InterActions

across physics and education

March/April 2007

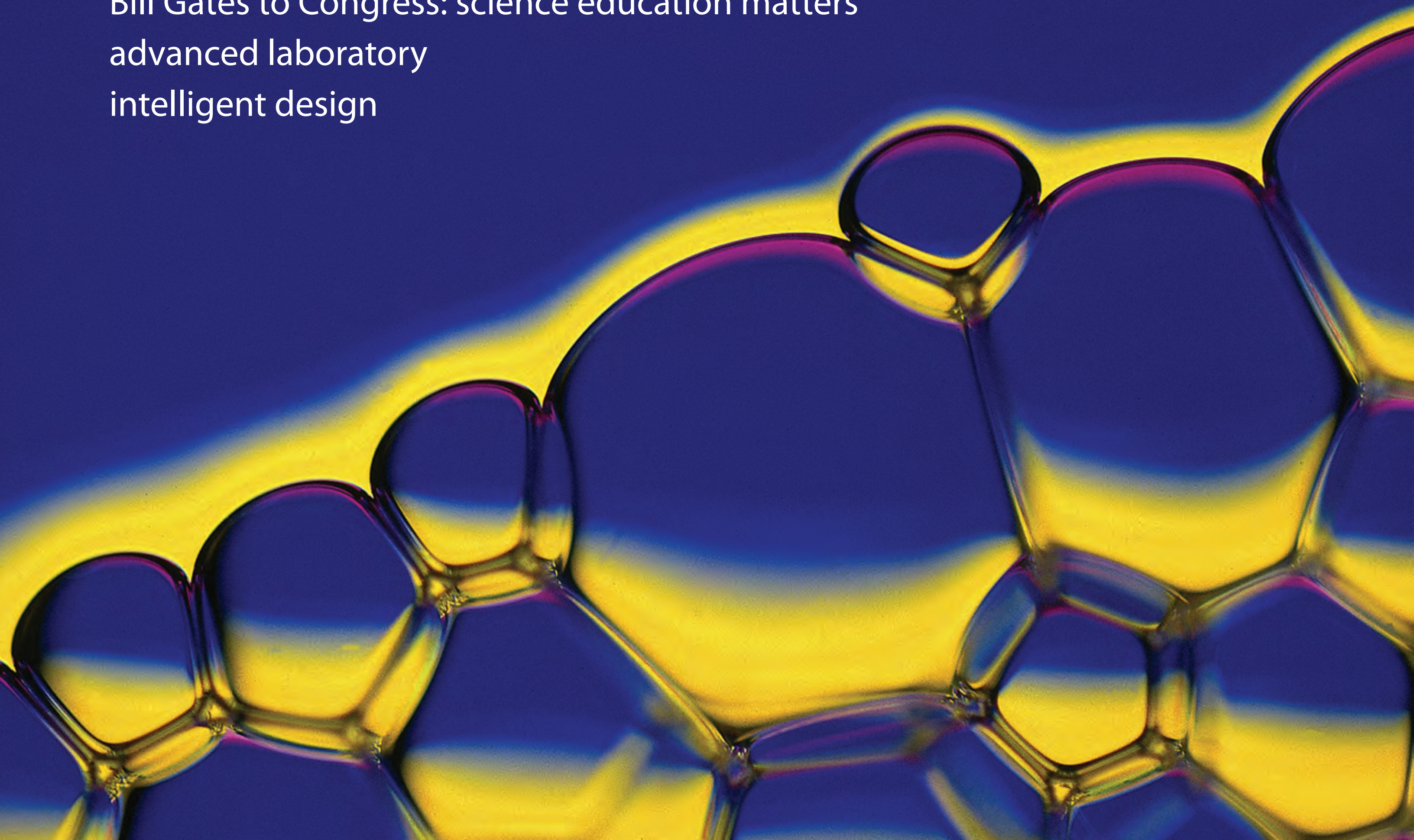
Focal Point
Undergraduate Physics

reinventing the classroom

remaking the curriculum

regenerating the physics major

plus:
Bill Gates to Congress: science education matters
advanced laboratory
intelligent design



InterActions
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About INTERACTIONS

Interactions is a general-interest magazine about physics education. Our mission is to inform and stimulate diverse conversations on teaching and learning by publishing thought-provoking news, analysis, and commentary on the people, programs, and policies that interact to influence scientific practices and knowledge—and, ultimately, human destiny.

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The editors welcome your response. Send comments, questions or suggestions to interactions@aapt.org or mail letters to Interactions Forum, One Physics Ellipse, 5th Floor, College Park, MD 20740. Please include your full name, mailing address, and daytime contact information. Space is limited and all published comments are subject to editing.

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Although most of the articles are commissioned by the editors, we encourage writer queries and story ideas. Email your query, and attach any writing samples, to asst-editor@aapt.org. Or mail the letter along with samples to Interactions Editor, One Physics Ellipse, College Park, MD 20740. We typically respond via email or letter within four weeks. Writing samples and other submitted materials will not be returned.

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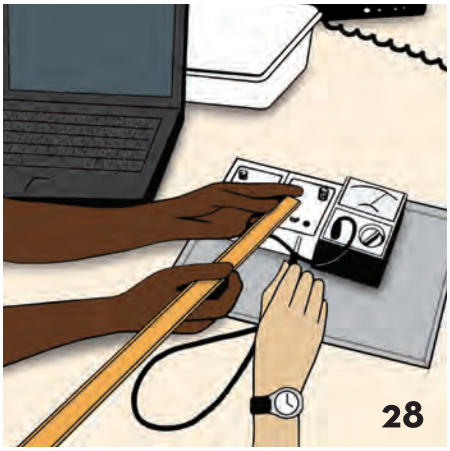

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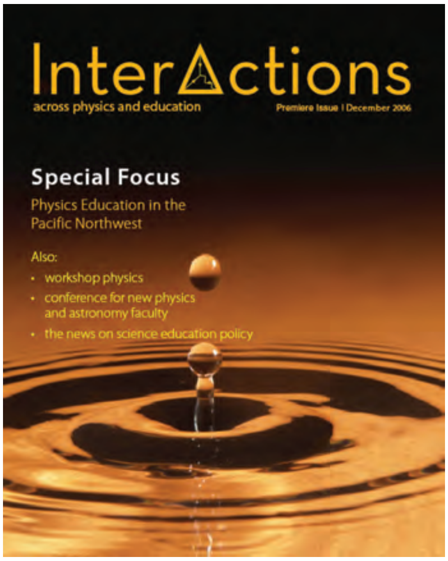
Kudos and Reviews

