and special programs at the Howard Hughes Medical Institute (HHMI), agrees. "It's difficult. One of the problems is: What is a control? To what do you make comparisons? We can see whether innovation is happening, and we can determine whether students and faculty adopt and like it. But what kind of difference it makes is a different and very difficult question to address."

UMass's Wilson illustrates the challenge of properly assessing teaching and learning with this scenario: "If you go into a classroom and find a faculty member giving a brilliant lecture, and the students reading the newspaper or sleeping, that isn't an interactive classroom. In an interactive class you might find the students doing brilliant things, and the faculty member sleeping. Of course that's a joke, but it's a joke with an edge. The edge is this: Too many people think that science education is about how great a teacher you are and not about how much the students learn. We have to redefine what it means to be a great teacher. A great teacher is someone who generates a lot of learning in your students. Unfortunately in the evaluation process for tenure, that's not what it's about. It's about whether you're a popular teacher and what do your teacher evaluations look like. That's good stuff and it's important, but it doesn't get to the issue of student learning at all."

CU-Boulder's Wood says, "We don't have a good way to measure teaching effectiveness, so it would be difficult for universities to reward superior teaching, even if they wanted to. If you just use student evaluations, it's clear that it's not a good measure of what students learn in a course. Maybe they liked it a lot, had a good time or got a good grade, but there hasn't been a way to measure how much they actually learn."

Robert Shelton, a physicist and president of the University of Arizona, says, "That's a really important and difficult question: How do you measure outcomes and the value added? Are your students knowledgeable and insightful simply because they came to you with knowledge and insight, or have you grown it? All the universities and accrediting bodies are struggling with this."

Nobel laureate Wieman also points to the need for new and better measurements. "We don't have valid ways to measure teaching in a widespread way. We've got student evaluations, and everyone knows how flawed they are as a measure of what students are really learning. Part of being scientific about it is to develop the tools so that we can evaluate in a meaningful way what students are learning. Then you can worry about a reward system that takes that into account."

4) POOR COMMUNICATION is endemic when it comes to teaching science, even though scientists excel at spreading the word about research.

The "scientific community" actually comprises a multitude of smaller communities organized by discipline, sub-discipline, academic department or research group. Within all these communities, formal and informal means of communication ensure that ideas, data,

innovations, techniques, materials, news, successes and failures — even gossip and rumors — are shared broadly and quickly. Effective scientific communication methods include peer-reviewed journals, online databases, weekly departmental seminars, small conferences in comfortable surroundings as well and large national meetings in major convention centers. Equally important are informal interactions, whether typed as an e-mail message, diagrammed on an office chalkboard or scribbled on a paper napkin at a coffee shop or bar.

Ironically, these networks serving the scientific community so well for information exchange about research are too rarely used for discussions about teaching.

The AIP's Stith says, "When we meet over the coffeepot, we talk about research. We don't talk a lot about teaching. When do we have conversations within our departments about teaching — about what's effective, how students learn, and how we can assess what we're doing? We didn't have a lot of these discussions when I was on the faculty [at a large, research university]. I was led to believe, from talking to my colleagues at other institutions, that my experience wasn't an exception."

Caltech's Lewis, says, "Communication is the big barrier. We don't have much personal transfer of information. There's a lack of familiarity with new techniques for teaching. It's difficult to find what else is working. You can learn about new techniques, but you have to be at the conferences where they talk about it. You have to be predisposed to make an effort. It's different from your research program where seminar speakers just come through and it's natural that you talk with them. Scientists go to scientific meetings and it's natural that you go and talk about science. It's definitely a different skill set and value proposition in the research enterprise than it is in the teaching enterprise."

MOVING FROM DOOR NO. 1 TO DOOR NO. 2: Six Strategies That Work

CHANGE ADOPT MEASURE EMBRACE ADAPT SUPPORT

While many of the reports of the past several decades have focused on documenting science education problems, scientists and educators have also been making great strides in developing and documenting science education strategies that work. The strategies and innovations come in many shapes, sizes and flavors, but a common core of principles can be distilled. If you, your students, your department and your institution want to spend less time behind Door No. 1 and more time behind Door No. 2, here are six of those common ideas to get you started.

One outstanding publication that captures the essence of the "new" science education and deserves special attention is *Scientific Teaching* by Handelsman, **Sarah Miller** and **Christine Pfund** (Wisconsin Program for Scientific Teaching, 2006). This book provides an excellent resource full of relevant background information documenting the strong case for a more scientific approach to science education, and it's also full of practical ideas for immediate implementation in the classroom.)

1) CHANGE course content to better reflect the process of science and its role in today's world.

Science and technology's role has changed remarkably in the past several decades, and the changes continue to accelerate. To engage students, both majors and non-majors, the content of science courses and textbooks must be brought into the 21st century. Here are some of the new approaches being adopted by leaders in the new science education:

Teach the content within the context of a larger societal issue, a relevant story or timely topic. Several textbooks developed in the past 10-15 years by the ACS have re-organized the way introductory chemistry is taught to high school students (*Chemistry in the Community*), to freshman non-majors (*Chemistry in Context*), and to freshman chemistry majors (*Chemistry*). In each case, according to the ACS's Kirchhoff, the textbooks "are very much focused on learning chemistry in a broader context, for example in the context of environmental or health issues."

Nobel laureate **Dudley Herschbach** taught a large introductory chemistry class to Harvard undergraduates for almost two decades. The general education course, numbered "Chemistry 10" in the catalog, became known as "Chemistry Zen" because of Herschbach's approach, which he calls his "method of parables." In articles describing his philosophy, Herschbach writes, "Most students taking freshman chemistry have already had a high school course. Thus, they have encountered many standard topics, such as the gas laws, acids and bases, covalent bonding, etc. However, rarely do students have any notion of how such prototypical concepts emerged, how widely applicable they are, or how they affected other developments. In view of this, in my lectures I now introduce each major topic with a story, usually having the character of a parable. By presenting science in a more humanistic mode, these parables can disarm fears, reveal a much broader context for nominally familiar concepts, and even induce students to relate the tales to others."

A different approach used successfully by a number of chemistry departments capitalizes on the recent popularity of the *CSI* (Crime Scene Investigation) television series. At the University of California, San Diego, for example, Cottrell Scholar **Seth Cohen** uses forensics and criminalistics as the focus for teaching some introductory chemistry. As one exercise near the end of the course, students analyze and critique the science and instrumentation portrayed in an episode of the television show.

Introduce students early on to the interdisciplinary nature of today's science. Judith Ramaley, president of Winona State University and former NSF assistant director for science and engineering education, says, "Disciplines haven't ceased to matter, but they are no longer the bounds for our conversation. A lot of the problems that I've encountered in recent years are related to this question: How do you make the undergraduate experience resemble in any way what a real scientist does?"

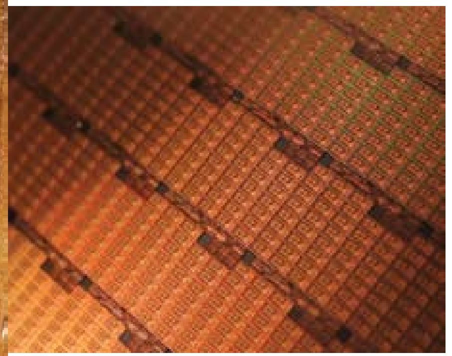
Traditional discipline-based courses across college campuses are being revamped to include related disciplines. For example, *Chemistry*, the ACS textbook for freshman chemistry majors, has a strong biological emphasis. A 2003 NRC report, "BIO2010: Transforming Undergraduate Education for Future Research Biologists," recommends:

> "Faculty in biology, mathematics and physical science must work collaboratively to find ways of integrating mathematics and physical sciences into life science courses as well as providing avenues for incorporating life science examples that reflect the emerging nature of the discipline into courses taught in mathematics and physical sciences."

Introduce mathematics into science courses at the appropriate time and place for that particular group of students. As mentioned above, biology courses are being revised to make them more quantitative, reflecting the evolution of the science itself. **Claudia Neuhauser** is an applied mathematician and chair of the Department of Ecology, Evolution and Behavior at the University of Minnesota, Twin Cities. She's also an HHMI Professor, and according to HHMI's Bruns, Neuhauser is using her award to build a statistics course around biological problems, add mathematical lessons to the freshman biology laboratory course and help other faculty incorporate math into their teaching.

"Today, most undergraduate biology majors take quite a bit of basic quantitative coursework early on, but then they never see it again," Neuhauser says. "A few years later, when they're graduate students, they encounter the new world of biology, full of massive amounts of data and analysis — and they're not prepared. We've got to change that."