If this is supposed to be a replacement for the *Announcer*, then it is a quantum leap improvement. It's been a long time—if ever—since I have read every article in a magazine. Thanks very much. Δ

Tom O'Hara
Midland (Texas) College

The new magazine is attractive, and I enjoyed reading the first number. But I almost threw it away without reading it, because there was no AAPT identification on the cover, so I thought this was some kind of educational hardware or software company sending me an infomercial. Δ

Bruce Sherwood
North Carolina State University



InterActions
across physics and education
Premiere Issue | December 2006

Special Focus
Physics Education in the Pacific Northwest

Also:
- workshop physics
- conference for new physics and astronomy faculty
- the news on science education policy

On "Putting Physics First"

Let me begin by saying that I think that physics for all is a wonderful idea—as long as it is not taught in the ninth grade. AAPT has once again confused physics for all and Physics First. The two are not inextricably linked. Physics First has nothing more than selective, private school anecdotes supporting it. All of the large scale trials in public schools have either failed or failed to collect any data.

I have a degree in physics, taught physics for 12 years, have written a physics lab manual, and have been the science coordinator at a county office in California for two years. In California, Physics First makes no sense, has proven all of the anecdotes incorrect with data, and has been tried and failed numerous times in numerous districts.

I have thoroughly analyzed Physics First data in California, have direct experience with the program, and have analyzed the connection between Physics First and the California science curriculum. They all show that Physics First is neither feasible nor reasonable.

There are numerous myths about Physics First and many of them are put forth in Denise Jarrett Weeks' article ("Putting Physics First," December 2006, page 14). Students who take physics before biology do better in biology. I collected data on Physics First and its effect on both physics and biology scores in California. The 16 worst physics scores were at Physics First schools. According to state testing data, 49 percent of students taking physics in ninth grade tested "below basic" and "far below basic." Thirteen of the top 14 physics scores were from biology first schools.

The next misconception is that students who take physics before chemistry do better in chemistry and that chemistry teachers like the Physics First sequence. In 2005, the only major district in California enacting

Calls for Renewal

In this issue we highlight a variety of ideas and opinions on the needs and opportunities in undergraduate physics. These articles are arranged under the common heading "Focal Point" and begin on page 16.

I have to confess to being somewhat surprised that change is a common theme running throughout this issue. The reader will repeatedly encounter words implying renewal such as "revise," "reform," and "reinvent." In fact, a cursory glance at the cover would cause even the most steadfast advocate of physics reform to wonder, aloud perhaps: "Is there anything about the physics curriculum worthy of praise, preservation or celebration?" The answer is a *qualified* yes.

In a new department called "Synopsis," Toufic Hakim considers some causes for concern (page 8); while Patrick Mulvey presents some numbers worth celebrating (page 52). Similarly, "A Physics Makeover" (page 38) and "Shifting Paradigms" (page 44), argue compellingly for reforming the introductory physics course.

These articles and others call attention to the challenges peculiar to undergraduate physics, ranging from curriculum reform to the recruitment of prospective physicists. This, the second issue, is the outcome of our view that an examination of physics education–its past, present, and future starts with *Interactions*. Δ

—Daryl Malloy

a Physics First curriculum had nearly the lowest chemistry scores in the state.

Other non-sequiturs mentioned in the article and other sources are that Physics First supports physics for all, that Physics First improves the ratio of females to males, and that Physics First increases enrollment in higher physics classes. In California, 48 percent of ninth-grade physics students are female and 47 percent of eleventh-grade physics students are female. In this state, only two years of science are required to graduate and to get accepted to the two major university systems. Taking physics in ninth grade almost eliminates the possibility of taking physics again in a higher grade. In a paper written by a Physics First textbook publisher, statistics are quoted showing that the number of AP physics tests taken at a Physics First school rose dramatically in a certain time period. Data from the AP website showed that across the country, the number of AP physics tests taken rose even faster. In essence, the program thwarted the AP physics program's growth compared to the rest of the country.

The fact that projects and inquiry labs are good for students is also a non-sequitur. Projects and inquiry labs are good for all students. These things are not unique to a Physics First program and should not be. They should not be unique to physics either.

Another misconception is the simple fact that students need high school chemistry and physics before high school biology. In California, seventh-grade science is life science and eighth-grade is physical science. In physical science, students learn about chemical reactions, the periodic table, solubility, the pH scale, phase change, simple thermodynamics, and basic biochemistry. These two courses together are plenty of preparation for ninth-grade biology.

My proposal related to high school science is to instill in middle school teachers the fact that they are preparing future biology students so that they may treat their courses that way. The state must increase the graduation requirement in science to three years. Universities must require (not just recommend) a biology, chemistry, and physics curriculum. The state must increase the frequency of science testing in elementary school to ensure that science is being taught in the early grades. Inquiry activities, hands-on activities, and field studies must be the focus of all science courses.

I was offended that AAPT used some of my membership dues to create pamphlets for a non-research-based program with proven failures and ship them around the country. ∆

Michael Horton
Menifee, California

Editor's Note: In response to Horton's comment: "AAPT has once again confused physics for all and physics first," the editors reiterate that the views expressed in *Interactions* are solely those of the author and do not reflect the views of AAPT, its employees, members, governing board, or those of its supporters and affiliates.

I have been teaching physics for 20 years and I vote with both my hands for a comprehensive physics education for everybody. However, I had mixed feelings when reading "Putting Physics First," by Denise Jarrett Weeks.

In the debate on whether it is possible to teach physics at a middle school, or if every student is capable of learning physics, or in what order should school subjects be taught, American scholars seldom use the experience of their foreign colleagues. The conceptual physics course for ninth-graders created by Larry Neznanski was "a radical change to the curriculum" at his school [according to Weeks], but similar curricula have been used in Russia for at least four decades. The question "are middle school students (including girls) capable of learning physics?" has a simple answer: yes. I and millions of former and current Russian students are living proof of that fact, because in Russia all school students start learning physics in the sixth or seventh grade. These three subjects go hand-in-hand in Russian schools. Separating the subjects, no matter which subject comes first, does not make much sense (from a Russian point of view). I am not saying that the Russian way of teaching is the only right one, I am saying that for a long time a working teaching model [has existed], which completely is a contradiction to the very idea of ordering the school subjects.