For some types of introductory science courses and general students, however, the best approach is to subtract — rather than add — the mathematics. The UA's Shelton says, "I've seen [at the UA and the University of North Carolina, Chapel Hill] creative classes that recognize you don't have to have many years of math to be effective in science education for the general education students. The quantitative approach doesn't appeal to everybody, but people have a natural fascination with science. We have to reach them without getting bogged down in massive amounts of equations. So now you have more general-ed science classes that speak to phenomena around you. These classes help people relate to their world with some scientific thinking, whether it's high-speed trains or the latest in semiconductor technologies and how they work. To me — and I don't know whether a physicist should say this — this is the more important aspect of science education."



2) ADOPT teaching methods that engage students in active learning.

"Active learning" is not a new idea or just a current fad. Since **Socrates** and **Plato**, effective teachers have engaged their students in the process of assimilating information and constructing knowledge. As discussed in greater detail in Handelsman's *Scientific Teaching*, "active learning includes a variety of methods. The common feature is that all students in a classroom need to do something. It may be quietly thinking, discussing an idea in a group, conducting an experiment or writing a question or idea. The key is to engage students so they are constructing knowledge." With this perspective, the focus changes from the teacher to the student, from teaching to learning.

The starting place for active learning is with the students' current ideas and conceptions about a subject. Often those conceptions are actually misconceptions. Students can see and interpret the world quite differently from the teacher. Wieman describes what happens when he and his colleagues test computer simulations they've developed to help their students understand certain phenomena and concepts. Wieman says, "We have something we think is really clear and shows what we want. And then students will just literally see a different thing happening on the computer screen. It's always a surprise. But once you can see how they are perceiving it and understand why, then you can teach so much more effectively. If you really don't understand how a novice thinks, you can talk to them all day long and they'll just be baffled."

Pedagogical approaches for active learning

Innovative science educators have developed a number of different approaches to bring active learning into their classrooms. Some approaches will work better for particular teachers, subjects, institutions and groups of students. To be truly effective, each approach must be adapted and tailored to the specific situation by a skilled teacher. As Herschbach says, "We've all heard the saying that 'all politics is local.' Well, all teaching is local, too."

Here are four innovative approaches being used in science classrooms today:

- **Peer Instruction**, developed and championed by Mazur (see mazur-www.harvard.edu/education), provides a method for collaborative learning in a large lecture format. The method's effectiveness has been established by a number of studies, and the approach has been adopted by teachers throughout the physics community. In the chemistry community, many of the same guiding principles are used in the method called "Peer led team learning" (PLTL, see www.pltl.org).

- **Process Oriented, Guided Inquiry Learning** (POGIL, see www.pogil.org) teaches scientific content and key process skills (e.g., ability to think analytically, ability to work effectively as part of a collaborative team) simultaneously in a classroom or laboratory. POGIL students work in small groups on specially designed guided inquiry materials, with the instructor serving as a facilitator.

- **Just-In-Time-Teaching** (JiTT, see www.jitt.org) incorporates web-based study assignments with an active-learner classroom. For example, students might be expected to respond electronically to a warm-up activity, a puzzle or an enrichment essay. The short assignments prompt the student to think about the upcoming lesson, and the assignments are due shortly before class (for today's undergrads that frequently means about 2 a.m.). The teacher can then read the students' responses "just-in-time" to adjust the classroom lecture to better fit the students' understanding and needs.

- **Teachable Tidbits** is the name that UW-Madison's Handelsman and colleagues use for an active learning activity; tidbits are just one small part of a "teachable unit." As described in Chapter 5 of *Scientific Teaching*, a teachable unit includes learning goals, intended learning outcomes, assessment activities and classroom activities. A teachable unit might contain materials for one class, a series of classes or an entire course.

Technologies to promote active learning

Science educators are taking full advantage of new technologies and applying them to bring active learning to more students. Project Kaleidoscope's Narum believes technology has been one of the three main driving forces in science education reform over the past 20 years. She says, "We've seen a growing confluence of three factors — technology, research on learning and cognitive science, and a growing group of pedagogical pioneers who were communicating with each other."

Here are three examples that illustrate how the power of technology is being harnessed to improve student learning:

- Before introductory chemistry students at UW-Madison walk into the laboratory, they're able to log on to their computers and review a set of **web pages** that include text, images, video and self-check questions. The topics include those commonly found in the first-year chemistry laboratory, everything from balances and burets to separatory funnels and spectrophotometers. These pre-lab websites are just one subset of a much larger set of software and online tools developed for UW chemistry students. One of the more popular programs is "Periodic Table Live!" It's an interactive program providing a wealth of information about the elements, including descriptions and pictures, biographies of discoverers, videos of reactions, information about sources and uses, numerical values of macro-scale and atomic-scale properties and crystal structures.

- Chemist Turro turned to **interactive software** when he wanted to give his Columbia University students a better grasp of IR (infrared) spectroscopy, an important tool for understanding molecular structure. In an article describing his approach to using information technology in the teaching of chemistry, Turro writes, "We grounded this software in what we knew would help students learn: We made it interactive to increase their engagement with the material; we used a lot of visualizations to give students a variety of ways to understand the data and help visual learners; and we tried to put the material into broad contexts of chemistry… This turned out to be a great program, especially for giving people introductory information on IR. In fact, I got my brother-in-law who knows no chemistry to use it, and in 20 minutes he was interpreting IR spectra." Encouraged by the success and effectiveness of this software, Turro and colleagues, with support from NSF and Columbia University, helped establish the Columbia Center for New Media Teaching and Learning.

- In a growing number of science lecture halls, students grab **"clickers"** as they walk into class. Known more formally as "electronic audience response systems," clickers are keypads into which students enter answers to a question. Individual responses are transmitted by infrared or radio waves to a central receiver, where the distribution of responses can be calculated and displayed. CU-Boulder's Wood, a strong proponent for using clickers to engage students and make lectures more interactive, writes, "They can produce results that are eye-opening and potentially of great value to both students and instructors for enhancing the learning process… The give-and-take atmosphere encouraged by the use of clickers, in our experience, makes the students more responsive in general." In his lectures, Wood typically poses a conceptual multiple-choice question that includes a common misconception (anticipated from past experience), such that around half the students choose the wrong answer. "When the results come up," he says, "they create palpable tension in the class around wondering who's right and wanting to identify the correct answer. The best way to exploit this 'teachable moment,' in my view, is to tell them that my previous explanation of the concept was as clear as I could make it, and they should simply debate among themselves and try to convince one another about who is right, after which we'll re-vote. Almost always, the distribution shifts from about 50 percent to greater than 90 percent correct. They are very good at identifying each other's misconceptions and setting them straight. This is obviously Mazur's Peer Instruction in action!" Wood has been introducing clicker technology to his biology colleagues at seminars, conferences and workshops. He says, "The first presentation I did was about three years ago, and only 10-15 percent of the audience members were familiar with clickers. Today, when I give a presentation, it's more like 50 percent. The response has been pretty positive." (More details about the technology and pedagogy of clickers are available in a special section of the Spring 2007 issue of CBE: Life Sciences Education.*)*

3) MEASURE whatever it is that you want to understand, change and improve.

In *Scientific Teaching*, Handelsman, Miller and Pfund write, "Assessment should seem natural to scientists because it parallels parts of scientific research. In science, data collection is central to discovery; in scientific teaching, instructors collect data to evaluate teaching and learning. The information generated by assessment is crucial because it informs choices, making assessment the fulcrum of scientific teaching."

Handelsman and colleagues also note, however, that assessment is probably the most ignored part of good teaching. They devote an entire chapter to assessment, presenting the philosophy and the cognitive psychology of assessment, as well as a series of practical guidelines for designing an assessment plan.

The use of measurement to enhance teaching and learning occurs on at least four levels and time scales.

Ongoing assessment: Also called "formative assessment," this process occurs every day as students sit in classrooms, work in labs and study in the library. Regular, ongoing assessment is a tool for understanding what students are learning. When used frequently, it helps promote and diagnose learning. This type of assessment is far more than just a grading process; it provides feedback to both students and instructors. In Mazur's Peer Instruction method, students use "ConcepTests." In Handelsman's scientific teaching approach, she calls them "enGAUGEments." For example, during a lecture, a professor might pose a multiple-choice question to students, who could use their clickers to record their initial answers. Then, after brief discussions with neighbors, they could answer the question again. Finally, the professor could use this feedback to focus the remaining minutes of the lecture.

Tests and grades: Also called "summative assessment," it is usually associated with the exams and grades that come at the end of a unit or course. As the content and pedagogy of science classes evolve in the directions outlined in this article, so too must exams and evaluations evolve. Biology professor **Graham Walker** notes that as the MIT introductory biology curriculum moved to an increased emphasis on understanding concepts (and a decreased emphasis on memorizing a multitude of facts), "we had to change how we designed our tests."