The common reason for putting physics first is that chemistry and biology are based on it. As the rationale, we can read often that "Chemistry is essentially the study of chemical bonding. Biology is the most complex of the sciences." However, saying this is misleading. Chemistry had formed as a science a century before the very idea of bonding was developed, and biology is obviously simpler than any of the social sciences (and I do not believe that, when developing his theory, Charles Darwin was heavily using any physics knowledge he had at the time). Even the chemistry teacher (Guy Hudson) is saying that the kids who have taken a physics class first are better at studying chemistry not because of their physics knowledge, but "because they're used to a little more critical thinking." Here I cannot agree more on the importance of learning physics (not Physics First); physics is one of the best subjects to develop critical thinking and problem-solving skills. But to be honest, teachers of all subjects are supposed to contribute to this; physics is just one of the oldest and most developed sciences, so it is easier for physics teachers to work on developing metacognitive abilities.

When reading the article, I see that all the described positive results are based not on the fact that physics is taught first at the school, but on the fact that the school has a very good physics teacher, who knows physics, loves teaching, and dedicates himself to his students. Δ

Valentin Voroshilov
Boston University, Mass.

I found the initial issue of *Interactions* an intriguing venture, particularly with the emphasis on Physics First.

In the 1970s and early 1980s I often roomed with Joe Meyer at AAPT Executive Board meetings. Joe taught physics at Oak Park High School, which I knew to be one of the select schools in the Chicago area. He pointed out the problems with high school curricula then in place. After teaching algebra to ninth-graders, we gave them a couple of years off to forget it before we showed them in twelfth-grade physics what it was good for. Plus the whole sequence was standing on its head. Biology was taught first because it was non-quantitative. Chemistry followed, somewhat quantitative. Then, finally, for the few survivors, came physics. But over the years, chemistry had become more quantitative and based on ideas such as potential energies of electrons in orbitals. Biology meanwhile was straining to explain the chemistry of carbohydrates as well as DNA, RNA, and nucleic acids.

I could appreciate the problems Meyer described, and thought with my experience at textbook writing I could help. What concerned me was the tendency to move college textbooks to the high school level or rewrite them in "simple" form. If standard twelfth-grade textbooks were "watered down" to freshman level, would there be anything left of physics? (Existing "physical science" texts were certainly not encouraging on this point.) Rather than the standard approach, which was a quick mathematical derivation followed by a scattershot attempt to show how the derived equation could be applied to a "realistic" (simplified) problem, it seemed better to start with everyday experiences, look at the problems they suggest, and then explore how physics could help high school students understand what was going on.

As the result of the implementation of a more modern, integrated approach (and the textbook—which students do read), by the end of the school year the students have been introduced to most of the topics of introductory physics, always starting with a "real-life" setting and exploring how physics provides answers. As a substitute for a ninth-grade physical science textbook it was successful (apart from binding problems for the mimeographed version), although students in the upper-middle-class high school questioned whether it would work as well for students less well prepared, and students in a historically black high school questioned whether it would work as well for students better prepared coming into the course. It also worked well as a precollege physics text at the college level, as well as for a graduate course for physics teachers (primarily teaching at the two-year level).

The difficulties arose in attempting to move to commercial publication (quite different from my previous experiences at the college level). The uniform response was, "No one is teaching such a course" as ninth-grade physics, usually augmented by the comment that they preferred to have their textbooks written by in-house authors. On the other hand, recent experience has certainly shown substantial interest in the Physics First concept, and my (non-physicist) wife believes strongly that the concept should not be abandoned. Δ

Robert Bauman
University of Alabama

The editors welcome your feedback. Send comments, questions, or suggestions to interactions@aapt.org. Include your full name, mailing address, and daytime contact information. Comments may be edited for clarity and space.

Synopsis

Cause for Celebration, Call to Action

BY TOUFIC M. HAKIM

The recent upswing in the number of undergraduate physics degrees awarded annually in the United States has been met with mixed reactions. The optimists interpret the data as ipso facto evidence that being proactive paid off for physics departments. The skeptics, however, see this trend as merely a natural market correction from earlier dips—soon to taper off. Although it is not known precisely why the number of physics bachelor's conferred in 2005 exceeded 5,100, it is valid to say that both interpretations are right, albeit partially.

The growth in physics bachelor's may have been driven by demographics or by a deliberate call to arms from faculty and department chairs confronting low student enrollments. Nonetheless, we are presented with an uncommon opportunity to build on rising student interest and retention in the physics major—especially when stronger education in the sciences (and in physics by association) is an integral part of the American competitiveness agenda.

Along with this opportunity comes an obligation to assess critically the value and utility of the physics undergraduate degree, from faculty expectations to curricular content.

Historically, the physics bachelor's has been accepted by faculty as a training ground for prospective Ph.D. students. Almost half of our physics majors continue on to graduate degrees in physics, astronomy, and other fields (and as many as two-thirds eventually pursue advanced degrees). They then assimilate into the academy or into the research and defense sectors. The balance crosses (and acculturates) into engineering or a mixture of other areas, or follows scattered career paths in pre-college teaching and a variety of industries—since physics has no industry per se, unlike its engineering, chemical or biotech counterparts.

If the traditional perception of the bachelor's as merely a pre-doctorate remains unquestioned—note that we still refer only to those with a Ph.D. as physicists—we may miss a unique opportunity to ride this cresting wave in undergraduate physics. Further, if we cling to our belief that a physics program is exclusively for the best and brightest—however loosely these two attributes are typically defined—our ability to recruit students, reconfigure the introductory courses, or reshuffle the curricula would be inauthentic, at best, and futile, at worst.

It should also be observed that the worth of the major far exceeds its being just an incubator for post-graduate students. The physics student's intellectual development is the true offering—maturing higher-order skills in modeling, analysis, and synthesis; enhanced ability to decipher a problem, make a conjecture, and test a solution; empowered new language and logic; strengthened sense of belonging to the discipline as a scholarly home. Evaluated this way, the degree has a high recruitment appeal on the front end, while holding high promise upon its completion.