Concept inventories and metrics for student learning: Science education took a big step forward in the 1990s with the creation and application of a 29-item, multiple-choice test called the Force Concept Inventory (FCI). Developed by **David Hestenes** of Arizona State University and physics education colleagues, this test probes students' concepts about how motions and forces work in the world around them. Through the series of forced-choice questions, students must choose between Newtonian concepts and commonsense alternatives. Hestenes writes, "The first impression of most physics professors is that the Inventory questions are too trivial to be informative. This turns to shock when they discover how poorly their own students perform on it."

For the first time, FCI gave teachers a simple instrument for measuring student learning in a science class. If students take the test before and after completing an introductory course, how much have they learned? How do scores change as variables such as curriculum and pedagogy are changed?

Using the Force Concept Inventory, physics educators began to design, conduct and analyze educational research experiments. The solid data and results have gone a long way toward encouraging teachers to reform physics education by addressing directly students' conceptions and misconceptions using the tools of active learning.

Inspired by the physics community's success with FCI, chemists and biologists are working to develop and apply concept inventories in their disciplines. Two examples of such efforts are the Biology Concept Framework (BCF) proposed by Walker and colleagues at MIT and the Chemical Concepts Inventory (CCI) developed by **Douglas Mulford** at Purdue University.

Longitudinal studies of student learning: A number of science educators interviewed for this article highlighted the importance of taking a long-term look at student learning. Instead of just asking for student evaluations on the last day of class, what if students were asked about the value of a class one or two — or even five — years after completing a course?

The UA's Shelton says, "We need to start following a subset of our students after they graduate. We need to see whether what we've done in our science classes makes a difference in how they view the world. We need to ask them, two years and five years post graduation, do you remember this class? Did it provide any long-lasting sense of knowledge that you're using in your everyday life? I'm not talking about physics and chemistry majors, I'm talking about the citizen who's not a scientist." Shelton suggests that it would be a good outcome if a student said, "You know that class I took from Professor So-and-so really helped me understand more when I read my water department's analysis of trace minerals in my water. I understand now that a little bit of zinc isn't bad, but a lot is really bad."

4) EMBRACE diversity to reach more students and improve science.

Diversity is one of the three key elements (along with active learning and assessment) in the "scientific teaching" approach outlined by Handelsman and colleagues in their book and workshops. The word "diversity" refers not only to demographic diversity, but also diversity in learning and teaching styles.

Handelsman points out that paying attention to diversity will bring benefits to science and society. "Research shows that various elements of diversity foster good science. Anyone who has ever run a research group knows that. If you have 10 clonal people in your groups, you'd have a lot less interesting ideas in science than if you have 10 people with different experiences, education, age, philosophy and, perhaps, race and gender. To me, the essence of research is that it's done by people, and it's better when done by diverse people. Could science be a lot better if we engaged a broader spectrum of people in it?"

To bring the benefits of diversity to science (and ultimately to society), the place to start is with the science education system. Handelsman says, "There's no question that our education system discriminates against certain types of people — people who don't memorize well don't make it in science, and people who don't think in terms of classification schemes have a very hard time with [our current] undergraduate curriculum. Maybe the people who have hard times are really creative and thoughtful and would make brilliant scientists. We don't know because we screen them out of the system so quickly."

She adds, "Diversity of cognitive styles is probably the most important kind of diversity that a teacher needs to think about. Every time you make a classroom decision, you're excluding someone in that class because it just doesn't fit their personality or their cognitive style. The only answer to that is to use a variety of methods. Then assess what you do and see if it's successful for most students. And then figure out a way to help students — the ones it doesn't work for — to compensate in some way."

Just as students have diverse learning styles, scientists need to have diverse teaching styles.

The ACS's Kirchhoff says, "You have to be more flexible in terms of your approaches to teaching and the different strategies you try. I learned a lot from my colleagues in education who talked about trying to address all students' learning styles during the course of a single class period. Some students do learn through the lecture method. Others need a demonstration. Others need to be working in small groups and talking through a problem. So I think the research that's gone into those different pedagogies and the benefits of them have really helped to influence faculty members in the way they approach their teaching."

Not every teacher will be comfortable with every teaching style; teachers have diverse cognitive styles and personalities, too. Kirchhoff says, "There are a lot of different options out there … It depends so much on the faculty member. If it's not a method they're comfortable with, then it's never going to be effective in the classroom. Students pick up on that. Some like PLTL. Some like POGIL, but others find it very frustrating."

Just as paying attention to diverse cognitive styles of students and teachers is critical in science education reform, so too is paying attention to demographic diversity.

Shelton emphasizes the importance of attracting bright women and minorities to science. "There are pockets of success, but we are not, in the country as a whole, attracting bright women and minorities to the sciences in the numbers that we could do. There's so much talent out there and we aren't attracting it."

While acknowledging that the issue has many facets, he says, "I think a lot of it is role models." Shelton points to an example that he witnessed while provost at the University of North Carolina. "When we had a woman as the physics department chair, the number of graduate student applications and acceptances from women skyrocketed. The classes were 50 percent women coming in." As a university administrator, Shelton says, "I've insisted to my deans that diversity is one of the factors we consider when we're searching [for new faculty]. I want to see them go out and aggressively find a broad, diverse pool of highly qualified candidates. The people are there; we just have to work harder to bring them in."

One of the special challenges in attracting diverse role models, Shelton says, is that "talented women and minorities can get paid a lot more in the corporate world." He adds, "I think the private sector should help us on this. We're going to produce the scientists of the future, so they have to work with us on this."

Increasingly, today's undergraduate student population includes "nontraditional" students, such as adults 25 years or older, single parents and part-time students. Not all undergraduates begin as freshmen at the age of 18 and graduate within six years. Bison Gear CEO Bullock points out that almost three-fourths of American undergraduates are "nontraditional" in some way, and that nearly two-thirds of highly untraditional students attend community colleges. When modifying course content and pedagogy and assessing the effectiveness of their teaching, scientists will need to take account of this highly diverse group of students.

5) ADAPT effective communication channels and techniques, originally developed for research communication, to communicate about teaching and education.

Although scientists have tended to be poor communicators about teaching, there are notable signs of change. Increasingly scientists are taking advantage of established structures first developed for research communications and increasingly using them to network about educational innovations, techniques and strategies.

Publications: Peer-reviewed journals provide the foundation for communication in the scientific community, serving as a forum where ideas and data are validated, debated and archived. For many years the chemistry and physics communities have published respected journals devoted to education within their disciplines. The Journal of Chemical Education was established in 1924 by Neil Gordon, who simultaneously founded the American Chemical Society's Division of Chemical Education; the American Journal of Physics was first published in 1933 by the American Association of Physics Teachers.

These journals, along with new publications devoted to discipline-based educational research (DBER) in various areas, have continued to thrive and evolve as the landscape has changed. For example, UW-Madison's Moore, editor of the Journal of Chemical Education, says, "In the last few years, we've published an increasing number of articles co-authored by chemists at research universities. I think this is influenced by the NSF's requirement that grants have a component that considers 'broader impacts.' At large NSF-funded centers, such as the Nanoscale Science and Engineering Center and the Materials Research Science and Engineering Center here at UW-Madison, the organizations are required to have an education outreach coordinator and program. So quite a few research people are now developing new materials and programs and then reporting on them in our journal."

In 2002, the American Society for Cell Biology launched a free, online quarterly journal. Originally titled Cell Biology Education, the name was changed in 2006 to CBE: Life Sciences Education to better reflect the breadth of its readership and the scope of its coverage.

Starting in 2006, Science magazine, which has a broad and influential readership across the entire scientific community, began to publish a series of articles in a new section called "Education Forum." In an editorial announcing the inauguration of this section (Science, December 16, 2005), **Donald Kennedy**, editor of Science, and **Thomas Cech**, HHMI president, wrote, "We want to showcase new approaches to teaching that work even in large lecture classes, or bring other disciplines, such as physics and computer sciences, together with biology into a single course. Learning is not a spectator sport, and through active involvement in the material, students will understand and retain concepts much better… We want to help faculty do what they would all love to do — teach better with less struggle."

The growing presence of peer-reviewed journals in science education provides a healthy sign that more scientists are beginning to accord education the respect it deserves. Here are additional tried-and-true methods easily adapted to serve the interest of science education:

Research groups: An increasing number of universities offer Ph.D. degrees with a focus on chemistry education, physics education or mathematics education. Within these departments, active research groups bring together a nucleus of interested colleagues — graduate students, post-docs and senior scientists — who share, collaborate, debate, critique and publish within their specialty. In other departments a senior scientist's research group might include a mix of students, some interested primarily in research about teaching and learning, and others interested primarily in basic scientific research. Harvard's Mazur always has students of both types in his physics research group and finds the mix to be extremely helpful.