As to curricular reform, our physics community has led the sciences in research on learning and teaching. The past 20 years have enriched our repertoire with widely tested, effective teaching and assessment strategies. More common today are student-focused teaching models in introductory physics and a scattering of other courses. Yet, disappointingly, the traditional lecture still finds its way into a classroom or two, and lingers.

More so, the teaching process may have evolved, but the curricular content has not kept pace. Atwood machines and inclined planes still crowd our intro courses; the course sequence is not relevant to our present-day realities; and calculus still reigns from the outset, erasing the distinction between concept and technique. Our excuse may be requisite preparation for other coursework, such as engineering; but if we believe the content needs to change, we can find a way.

Enrollment in physics is not only a matter of numbers; it results from our true conviction in the significance and impact of the major. In that vein, we are called upon to revisit our long-held perspectives on what the physics major is, to whom it should speak, and how, and where it should lead. Only then can we keep it attractive, assuring its viability and vibrancy. Δ

Toufic M. Hakim is executive officer of the American Association of Physics Teachers.

Physics and Politics

Gates Relates

From the March 7, 2007, testimony of Bill Gates before the U.S. Senate Committee on Health, Education, Labor, and Pensions. The excerpt focuses on the state of math and science education in the United States.

[An] area where America is falling behind is in math and science education. We cannot possibly sustain an economy founded on technology pre-eminence without a citizenry educated in core technology disciplines such as mathematics, computer science, engineering, and the physical sciences. The economy's need for workers trained in these fields is massive and growing. The U.S. Department of Labor has projected that, in the decade ending in 2014, there will be over two million job openings in the United States in these fields. Yet in 2004, just 11 percent of all higher education degrees awarded in the U.S. were in engineering, mathematics, and the physical sciences—a decline of about a third since 1960.

Recent declines are particularly pronounced in computer science. The percentage of college freshmen planning to major in computer science dropped by 70 percent between 2000 and 2005. In an economy in which computing has become central to innovation in nearly every sector, this decline poses a serious threat to American competitiveness. Indeed, it would not be an exaggeration to say that every significant technological innovation of the 21st century will require new software to make it happen.

The problem begins in high school. International tests have found our fourth graders among the top students in the world in science and above average in math. By eighth grade, they have moved closer to the middle of the pack. By 12th grade, U.S. students score near the bottom of all industrialized nations. Too many students enter college without the basics needed to major in science and engineering. Part of our effort to transform the American high school for the 21st Century must focus on reversing this trend and improving education in math and sciences.

Microsoft co-founder testifies on Capitol Hill.

I believe our schools can do better. High schools are emerging around the country that focus on math and science, and they are successfully engaging students who have long been underrepresented in these fields—schools like the School of Science and Technology in Denver, Aviation High School in Seattle, and University High School in Hartford, Connecticut. These schools have augmented traditional teaching methods with new technologies and a rigorous, project-centered curriculum, and their students know they are expected to go on to college. This combination is working to draw more young people, especially more African American and Hispanic young people, to study math and science.

Schools are also partnering with the private sector to strengthen secondary school math and science education, and I want to mention one recent initiative in particular with which Microsoft has been involved. It is called the Microsoft Math Partnership, and it is a public-private initiative designed to focus new attention on improving middle-school math education. Although the program is currently focused on schools in Washington State, we believe this Partnership provides a sound model for public-private sector efforts across America.

To remain competitive in the global economy, we must build on the success of these schools and initiatives and commit to an ambitious national agenda for high school education. But we also must focus on post-secondary education. College and graduate students are simply not obtaining science, technology, engineering, and mathematics (STEM) degrees in sufficient numbers to meet demand. The number of undergraduate engineering degrees awarded in the United States fell by about 17 percent between 1985 and 2004.

This decline is particularly alarming when we look at educational trends in other countries. In other countries, a much greater percentage of college degrees are in engineering than in the U.S. If current trends continue, a significant percentage of all scientists and engineers in the world will be working outside of the U.S. by 2010.

For years, the decline in the percentage of graduate degrees awarded to American students in science, technology, engineering, and math was offset by an increase in the percentage of foreign students obtaining these degrees. But new security regulations and our obsolete immigration system...are dissuading foreign students from studying in the United States. Consider this: applications to U.S. graduate schools from China and India have declined and fewer students are taking the Graduate Record Exam required for most applicants to U.S. graduate schools. The message here is clear: We can no longer rely on foreign students to ensure that America has enough scientists and engineers to satisfy the demands of an expanding economy.

Tackling this problem will require determination by government and support by industry. The goal should be to "double the number of science, technology, and mathematics graduates by 2015." Achieving this goal will require both funds and innovative ideas. For high schools, we should aim to recruit 10,000 new science and mathematics teachers annually and strengthen the skills of existing teachers. To expand enrollment in post-secondary math and science programs, we should provide 25,000 new four-year, competitive undergraduate scholarships each year to U.S. citizens attending U.S. institutions and fund five thousand new graduate fellowships each year. America's young people must come to see STEM degrees as opening a window to opportunity. If we fail at this, we simply will be unable to compete with the emerging innovative powerhouses abroad.

I recognize that implementing these solutions will not be easy and will take strong political will and courageous leadership. But I firmly believe that our efforts, if we succeed, will pay rich dividends for our nation's next generation. We have had the amazing good fortune to live through one of the most prosperous and innovative periods in history. We must not squander this opportunity to secure America's continued competitiveness and prosperity. Δ

Physics and Culture

Hip Students

"Cool Science: Physics is losing its geeky image, as more students are taking interest in 'how everything works,'" by Meredith Cummings. The article originally appeared in Tuscaloosa News*, Feb. 6, 2007.*

Sydney Flowers, 18, is, in many ways, a typical college student. But she is also an example of a student helping turn the idea of physics as a geeky science on its head.

On a Friday, Flowers walked through Ferguson Center on the University of Alabama campus, books in hand, on her way to class. She has a pretty face with petite features and blonde hair.

She is anything but a geek or nerd, but that's what she once would have been called.

Flowers is a mechanical engineering major at UA who took a keen interest in physics in high school.

It is students like her that are turning the thick glasses, geeky image of physics on its head. And television doesn't hurt either.

Julie Covin, who works with the UA Science in Motion program as a physics specialist, travels around the state introducing teens to physics and said today's TV portrayals of physics as "cool"—on shows like CSI and Numb3rs—have attracted more students to physics and science in general.