When MIT biologist Walker was named as an HHMI Professor, he turned to the research group model. "When I got the HHMI professorship, I realized it was the same amount of money that you would typically get for an NIH grant [$1 million for a five-year period], so I started thinking about the way we do research and how we do teaching." When he put out the word that he was forming a group to focus on teaching and education, he received an enthusiastic response from grad students, post-docs and faculty — and not just from MIT. Walker says, "There's a tremendous desire for people to do more in education. It was unbelievably exciting these ideas that bubbled up." He compares his research group to a seed crystal added to a saturated solution.

Small specialty conferences and summer workshops: Since 1994 the chemistry education community has held a Gordon Research Conference on Chemistry Education Research and Practice. Topics discussed in recent years include measuring student learning, visualization and language in learning chemistry and learning within cultural contexts.

For the past three years, the National Academies and HHMI have conducted a summer institute at UW-Madison. Small teams from 15-20 different departments across the country gather for the five-day National Academies Summer Institute on Undergraduate Education in Biology. Each team includes two or three faculty members, with both a senior and junior scientist and sometimes an administrator. The goal of the institute is "to transform biology education at research universities by improving classroom education and attracting more diverse students to research." The objective is to train a new generation of faculty by introducing them to a scientific approach to teaching that reflects the way researchers function. Workshop participants learn about and practice the elements of scientific teaching, from active learning to assessment to diversity.

Workshop co-chairs Handelsman and Wood believe it's making a difference back on the college campuses. And true to the spirit of scientific research, the impact and effectiveness of the summer institutes are being carefully measured and analyzed by science professionals with expertise in program metrics.

Research Corporation holds a three-day conference each summer for its Cottrell Scholars, a select group of young scientists dedicated to excellence in both research and teaching at their research universities. Recent awardees get a chance to meet Cottrell Scholars from previous years and to learn from two invited senior scientists who exemplify the teacher-scholar model. **Martin Gruebele**, a chemist from the University of Illinois at Urbana-Champaign and a 1995 Cottrell Scholar, has attended several conferences. He says, "The Research Corporation staff had told us that the conference was different from other meetings we'd been to before. The most pleasant surprise was that people were talking about teaching. As a faculty member, I go to 20 meetings a year to talk about my research, but the Cottrell Scholar conference has been the only small, cozy meeting that is geared to teaching."

Departmental seminars: Nearly every week, in nearly every science department at most research universities, invited scientists meet with faculty and students and present seminars. At the UW-Madison chemistry department, some of these invitees are specialists in science education. UW-Madison's Moore, who currently has four graduate students working on topics related to science education, says, "We invite people to give seminars and the students can go and ask them, 'I've got these data, what should I be doing?'"

Faculty meetings and colloquia: At some institutions, faculty meetings include a discussion of education issues. The AIP's Stith recalls the value of such meetings when he was on the physics faculty at the U.S. Military Academy at West Point. "We would meet with the entire faculty to talk about our philosophy of teaching, about the kinds of things that students had difficulty with, and about the best way to help our students understand certain difficult concepts. I found those discussions extremely useful. I believe they should be more a part of the landscape than they are across the professoriate."

CU-Boulder's Wood suggests, "When you have faculty colloquia, don't always talk about research. Sometimes, talk about teaching, about some of the new techniques that are available. It's been my experience that people who were very skeptical at first are starting to come around. They're even getting excited about this as an intellectual endeavor and not just as a teaching load that has to be borne. And it is a fascinating question and intellectual challenge: How can you actually promote someone else's learning?"

Web-based resources: A wealth of science education materials are now available online. Many of the innovations discussed in this article can be explored further online, on websites developed by individuals, departments and organizations. The National Science Digital Library (nsdl.org), funded by the NSF, was established in 2000 with a mission "to provide organized access to high-quality resources and tools that support innovations in teaching and learning at all levels of science, technology, engineering and mathematics education." The NSDL partners with other organizations to provide "pathways" that serve specific communities of educators and students, such as the Biological Sciences Pathway, the Materials Sciences Pathway, and the Pathway for Community and Technical Colleges.

6) SUPPORT the change agents — the key individuals, incentives and organizations that can help drive change.

Anyone who's worked with organizational change knows it's almost always slow and challenging as well as energizing and rewarding. The interviewees highlighted in this article are all leaders in reforming undergraduate science education. They've identified places in the system where change is likely to make the biggest impact. Here are some of those places:

Money, especially peer-reviewed grants: UCSF's Alberts says, "In general, in science put out money for something and people jump. Money is what talks on college campuses. If I get a grant for something, it helps in two ways. First, it gives me credibility because it was competitively awarded. And second, it gives me resources to do things. Any time you change something, it takes a lot of time and resources."

As previously mentioned, almost all the grant money in research universities has flowed to scientific research, not to teaching. However, there are some signs this could be changing. HHMI's Bruns says, "A lot of the scientific culture moved in the direction it is now because of the research funding. And if the funding can't support that anymore, you either give up and quit, or you turn to something else to do. The problem that NIH funding is facing right now — which is very real and very acute — may actually force institutions to think more about education as one of the primary products they're supposed to be churning out. That means that it may become perfectly OK to do really interesting things in science education."

Role models: One strategy for driving change in science education is to spotlight role models through awards, recognition and financial support. Foundations and scientific societies have been playing an important part in making this happen. Among the programs (and organizations) that have raised the profile of science educators are the following:

- Distinguished Teaching Scholars (National Science Foundation)
- Cottrell Scholars (Research Corporation)
- HHMI Professors (Howard Hughes Medical Institute)
- Presidential Awards for Excellence in Science, Mathematics and Engineering Mentoring (National Science Foundation and the White House)

When looking to find role models and spokespersons for change in science education, the scientific community can be hard to please. CU-Boulder's Wood says, "Ironically, I think to be effective [as an advocate for change in science education] and to be listened to, you have to have a good scientific research reputation. If an educator who really knew what he was talking about with respect to a new pedagogical technique or assessment protocol went to a science department at Princeton or somewhere else, and tried to give a seminar, I don't think many people would come. But when they see someone with a research reputation interested in this as an intellectually challenging problem — that it's fun to think about and solve — then it has more of an impact."

Department as the unit of change: Within an academic system, change (and resistance to change) can come from the top or the bottom. To effect change in undergraduate science education, both are necessary. Project Kaleidoscope's Narum says, "We're going to need a sandwich effort, both top down and bottom up."

Wood agrees, "It has to come at all levels. It's going to help to have pressure from outside, from university administrators who encourage movement in the right direction. But the primary unit has to be the department. Departments are still pretty powerful. If there are a fair number of people in a department who want to resist change, it's going to be difficult."

Nobel laureate Wieman is focusing his efforts at change at the departmental level. He's working with five science departments at the University of Colorado at Boulder and with a similar number of departments at the University of British Columbia. He says, "The department level is kind of the missing step in these science education efforts. It's really the department that sets the agenda — they determine what's taught, who teaches it and how it's evaluated. This is particularly true at research universities that train the future science teachers as well. So if you really want to make a widespread change, that's the unit that's got to be changed. A university president, no matter how much they want to do about it, can't really make a difference in how second-semester physics or chemistry is taught."

National organizations that help drive change: Within the scientific community, a number of national organizations have identified undergraduate science education as an important part of their mission. These organizations serve a valuable role in encouraging the development and distribution of innovations and information, in recognizing role models and in providing financial support. The programs and the websites of these organizations provide an excellent starting point for anyone interested in improving undergraduate science education. Here's a sampling of organizations serving as change agents:

- Private foundations (Research Corporation, HHMI, M. J. Murdock Charitable Trust, Alfred P. Sloan Foundation)
- Federal agencies (National Science Foundation's Directorate for Science and Engineering Education)
- Centers, institutes and consortia (Project Kaleidoscope; Center for the Integration of Research, Teaching and Learning; Carl Wieman Science Education Initiative)

- Scientific societies (American Chemical Society's Division of Chemical Education and Education Division, American Association of Physics Teachers, AAAS Project 2061, American Society for Cell Biology)

IT'S TIME TO DECIDE: Will it be Door No. 1 or Door No. 2?

Remember those students milling around the lobby of the UW-Madison chemistry building? They're now finally walking through the door and entering the classroom. They're about to find out if it's Door No. 1 or Door No. 2.

Of course, these students weren't really allowed to pick between the two doors, between the two approaches to science education. They'll have to make do with the system provided to them.