"It's taken that stereotypical nerdyness away from the equation," Covin said.

"You hate to admit that television has such an influence on teenagers, but when they see women scientists that are cool, they talk about it."

Physics has come a long way since students sat in bleak rooms poring over textbooks of equations. Now physics is taught by activities such as measuring crime scene blood spatters to determine how tall the assailant was. It is fun. It is hip. And it is not, as teen physics lovers will adamantly tell you, a geeky thing anymore.

It is real-life applications that many students say got them into physics.

Take Flowers, who got interested in physics in high school after realizing she was good at math, and said she is usually one of four or five women in a class of 40. But her attraction to physics lies in its uses.

"You can see how everything works and flows," Flowers said.

"You learn all of these concepts and then their practical application in the real world."

More high school students are taking physics than ever before, according to data released recently by the American Institute of Physics. More than 30 percent of high school seniors have taken physics classes, a percentage that has been rising steadily since the mid-1980s.

Girls and minorities are also enrolling in high school physics classes at higher rates, according to the recently released data. The researcher attributed the surge to the wider variety of physics classes now made available to students.

And many schools are taking a Physics First approach, a national movement that has slowly made its way to Alabama that introduces physics to teens as freshmen in high school.

More than 200 of those physics lovers competed in the University of Alabama's 31st Annual Physics Competition on February 2, 2007. The top two finishers in the contest's written exam received four-year, in-state tuition scholarships if they choose to attend UA.

Stephen Fordham, a senior at Ranburne High School in Cleburne County, near the Georgia state line, was one of those students. Clad in a black T-shirt with a skull and crossbones on it, along with the rest of his schoolmates, he looked more like he belonged in a biker gang. Instead, he talked about why he likes physics and why he sticks with it, in spite of its formerly geeky image.

"At our school if you take physics you're the best of the best," he said. "Physics is what happens in every day reactions," he said.

His physics teacher, Jason Cole, then punched Fordham in the arm.

"Yeah, see? If you punch somebody there's a force. If you drop an egg off of a building how long will it take it to fall? You get physics in that," Fordham said.

Cole, who described his school as "probably the poorest and smallest" in attendance at the physics competition, has taken his students to compete for eight years. And even though when he grades papers the school ceiling leaks on his desk, the school still manages to find a way to afford to teach physics, which can be pricey due to the high cost of lab equipment.

"After coming to these things for years, you can get phy-sick," Cole said, laughing along with Fordham. OK, so maybe the geekyness is gone, but nobody promised good jokes.

Colleges are also taking note of physics enthusiasts. Physics bachelor's degree recipients in the nation have increased 31 percent since 2000, according to the American Institute of Physics. The number of UA students declaring physics as their major has also increased, even beyond what could be attributed to UA's overall enrollment increases. Between 2001 and 2004, 18 UA students, on average, were majoring in physics. In 2005, 33 students did so, and in this latest academic year, UA reports 40 physics majors.

Clair McLafferty, 18, a senior at Homewood High School in Birmingham, is a student UA might want to be on the lookout for. After the physics competition, McLafferty said someday she wants to be a diplomat, so she will probably only minor in physics in college. Her drive and enthusiasm was evident.

"It's just fun," she said. "I love working stuff out. I really like the math and science. It gives you a solution right then and there."

Her physics teacher, Bill Helf, has been taking his students to UA's physics competition for years.

"These kids are competitive anyway," Helf said. "It gives them a way to vent that."

William A. "Bill" Keel, a professor in UA's department of physics and astronomy who chaired this year's contest committee, and Pieter Visscher, a professor of physics at UA who chaired the contest for 10 years, both expressed concern that attributes of the No Child Left Behind Act could put the recent gains in high school physics enrollment at risk and could hamper enrollment in the state's high school physics classes. For example, physics is not part of the Alabama High School Graduation Exam, the measure the state opts to use in assessing standards related to No Child Left Behind. This, the faculty members point out, deemphasizes the field.

Visscher said discoveries by physicists often lead to new technologies later implemented by engineers and others.

"If there were no physicists, existing technologies would be maintained and improved, but few new technologies would be developed," Visscher said.

Physics enrollment declined during the 1980s and 1990s as globalization made it tougher to recruit American students into physics, Visscher said.

"Whereas 40 years ago an American going into physics competed mostly with other Americans, starting in the 1980s he or she had to compete with everyone in the world."

Employment opportunities for physicists exist in many high tech industries, as well as research and teaching opportunities in colleges and universities.

Flowers, who has already had a taste of the college world, says it is important that students—especially girls—know that physics can be fun and enjoyable. Even with the increases in physics classes in college, she wonders where the girls are when she looks around her classrooms.

"I don't know if it's a stereotype that girls are fighting or if it's the discouragement because of the numbers of girls taking [the classes]," Flowers said. "But I see that a lot as a mechanical engineering major. Girls aren't supposed to work on cars, you know." Δ

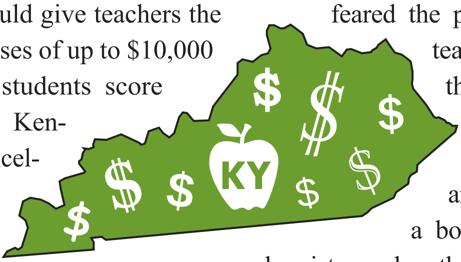
Local Initiative

Taking a Chance on Merit Pay

Physics teachers and students in Kentucky could earn cash bonuses based on their performance.

Two bills that promote a more rigorous curriculum for math and science courses won approval in the Kentucky Senate and have been passed to the House for consideration. The bills offer cash incentives for improving student and teacher performance that Senate leaders say is necessary for the state to remain competitive in an economy increasingly based on technology. The total cost of the plan is estimated to be $10 million per year.

Specifically, the first bill would give schools grants of $10,000 to start advanced-placement classes in calculus, physics, and chemistry. It would give teachers the opportunity for bonuses of up to $10,000 a year when their students score highly on AP tests. Kentucky Educational Excellence Scholarships would increase for students of low-income families if they get high scores on AP tests. And middle school math and science programs would be developed to ensure students are prepared for higher-level courses in high school.



The second bill will boost the salaries of teachers who get particularly high scores on teacher compensation tests.