However, as a scientific community and a larger American society, we are able to make a choice as we move forward in the coming years. Will it be Door No. 1 or Door No. 2?

For the leaders interviewed for this article, the choice is clear and critical. We must improve undergraduate science education for everyone — for future scientists, STEM workers and American citizens.

Shirley Malcom believes that "undergraduate science education is absolutely central" to the larger issue of improving science education at all levels throughout our society. Issues with K-12 STEM education are linked closely with undergraduate science education, because K-12 teachers are all products of the higher education system. She adds, "Higher education need only look at itself and own up to the responsibility it has in terms of the quality of classes and the quality of the experiences being provided to students. This applies not only to people who will become K-12 teachers but also to people who are going to become politicians, judges, journalists, lawyers and everything else in our society."

Bruce Alberts also sees a clear link between undergraduate and K-12 science education. "I used to blame all the K-12 people for everything, but I think we [in higher education] need to take a lot of responsibility. My perspective on this changed while I was at the National Academy of Sciences. I came to realize that all the prestige is at the university/college teaching level. And because that's the way parents experience science, you can't really change the K-12 system until you've changed the college system. K-12 teachers who teach science learned it first from science courses in college. You really want to be able to start with school teachers who already understand good science teaching, based on their college courses. So we have an incredibly inefficient system right now. We're starting behind the eight ball."

Leon Lederman argues forcefully that today's college graduates need more and better science courses. He says, "Liberal arts students ought to take a minimum, I think, of two years of science where the college puts a high priority on the quality of the teaching. Once upon a time the knowledge of Latin and Greek was essential to being educated, but that's no longer true. Everywhere you look in modern society in the 21st century, science plays a role that's crucial. It's hard to think of any policy decision on the national level that doesn't have some important scientific criteria that should weigh in on the decisions you make. It becomes a matter of survival in democratic societies that the voters do a much better job."

Lederman continues, "If science is being taught sincerely and well, not only will it teach the content of science, but in

the course of the two years it will also teach the process of science. Some colleges and their presidents make it clear that teaching is a high priority and others don't. It's a mixed bag. We're not nearly as set on high-quality teaching as we are on hotshot research. There's no reason you can't have both. I know from my own experience and that of many of my colleagues that you can have Nobel prize-winning research people who are also passionate teachers. The big problem is that you've got to match that passion often with a proper environment — with reasonable grants to study how your education works, with reasonable equipment in the laboratory, and with a clear reward for successful teaching."

Dudley Herschbach says, "So often the science education issue is put in terms of workforce needs and competitiveness. Of course, that's a factor. But for me it's even more fundamental. How can you have a democracy if you don't have literacy? Without scientific literacy, citizens don't know what to believe, and 'snake-oil' people can mislead them. It is so sad that in the world's richest country, a country that prides itself on being a leader in science and technology, we have a large fraction of the population that might as well live in the 19th, 18th or 17th century. They aren't getting to live in the 21st century except in the superficial way of benefiting from all the gadgets. But they don't have any sense of the human adventure and of the worldview that science brings to us. It's so tragic. It should be part of the birthright of anyone born in the 21st century, whether they're born in the U.S. or anywhere else, to have a decent understanding of what science is all about."

AFTERWORD

by James M. Gentile, President
Research Corporation

While Randy Wedin's comprehensive article is focused on undergraduate science education, I'm impelled to add that only when quality, inspiring science education is bolstered by federal funding to ensure rewarding research and science teaching careers, will we finally be on the path to regaining and sustaining the greatness of U.S. science. The two — superior education and viable career options — must be in lock-step.

Until that high-powered synergy becomes reality, however, effective undergraduate science education remains important not only because it can help the U.S. maintain its lead during an era of increasing economic competition, but also because it encourages development of an "enlightened citizenry" essential to a flourishing, progressive democracy.

Traditionally hard-nosed realists, Americans have always placed great value on understanding how things work. Science is the ultimate source of that knowledge, and so it just makes good sense — intellectual and economic — to do our best to extend scientific knowledge to all citizens whenever possible.

Project Kaleidoscope (PKAL), an effort I've been fortunate enough to be a part of for the better part of a decade, has distilled the essential wisdom of numerous recent reports issued by scientists, educators, administrators, business leaders and politicians concerned with transforming America's scientific and technological infrastructure.

Broadly, PKAL sees these varied cohorts calling for wide use of inquiry-based learning to foster a deep understanding of the nature of science, the language of mathematics and the tools of technology among America's great diversity of students. PKAL finds widespread support for rewarding faculty who make the same kind of cross-discipline connections for their students that today's top researchers must create to tackle the most difficult problems in science. And PKAL says nearly all segments of a concerned America would like to see us building our nation's future workforce through collaborations of academic, business and civic groups. We're all in this together, after all.

As Wedin has shown us, there is tremendous room for improvement and many ideas on how to accomplish the task of ensuring American undergraduate science education is the best in the world. With a change coming in national leadership in the next year or so, it's high time American political leaders, educators and academic-based researchers get down to doing the actual work of improving U.S. science education, as well as pursuing the many other opportunities a renewed dedication to the advancement of science demands.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Bruns


Bullock


Handelsman


Herschbach


Kelley


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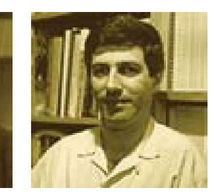
Lederman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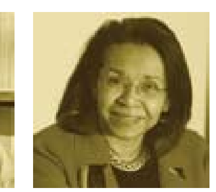
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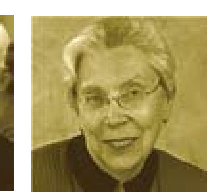
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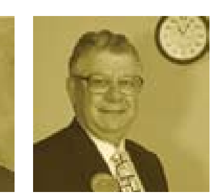
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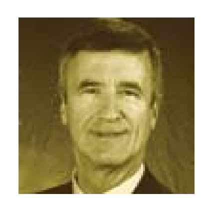
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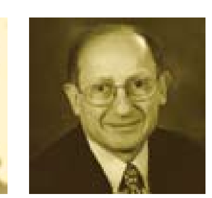
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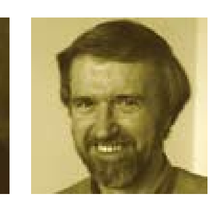
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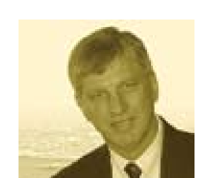

Wilson


Wood

Scientists interviewed for this article:

Bruce Alberts is professor of biochemistry and biophysics at the University of California, San Francisco. From 1993 to 2005, he was president of the National Academy of Sciences.

Peter J. Bruns is Cornell University professor of genetics emeritus and vice president for grants and special programs at the Howard Hughes Medical Institute.

Ronald D. Bullock is chairman and CEO of Bison Gear and Engineering Corporation.

Jo Handelsman is professor of plant pathology at the University of Wisconsin, Madison and an HHMI Professor.

Dudley R. Herschbach is Frank B. Baird, Jr. Professor of Science at Harvard University. In 1986, he received the Nobel Prize in Chemistry.

Darcy B. Kelley is Howard Hughes Medical Institute Professor of Biological Sciences at Columbia University and an HHMI Professor.

Mary M. Kirchhoff is director of the education division at the American Chemical Society.

Leon M. Lederman is director emeritus of Fermi National Accelerator Laboratory in Batavia, Illinois, and holds an appointment as Pritzker Professor of Science at the Illinois Institute of Technology, Chicago. In 1988, he received the Nobel Prize in Physics.

Nathan S. Lewis is George L. Argyros Professor and professor of chemistry at the California Institute of Technology.

Shirley M. Malcom, an ecologist, is head of the Directorate for Education and Human Resources Programs at the American Association for the Advancement of Science.

Eric Mazur is Gordon McKay Professor of Applied Physics and professor of physics at Harvard University.

John W. Moore is W. T. Lippincott Professor of Chemistry at the University of Wisconsin, Madison, and editor of the Journal of Chemical Education.

Jeanne L. Narum is director of Project Kaleidoscope.

Judith A. Ramaley, a biologist, is president of Winona State University in Winona, Minnesota. From 2001–2004, she was assistant director, Education and Human Resources Directorate, at the National Science Foundation.

Bassam Z. Shakhashiri is professor of chemistry at the University of Wisconsin, Madison, and the first holder of the William T. Evjue Distinguished Chair for the Wisconsin Idea. From 1984 to 1990, he was assistant director, Science and Engineering Education, at the National Science Foundation.

Robert N. Shelton, a physicist, is president of the University of Arizona.

James H. Stith is vice president**,** Physics Resources Center for the American Institute of Physics.