But the Kentucky Board of Education argues that providing cash incentives for some teachers of selected subjects will hurt teacher morale and may diminish the efforts of teachers in other subjects. Others feared the plan would encourage teachers to recruit only the brightest students, who are likely to score highly on tests and earn the instructor a bonus, to their physics, chemistry and math classes.

"There is no evidence that merit pay improves teaching or learning," said Kentucky Education Association President Frances Steenbergen, during a Senate Education Committee meeting on February 15 where both bills were debated and passed. Δ

—**Lissa Reynolds**

Corporate Finance

UTeach Expands as National Model

The private sector is supporting science education. ExxonMobil announced a $125 million award to the National Math and Science Initiative (NMSI). The gift, believed to be the largest corporate gift ever to math and science education, was announced in March. The National Math and Science Initiative was recently created to help the United States regain its global edge in technology and science. NMSI was formed in response to a call for action in a National Academies' 2005 report, "Rising Above the Gathering Storm," which said improving students' performance in math and science is critical in improving U.S. competitiveness.

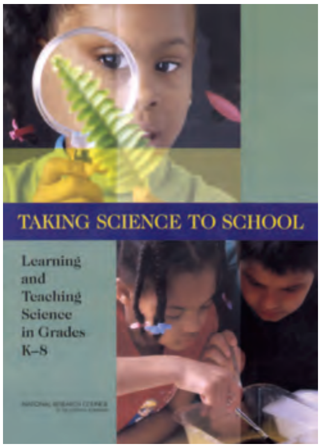
The national effort is designed to scale up two proven programs: UTeach and training and incentive programs for AP and pre-AP courses that were used in more than 60 Texas schools. UTeach Institute, a University of Texas at Austin program to promote math and science teacher preparation, will be able to expand its efforts nationally with the new commitment. UTeach (http://uteach.utexas.edu) is a model for recruiting and preparing science and math teachers.

THE UTEACH INSTITUTE

NATIONAL MATH and SCIENCE INITIATIVE

Universities across the country will now be able to apply for grants to replicate the UTeach program. NMSI plans to award grants to up to 10 colleges and universities for fall 2007 to replicate UTeach. Grants to 10 states will be awarded for the AP and pre-AP course training and incentive programs. Over the next five years, more awards will go to both programs. For information on the grant selection process, go to the NMSI website (www.nationalmathandscience.org.)

The AP training programs include extensive training of teachers, identification and cultivation of lead teachers, additional time on task for students, and financial incentives based on academic results. UTeach Institute encourages math and science majors to enter the teaching profession by offering a math or science degree plan integrated with teacher certification, financial assistance, and early teaching experiences for undergraduates. Δ



Research Findings

Science Goes to School

At a series of panel discussions at the Keck Center for the National Academies in Washington, DC, the National Research Council's Board on Science Education released its new report on learning and teaching science in grades K-8 on March 12. Through this report, the Board's Committee on Science Learning (Kindergarten Through Eighth Grade) addressed three broad questions: (1) How is science learned, and are there critical stages in children's development of scientific concepts? (2) How should science be taught in K-8 classrooms? (3) What research is needed to increase understanding about how students learn science?

The report relays from research findings that four areas of scientific proficiency, which the report calls strands, are not independent in the practice of science; nor should they be separable in the teaching and learning of science. These competency strands deal with knowledge and interpretation of scientific explanations of the natural world, generation and evaluation of scientific evidence, understanding of how scientific knowledge is developed, and productive participation in scientific practice and discourse. These, the report argues, become learning goals for students in the teaching of science at the elementary level.

Commonly held views that young children are concrete and simplistic thinkers are debunked in the report. Children enter school with substantial knowledge of the natural world, according to new research. This prior knowledge, which is influenced by demographics and socioeconomics, plays an important role in how they learn. Instructional approaches would be effective to the extent they engage children's pre-school ideas of nature. While some such pre-concepts may be naïve and incorrect, teaching methods need to acknowledge and reinforce the accurate observations before simply confronting the erroneous pre-concepts. Developing scientific proficiency among children would necessitate a full range of activities that touch upon all four strands.

There are serious implications to these evidence-based findings on how students learn, especially in terms of curricular development. The report recommends that developers of standards and assessment revise their frameworks in ways reflecting new models of children's thinking and taking better advantage of children's capabilities. Furthermore, it urges educators to focus on a few core ideas in a given discipline and building on these ideas progressively over grades K-8, and to teach science consistently with the process of scientific practice and discourse itself.

In terms of teacher education and professional development, the report concludes that teachers need to know the science content well, but also be well versed in how children learn, and how, according to research, children's understanding of core ideas in science builds across grades. ∆

Sustainable Student Research

A new publication was released on February 21 at the National Press Club by the Council on Undergraduate Research (CUR) that showcases student-faculty research practices across the country at colleges and universities. The large volume shares successful approaches that have enabled faculty and institutions to design, implement, and sustain a research-supportive undergraduate curriculum. Three broad areas are addressed: curricular elements that develop critical research skills, institutional infrastructure that enhances a research-advancing curriculum, and administrative contributions that initiate and sustain such a curriculum. The ideas presented in this compendium build on many years of work by faculty and administrators toward integrating research and education at various types of institutions, starting from chemistry and physics and reaching out beyond the sciences to other disciplines. ∆

Tim Elgren, a former president of CUR, discusses the benefits of a new publication chronicling research-supportive undergraduate curricula.

Lighting the Fire

The advanced laboratory experience plays a pivotal role in undergraduate physics, yet it is often taught in isolation. A former AAPT president explains why it's crucial to bring the advanced physics lab in from the cold.