Nicholas J. Turro is William P. Schweitzer Professor of Chemistry at Columbia University.

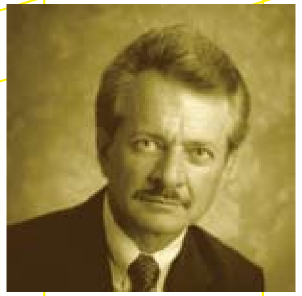
Graham C. Walker is American Cancer Society Research Professor of Biology at the Massachusetts Institute of Technology and an HHMI Professor.

Carl E. Wieman is professor of physics and director of the Carl Wieman Science Education Initiative at the University of British Columbia, Canada, and Director of the University of Colorado Science Education Project. In 2001 he received the Nobel Prize in Physics.

Jack M. Wilson, a physicist, is president of the University of Massachusetts System.

William B. Wood is distinguished professor of biology at the University of Colorado at Boulder, and editor of *CBE: Life Sciences Education*.

PROGRAM REVIEW



In 2006 Research Corporation saw a remarkable jump in proposals — a total of 345, or a 30 percent increase over the previous year. Possible causes for this increase may include a wave of new hires among the nation's colleges; a change in the way other foundations are supporting research at primarily undergraduate institutions; and, of course, the chronic, somewhat lackluster state of federal funding for the physical sciences.

Unfortunately, a small foundation such as Research Corporation simply doesn't have the resources that would allow it to meet all the meritorious funding needs when factors such as these, alone or in combination, impact the national research community.

It is frustrating when one realizes the dire need for scientific manpower building on the nation's horizon. As President James Gentile notes in his introductory letter, the United States graduates mere tens of thousands of science and engineering students each year to India and China's hundreds of thousands; basic research, long a staple of U.S. science programs, is inexorably migrating overseas to less expensive venues; continued flat federal funding means that many talented young U.S. researchers will not be given the chance to make the breakthroughs so essential to maintaining our nation's technological dominance. Even today, many of our best and brightest are turning away from careers in science, resulting in losses to our collective future prosperity that are, quite literally, incalculable.

Research Corporation, which has nimbly changed form and evolved — sometimes radically — over the past 95 years, has a long history of advancing science in the U.S. This foundation contributed to the work of rocket pioneer Robert Goddard, assisted E. O. Lawrence in the construction of the first big cyclotron, was instrumental in wiping out pellagra and beriberi and had a hand in the early development of numerous advanced technologies, including radar and the laser, even as it bolstered the careers of more than 30 Nobel laureates. It is simply not in our "corporate culture" to stand idly by while the United States slips from being the leader in frontline, fundamental research into a kind of scientific eddy – a downward spiral which seems to be ignored by the federal government, which is in the best position to address the problem.

As a small foundation with limited resources, however, we must choose our programs carefully and manage them wisely. In today's reality that means that we must avoid programs and funding schemes that larger organizations, governmental and private, are willing to pursue. Frankly, we see our role as one of providing catalytic and opportunistic funding for innovative research that will make a lasting impact on science and society. Doing so in today's all too complacent environment, however, may require new and novel approaches from Research Corporation.

For more than a decade, many researchers have been pushing through the boundaries of the various traditional disciplines, and Research Corporation has responded accordingly, supporting fundamental research, both experimental and theoretical, in areas such as biophysics, chemical biology, materials science, nanotechnology and environmental science — all while continuing to support innovative research at the center of the physical sciences. Our funding programs, which have a strong history of change over the past nine decades, will continue to evolve — radically, if necessary — to help U.S. science advance in the face of growing global competition.

Ray Kellman

Vice President

PROGRAM SUMMARY

122 awards were made in support of faculty research, research-enhanced teaching and special projects in science in 2006. Funding for the foundation's programs, noted at right, totaled $6,045,656. There were an additional 13 awards made, totaling $190,950.

COTTRELL COLLEGE SCIENCE AWARDS

Cottrell College Science Awards are the foundation's largest program, supporting faculty in chemistry, physics and astronomy at primarily undergraduate institutions. The number of applications in 2006 was up 30 percent over the previous year and represents a 15-year high. The program, which encourages faculty research with undergraduate involvement, funded 104 out of 345 faculty applicants. Two cycles of awards are featured each year; in 2006 the foundation granted a total of $3,895,680, averaging $37,458 per award.

COTTRELL SCHOLAR AWARDS

Cottrell Scholar Awards support excellence in both research and teaching in chemistry, physics and astronomy at Ph.D.-granting institutions. Each award totals $100,000, to be used largely at the discretion of the scholar. Out of 164 requests submitted, 13 Cottrell Scholar Awards were made, totaling $1,300,000.

RESEARCH OPPORTUNITY AWARDS

Research Opportunity Awards support mid-career faculty of demonstrated productivity who seek to explore new experimental research at Ph.D.-granting institutions. Out of 18 candidates nominated by their department chairs for awards in 2006, four proposals were funded for a total of $199,976.

OTHER AWARDS

Also in 2006 one Departmental Development Award of $500,000 was made to Hamilton College.

COTTRELL COLLEGE SCIENCE AWARDS

American University
Harshman, Nathan L.: Quantum information theory and particle physics: Entanglement in multiparticle scattering – $22,386.00

Bloomsburg University of Pennsylvania
Hawrelak, Eric J.: Catalytic synthesis of nitrogen-containing heterocyles using organocobalt complexes – $36,500.00

Brock University
Hudlicky, Tomas: Development of new catalysts for asymmetric synthesis: Chemoenzymatic total synthesis of thebaine – $29,500.00

Brock University
Lemaire, Martin T.: Design, synthesis, and study of new oligo– and polymeric valence tautomeric materials – $32,000.00

Brock University
Nikonov, Georgii: New early-late heterobimetallic catalytic systems supported by bridging phosphido ligands – $32,616.00

Brock University
Pilkington, Melanie: The synthesis and characterization of novel spin bearing tetrathiafulvalene ligands – $29,800.00

Brock University
Yan, Hongbin: Solid-phase synthesis of small interference RNA (siRNA) using the Cpep as a novel protecting group for the 2'-hydroxy functions – $42,000.00

California State Polytechnic University, Pomona
Rego, James A.: Design and synthesis of environmentally responsive liquid crystal thin films: Toward liquid crystal sensors – $37,036.00

California State University, Chico
Edwards, Daniel J.: Lyngbyatoxin a biosynthesis: Kinetic and mechanistic characterization of the reverse prenyltransferase LtxC – $42,218.00

California State University, Dominguez Hills
Price, John: Novel baryon spectroscopy with the CLAS detector at Jefferson Laboratory – $37,218.00

California State University, Fullerton
Hyland, Christopher: Palladium-catalyzed asymmetric reactions of benzylic carbonates – $42,142.00

California State University, Long Beach
Gu, Jiyeong: Proximity effect in ferromagnet/ superconductor (MgB2) hybrid system – $31,134.00

Calvin College
Anderson, Carolyn E.: Chromium carbene-accelerated type II intramolecular Diels-Alder reactions as a gateway to strained ring libraries – $36,418.00

Central Michigan University
Fahlman, Bradley D.: Mechanistic studies of low-temperature nanostructural carbon growth – $31,218.00

Central Washington University
Fabry-Asztalos, Levente: Novel 1,3-azaborine heterocycles as aspartic protease Inhibitors – $38,828.00

Chapman University
Kim, Christopher S.: Aggregation-based growth of iron oxyhydroxide nanoparticles and associated metal sorption/incorporation processes – $34,798.00

Cleveland State University
Streletzky, Kiril A.: Synthesis, structure, transport, and swelling properties of a potential drug delivery system: HPC microgel nanoparticles – $40,684.00

Cleveland State University
Zurcher, Ulrich: Mathematical description of surface electromyography time series – $32,220.00

Colby College
Katz, Jeffrey: Heteroatom-bridged aromatic macrocycles: Development of an oxacalixarene-based molecular toolbox – $42,684.00

Colgate University
Buboltz, Jeffrey T.: Establishing tie line patterns in phase-separated lipid raft mixtures by equilbrium surface pressure analysis – $39,771.00

College of the Holy Cross
Farrell, Joshua R.: Modular design of biomimetic ligands synthesized by Mannich condensations – $35,038.00

College of the Holy Cross
Herrick, Richard S.: Novel group 7 organometallic compounds as diagnostic imaging agents – $37,040.00

College of the Holy Cross
Oxley, Paul: Charge transfer collisions using coherent elliptical state atoms – $43,997.00

Colorado College
Repasky, Gretchen A.: Biochemical role of the PEDF tumor suppressor in ras-mediated pancreatic oncogenesis – $42,645.00

Creighton University
Sidebottom, David L.: Dynamic light scattering investigation of the mixed alkali effect in alkali metaphosphate glasses – $37,200.00

CUNY, Herbert H. Lehman College
Garanin, Dmitri A.: Microscopic investigation of energy barriers, thermal stability, and relaxation of magnetic nanoparticles with surface anisotropy – $33,218.00

CUNY, York College
Profit, Adam A.: Peptide conjugate inhibitors of protein kinase B – $35,684.00

DePaul University
Sarma, Anuj P.: High angular resolution Zeeman effect observations of water masers in star forming regions – $20,656.00

DePauw University
Roberts, Jacqueline R.: Determination of important metal binding residues in an archaeal SmtB/ArsR transcription factor – $39,682.00

Drew University
Morgus, Laurie L.: Experimental studies of hyperfine state changing collisions in atomic cesium using noble gas perturbers – $42,656.00

East Carolina University
Li, Yumin: Molecular dynamics studies on S100 proteins and rational drug design – $38,218.00

Eastern Washington University
Kinney, Chad A.: Earthworms - sentinel indicators of exposure and bioaccumulation of wastewater derived contaminants in biosolid-impacted soils – $44,766.00

Elon University
Karty, Joel M.: Resonance and inductive/field effects in fundamental chemical systems – $30,148.00

Fordham University
Das, Kunal K.: Quantum interference effects in strongly-correlated and spin-entangled states in nanostructures and ultra-cold atomic systems – $41,220.00

Framingham State College
Dignam, Catherine: Development of amino acid-functionalized chiral b-diketimine metal complexes for asymmetric catalysis – $39,218.00

Franklin and Marshall College
Crawford, Fronefield: Cluster computing for new large-scale pulsar surveys with the Arecibo radio telescope – $43,460.00

Goucher College
Pichler, Marin: Formation and investigation of ultracold polar KCs molecules – $42,000.00

Hope College
Gillmore, Jason G.: Photochromic photooxidants: Developing a series of electron poor photochromes to gate photoinduced charge transfer – $43,219.00

Humboldt State University
Hoyle, Charles D.: Novel torsion pendulum for precision tests of gravitational physics – $43,720.00

Idaho State University
Holland, Andrew W.: Chelated amidometal complexes for catalytic C-N bond formation: N-H bond activation and strongly nucleophilic nitrogen centers – $35,704.00

Illinois State University
Grobe, Rainer: Computational quantum field theory – $35,218.00

Indiana State University
Fitch, Richard Wayne: Enantioselective sulfur-mediated oxidation of alcohols – $38,218.00

Indiana State University
Glendening, Eric D.: Oxidation of organic molecules on metal oxide clusters – $30,218.00

Indiana University-Purdue University, Fort Wayne
Wang, Gang: Scattering effect of designed defects in optical lattices – $41,651.00

Ithaca College
Larsen, Anna: Non-coordinating carborane counterions for cationic organometallic catalysis – $38,035.00

James Madison University
Minbiole, Kevin P.: Small ring fragmentation strategies for the synthesis of chiral heterocycles – $15,071.00

Kennesaw State University
Chrestensen, Carol: Regulation of MAPKAP kinase 2 (MK2) by glutathionylation – $44,218.00

Kennesaw State University
McMurry, Jonathan L.: Isolation, purification and characterization of the flagellar export complex, a Type III secretion apparatus – $43,000.00

Kennesaw State University
Duda Rippe, Karen M.: Effects on HNF4-*cx* a cofactor binding in response to variation of fatty acid ligand populations – $34,351.00

Lawrence University
Thompson, David E.: Developing and investigating noble metal infused porous silicas as multilayered substrates for surface enhanced Raman spectroscopy – $43,717.00

Lebanon Valley College
Peelen, Timothy J.: Direct synthesis of Fmoc-protected amines via acyl iminium chemistry – $43,758.00

Luther College
Pedlar, Todd K.: Studies of heavy quarkonium spectroscopy with the CLEO and CLEO-c experiments – $36,076.00

Macalester College
Ter Veldhuis, Tonnis: The construction of brane world effective field theories – $33,218.00

Miami University
Clemens, James P.: Many-atom entanglement produced via collective spontaneous emission – $38,236.00

Northern Arizona University
Bowman, Gary E.: Quantum trajectories and decoherence in an archetypal chaotic system – $23,682.00

Northern Kentucky University
Paula, Stefan: Development of novel hydroquinone-based inhibitors of the sarcoendoplasmic reticulum calcium – ATPase - $34,809.00

Oberlin College
Whelan, Rebecca J.: Development of aptamer-based assays for biomarkers of ovarian cancer – $32,220.00

Occidental College
Schroeter, Darrell F.: Quantum number fractionalization in an exactly solvable model for the chiral spin liquid – $38,398.00

Pacific Lutheran University
Cotten, Myriam: Solid-state NMR investigations of molecular recognition and structure-function relationships in antimicrobial piscidin at water-lipid interfaces – $42,000.00

Pacific Lutheran University
Davis, Paul H.: SERS microscopy using gold nanoparticle aggregates: High sensitivity detection and identification of molecules – $45,610.00

Pacific University
Hall, Stephen C.: Investigation of possible intermediate phase transition in the crystal growth of highly supercooled fragile glass formers – $43,303.00

Rhodes College
Jackson-Hayes, Loretta: A genetic approach to identifying and characterizing proteins responsible for fungal cell wall stability – $44,606.00

Rutgers University, Camden
McAlevy Bubb, Daniel-Dennis: Resonant infrared matrix assisted pulsed laser deposition of polymers and biomaterials – $35,000.00

Saint Joseph's University
Hammes, Brian S.: Controlling oxygen activation of Fe(II)-polyimidazole complexes via proton-coupled electron transfer – $39,886.00

Sam Houston State University
Liang, Gan: A novel approach to resolve the controversy about the origins of the electronic conductivity in cation-doped LiFePO4 cathode materials – $43,984.00

San Jose State University
Muller, Gilles: The design and photophysics of lanthanide complex-based luminescent probes – $45,000.00

Seattle University
Langenhan, Joseph M.: Optimization of oxyamine-mediated glycosylation: Improving stereoselectivity, enhancing diversity, and novel applications – $38,318.00

Seattle University
Loertscher, Jennifer A.: Analysis of protein stability in diabetes using a yeast model system – $36,939.00

Seton Hall University
Curti, Frank G.: Electrochemical properties of metallic quantum wells – $28,274.00

Southern Connecticut State University
Enjalran, Matthew: A study of geometric frustration in the two dimensional Hubbard model – $26,684.00

Southern Illinois University at Edwardsville
De Meo, Cristina: Oxazolidinone protected sialosyl donors and acceptors: Effect on the stereoselectivity and reactivity in glycosylation reactions – $39,998.00

Sweet Briar College
Hyman, Scott D.: A galactic center transient radio source monitoring program – $25,342.00

Texas A&M University – Kingsville
Chi, Xiaoliu: Enhancing charge transport in organic semiconductors by p-stacking of rubrene derivatives – $35,958.00

Texas State University, San Marcos
Rudzinski, Walter: The effects of immobilizing the matrix in laser desorption ionization/mass spectrometry – $33,657.00

United States Naval Academy
Gutteridge, Clare E.: Design, synthesis and testing of potent, metabolically-stable inhibitors of Plasmodium falciparum – $38,000.00

University of Colorado at Colorado Springs
Glushchenko, Anatoliy: Colloidal particles driven by a nematic-isotropic interface: Creation and exploration of structured colloids - $44,684.00

University of Colorado at Denver and Health Science Center
Lin, Hai: Reaction mechanism and dynamics of cytochrome P24503A4 enzyme by combined quantum mechanical/molecular mechanical computation – $34,950.00

University of Mary Washington
Sharpless, Charles M.: Probing the origins of natural organic matter photochemistry using spectroscopic and electrochemical approaches – $25,461.00

COTTRELL COLLEGE SCIENCE AWARDS [continued]

University of Massachusetts, Boston
Arnason, Stephen B.: Noise spectroscopy of a relaxing electron glass – $33,868.00

University of Memphis
Laradji, Mohamed: Numerical studies of compositional and morphological inhomogeneities in lipid membranes – $35,264.00

University of Minnesota, Duluth
Mereddy, Venkatram R.: Synthesis of folate aminoboronates as anticancer antifolates – $26,144.00

University of Minnesota, Duluth
Nemykin, Viktor N.: Synthesis, characterization, and theoretical modeling of ferrocenyl-substituted tetraazaporphyrins – $35,680.00

University of Minnesota, Duluth
Rumbley, Jon N.: Complementarity between transmembrane amino acids of the organic anion transporters and substrates by QSAR and mutational analysis – $35,900.00