BY DICK PETERSON

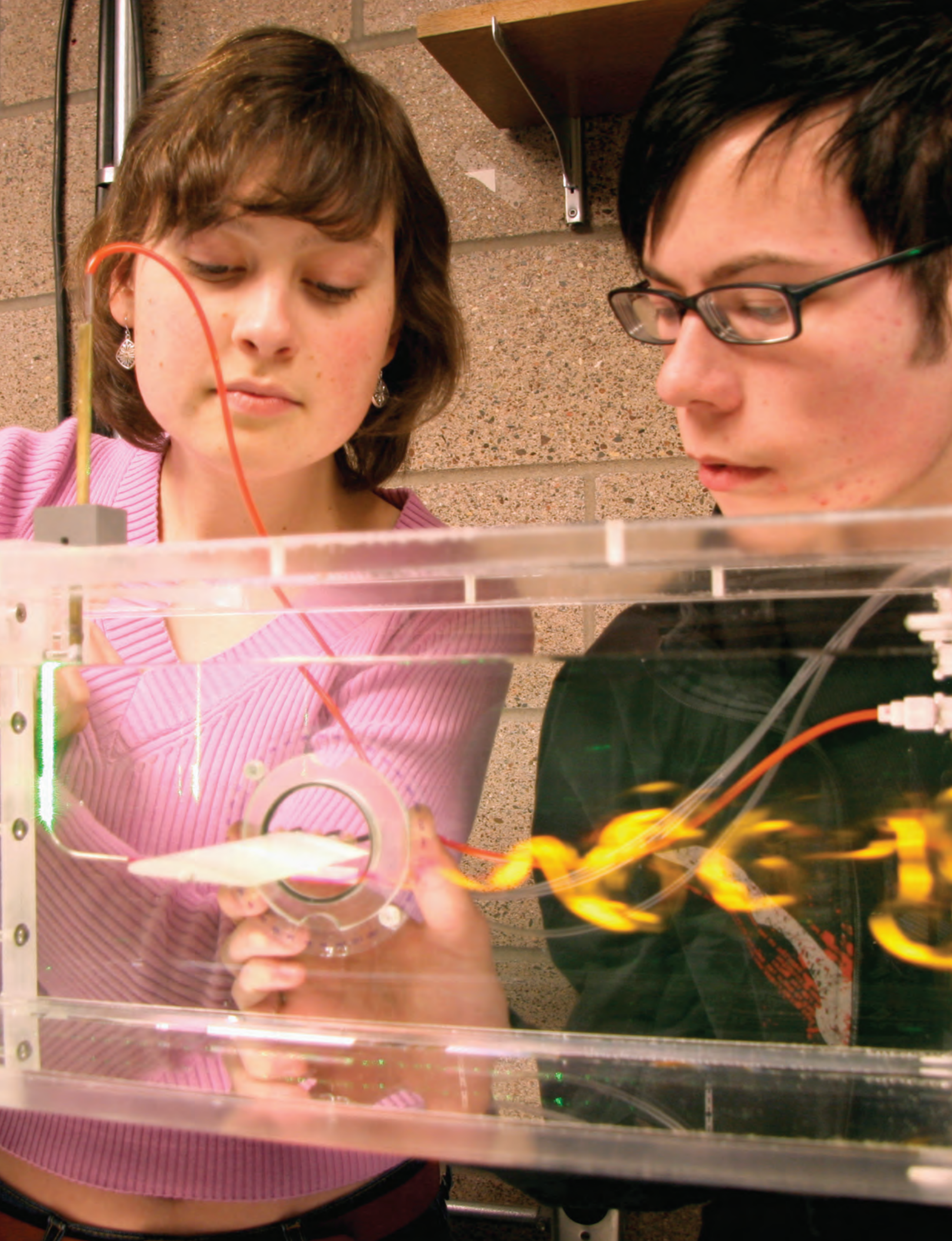
Advanced physics laboratories (typically junior or senior level—atomic and nuclear, condensed matter, optics, fluids or acoustics) have a long tradition in colleges and universities, yet they often have different goals and curricular structures at different institutions. Sometimes advanced lab experiences are incorporated within distinct upper-division courses—such as optics, electronics, atomic or nuclear physics—while other departments have a more traditional, stand-alone "advanced lab" that seeks to effectively bring together several areas of physics and their respective experimental techniques.

The departmental structure of such labs has often resulted from heroic works of the past in a department, and yet it is still true that a young experimentalist may be assigned to cover such a lab, and—after looking over a chaotic assemblage of dusty equipment—decides on a survival strategy for the short term that also builds on his or her particular background and interests. Still, whether in a college or large university, such a "can do" individual will likely develop his or her own approach, given that department's resources, and often observes that the learning and maturing experiences of impacted students are some of the most influential of their undergraduate years. But these diverse advanced lab challenges are often experienced in relative isolation from other workers, and, even in large departments, colleagues may have limited experience with essential lab equipment or access to helpful pedagogical insights or even share an underlying commitment to the cause. Accordingly, the Advanced Laboratory Task Force (see Sidebar, page 18) has presented several recommendations aimed at bringing advanced lab instructors together for mutual assistance and to sharing ideas and experiences.

It's All About Students

"Education is not the filling of a pail, but the lighting of a fire," wrote W. B. Yeats. The advanced lab instructor, whether in a stand-alone course or as the lab component of another upper-division course, is invariably looking for creative student experiences that both affirm and light a fire. Yet even at the junior and senior level, an experiment that yields an illuminating "eureka" moment for one student can be a "burn-out" for another. So the advanced lab instructor must orchestrate varying student strengths and interests, build on lab group dynamics, and always be on the lookout for a positive "ignition" event. Combining this creative investigative quest with the pressures for a broad experimental exposure, building lab computer and data analysis skills, along with polishing written and oral communication skills,

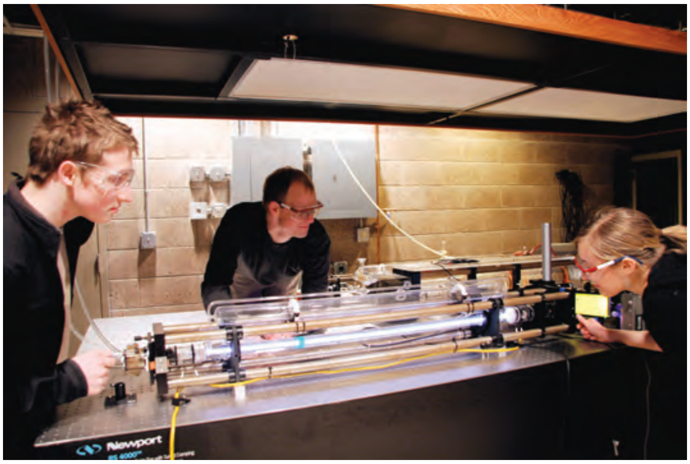
Physics majors Laura Steen and Matt Freeland measure vortex shedding (as a function of wing angle and fluid velocity) from a wing cross section in a fluid mechanics water tunnel.



leads to the daunting, yet rewarding, role of the advanced lab instructor. These many pressures have motivated some departments to strategically spread advanced lab experiences over several instructors and courses.