University of North Alabama
Thompson, David Brian: Separation-sensitive measurements of morphology-dependent resonances in coupled cavities composed of microspheres – $33,612.00

University of North Carolina at Greensboro
Cech, Nadja: Elucidation of *Echinacea's* mechanism of action: A proteomic approach – $34,084.00

University of North Florida
Vergenz, Robert: Role of methyl-donated hydrogen bonds in protein secondary structure and folding – $41,554.00

University of Northern British Columbia
Rader, Stephen: The role of U4 snRNP in spliceosome assembly – $40,050.00

University of Ontario Institute of Technology
Paal, Krisztina: Preparation of site-specific vitamin-albumin conjugates: Potential vehicles for tumor targeting of paclitaxel – $35,000.00

University of Richmond
Dattelbaum, Jonathan D.: Design of novel fluorescent protein biosensors – $33,420.00

University of San Diego
Tahmassebi, Debbie: Fluorescence studies of polymerase-DNA complexes – $40,684.00

University Of South Alabama
Sykora, Richard E.: Synthesis and characterization of f-block thiogallates and Selenogallates – $41,148.00

University of South Dakota
Hoefelmeyer, James D.: Nonhydrolytic synthesis of structurally well defined RuO2 nanocrystals; application in water oxidation catalysis – $36,072.00

University of South Dakota
May, P. Stanley: Potential for metal-surface enhancement of upconversion luminescence from lanthanide-doped nanoparticles – $39,002.00

University of Wisconsin, Eau Claire
Boulter, James E.: Laboratory studies of hydrocarbon uptake on mixed ammonia hydrate and sulfide ices present in the Jovian atmosphere – $43,190.00

University of Wisconsin, Eau Claire
Halfen, Jason A.: Chemistry of high-valent imidoiron complexes – $36,176.00

University of Wisconsin, Eau Claire
Hati, Sanchita: To explore the molecular basis of domain-domain communication in prolyl-tRNA synthetases - $39,000.00

University of Wisconsin, La Crosse
Opdahl, Aric M.: Characterizing the assembly of complex DNA structures attached to gold surfaces via adenine nucleotides – $38,482.00

Villanova University
Dudley, Timothy James: Theoretical investigation of chromium oxides and hydroxides and their reactions with hydrocarbons – $33,500.00

Wellesley College
Elmore, Donald E.: Dissecting membrane interactions of the antimicrobial peptide Buforin II using computer modeling and experimental biochemistry – $41,561.00

Wilfrid Laurier University
Kitaev, Vladimir V.: Highly-ordered metallodielectric nanocomposites for photonics via self-assembly of monodispersed rationally designed nanoparticle – $35,806.00s

Wilkes University
Castejon, Henry J.: Modeling the liquid-gas interface using self-assembled Monolayers – $34,362.00

Willamette University
Duncan, Andrew P.: A method for the asymmetric organocatalytic conjugate addition of carbinols to unsaturated aldehydes – $38,658.00

William Jewell College
Bunton, Patrick H.: ESR and optical spectroscopy of the metal-insulator transition in nanoscale VO2– $39,893.00

Youngstown State University
Oder, Tom N.: Growth and delta doping of ZnO epitaxial films by magnetron sputter deposition – $43,470.00

COTTRELL SCHOLAR AWARDS

George Mason University
Dr. Joseph C. Weingartner: The alignment of grains with the interstellar magnetic field – $100,000

Indiana University at Bloomington
Dr. Mu-Hyun Baik: Towards a quantitative understanding of diastereoselective carbocyclizations through quantum chemical modeling – $100,000

Johns Hopkins University
Dr. Justine P. Roth: How do intra-protein redox reactions control the activities of enzymes involved in oxidative stress? – $100,000

Purdue University
Dr. Erica W. Carlson: Quantum soft matter – $100,000

Texas A&M University
Dr. Jairo Sinova: Spin-Hall effect in semiconductors and related phenomena in nano-spintronics – $100,000

University of California, Irvine
Dr. Thorsten Ritz: Weak magnetic field effects on blue-light signaling in *Arabidopsis thaliana*: A model system for geomagnetic field detection – $100,000

University of California, Santa Barbara
Dr. Jeffrey W. Bode: New ligation reactions for the synthesis of biomolecules and biomaterials – $100,000

University of Michigan, Ann Arbor
Dr. Melanie S. Sanford: Transition metal-catalyzed carbon–fluorine bond–forming reactions – $100,000

University of Notre Dame
Dr. Masaru K. Kuno: Disorder induced optical heterogeneity in solution-based straight/branched semiconductor nanowires – $100,000

University of Oregon
Dr. Darren W. Johnson: Supramolecular arsenic coordination chemistry – $100,000

University of Pittsburgh
Dr. Adam Leibovich: Particle physics calculations using effective field theories – $100,000

University of Washington
Dr. David S. Ginger: Probing optoelectronic processes in conjugated polymer blends – $100,000

Vanderbilt University
Dr. Keivan Guadalupe Stassun: A systemic approach to problems in star formation and minority representation – $100,000

RESEARCH OPPORTUNITY AWARDS

New Mexico State University
Dr. Rene A. M. Walterbos: Galaxy dynamics in halos and outer disks using multi-longslit optical spectroscopy – $49,976

Southern Illinois University at Carbondale
Dr. Naushad Ali: Investigaton of giant magnetocaloric effects in Ni-Mn-Ga based Heusler alloys – $50,000

University of Kansas
Dr. Hume A. Feldman: Probing particle physics and cosmology with cosmic velocity fields – $50,000

University of Pittsburgh
Dr. Tara Meyer: Synthesis of repeating sequence copolymers – $50,000

Research Corporation's condensed statements of financial position and activity for the years ended December 31, 2006 and 2005 are presented in this section. The foundation's audited statements for 2006 and 2005 can be viewed online at www.rescorp.org.

Condensed Statements of Activity and Changes in Net Assets
YEARS ENDED DECEMBER 31, 2006 AND 2005

REVENUES	**2006**	**2005**
Investment income, net	$21,887,395	$17,285,706
Other income	358,968	107,780
TOTAL REVENUES	22,246,363	17,393,486
EXPENSES		
Grants approved	6,046,102	5,622,515
Program-related	4,800,000	1,886,076
Science advancement	1,490,038	1,387,258
General and administrative	1,367,825	1,329,656
Other	499,109	345,659
TOTAL EXPENSES	14,203,074	10,571,164
INCREASE IN NET ASSETS	8,043,289	6,822,322
NET ASSETS – Beginning of the Year	148,510,151	141,687,829
NET ASSETS – End of the Year	$156,553,440	$148,510,151

Condensed Statements of Financial Position
DECEMBER 31, 2006 AND 2005

ASSETS	**2006**	**2005**
INVESTMENTS	$164,980,907	$146,061,571
Cash and cash equivalents	–	663,103
Notes and other receivables	2,960,056	6,815,313
Interest in LLC	1,878,277	1,951,071
Prepaid pension cost	629,825	914,468
Other	922,368	887,504
TOTAL	$171,371,433	$157,293,030
LIABILITIES AND NET ASSETS		
LIABILITIES		
Grants payable	$5,160,538	$4,747,679
Line of credit	2,285,851	–
Notes payable	1,213,611	1,294,925
LSST liability	2,732,000	–
LBT liability	1,801,912	1,427,766
Other	1,624,081	1,312,509
TOTAL LIABILITIES	14,817,993	8,782,879
UNRESTRICTED NET ASSETS	156,553,440	148,510,151
TOTAL	$171,371,433	$157,293,030

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Students sitting in a lecture hall.
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Marcel Duchamp's door at 11 rue Larrey (1927). When door opens one entry, it closes the other. © 1995 Artists Rights Society (ARS), New York / ADAGP, Paris.

Hall of doors.
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Evolution from college student to businessman.
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Artist conception of translucent medical nanobots fixing blood cells.
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3D rendering of neuron cell.
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Vintage school desk with a stack of old textbooks, a pencil, and an apple.
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Young professor measuring up via grant monies.
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Teaching in the traditional way.
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Informal meeting over coffee.
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Forensic evidence.
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A close-up of a semiconductor wafer. This is the circular disc of silicon which computer chips are made on. After processing, it is cut up into individual chips.
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3D rendering of DNA double helix.
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Students using clickers.
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Clicker feedback on laptop monitor.
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Two science technicians survey the results of their experiments.
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Attending a seminar.
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Small workshop.
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Wide field long exposure photo of the Milky Way. Cygnus region of the Milky Way with the Summer Triangle visible.
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Doors of choice.
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Intensity of science.
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