For example, besides extensive sophomore-level experiences in electronics and atomic/nuclear labs, the Bethel University physics and applied physics B.S. programs emphasize significant advanced lab experiences within optics, laser physics, fluid mechanics, and computer methods classes. Advanced labs (in classes averaging about 15 students) often start with five to six or more weeks of constrained and guided exercises, followed by six to seven weeks of open-ended projects. The larger projects conclude with LaTeX journal-quality written reports and group oral presentations.

What are the biggest challenges and payoffs from a major emphasis on advanced labs? In many upper-division classes, associated labs may require at least as much time as lectures during portions of the semester, and this must be reflected in teaching loads. In my experience teaching optics or laser physics classes in this mode, lecture and lab often combine to nearly a full-time job. In addition, while clever and challenging advanced lab projects can be built around modest equipment, it is still clear that state-of-the-art physics at this level can often profit from good quality and rather costly equipment items. The major benefactors of these investments in staff and apparatus must be students; yet, when successful, these programs can impact the morale and visibility of an entire department, especially in the case of smaller undergraduate institutions.



Photos provided by Bethel University Department of Physics.

Chad Hoyt (center) works with students Gus Olson (left) and Sarah Anderson in achieving rotational line tuning of a frequency stabilized, sealed-off CO2 laser.

PUTTING ADVANCED LABS ON THE FRONT BURNER

AAPT has long been identified with encouraging effective teaching of advanced undergraduate physics courses, in general, and advanced laboratory, in particular. In fact, the quest for community among and recognition of physics educators who devoted their energies to the advanced labs was a raison d'être for the association's founding over 75 years ago. For nearly half a century the AAPT Committee on Apparatus has sponsored a competition to recognize creative, innovative approaches to advanced laboratories.

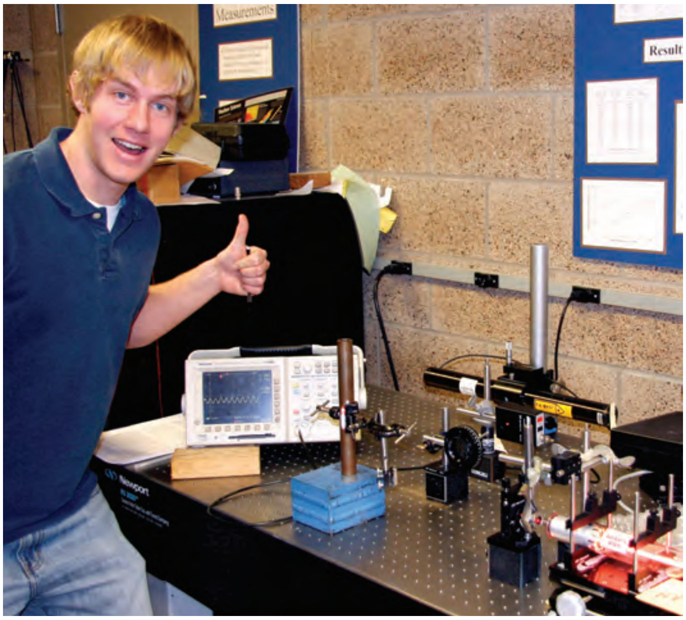
Acting at the urging of Jonathan Reichert (TeachSpin, Inc.) and AAPT President Harvey Leff (Calif. State Polytechnic Univ.), AAPT founded a task force comprising eight of its members to assess how AAPT could encourage collegiality among advanced labs practitioners as well as bring visibility to their distinct challenges and notable accomplishments within the larger physics education community. The Advanced Laboratory Task Force (ALTF) was formed in late 2005, and it issued its final report in July 2006 (www.aapt.org/aboutaapt/AdvLabTaskForceReport.cfm). Among ALTF's recommendations, several are highlighted below:

1. **AAPT should establish the tradition of predictable advanced lab sessions, tutorials, and workshops at national meetings.**
2. **Toward raising the visibility of AAPT's commitment to the advanced laboratory, an initiating special conference should be held on common issues faced in the teaching of advanced laboratories.**
3. **AAPT should establish an award to recognize significant accomplishments in advanced laboratory development and instruction.**
4. **AAPT should demonstrate its leadership in improving advanced laboratory instruction by developing the premier website for advanced laboratory course materials and "tricks of the trade." The website should also serve to maintain communication within the community of advanced laboratory instructors.**

AAPT has established a listserv at www.aapt.org/advlabs.

The goal of the listserv is to foster a continuing conversation on topics related to advanced labs, ranging from equipment purchases to experimental procedures. Also, as part of the ComPADRE project, AAPT will soon launch a website to provide information and other resources on advanced lab materials. Stay tuned at www.compadre.org.

What do students remember from advanced labs? Most likely they first recall the humorous events or goof-ups. Perhaps more than one reader will never forget that sinking feeling seeing that open, full box of holographic plates—after a few minutes of room lights. I remember one embarrassed Zeeman effect group (and this instructor) the next day with puffy, red eyes after ignoring the UV from the unshielded Hg lamp! However, following from the pedagogical goals summarized above, some students will also recall real gain in self-confidence or professional direction during advanced lab experiences. Almost every advanced lab instructor can tell of students who, having been "brought low" by a plethora of differential equations or Feynman diagrams, were able to find some redemption and confidence from a lab experience where they could really build something, make it work, and measure some physics—and they went on to great careers. Other times they also see the lab experience contributing to their resume for that great summer job or NSF-REU. LabVIEW, MATLAB and LaTeX experiences are expanded, and they may be better guided toward professional careers befitting their special aptitudes and interests.



Bethel University student Chris Scheevel celebrates his successful alignment of a helium-neon laser.

Some Big Questions

What larger issues loom that many see as foundational to advanced lab instruction in the 21st century? There are many, and they result from growing knowledge of effective pedagogy for today's students, upper-division curricular responses to changing student needs and career paths, impacts of new technologies on lab procedures and analysis, and changing sources of funding for advanced labs. Clearly the agenda for debate and presentations at an opening conference on advanced labs would not be wanting for pressing issues, including the following:

1. Does the traditional advanced laboratory based on a semester or two of foundational experiments make sense today? If so, how can these experiments best build on student creativity and flexibility while still conveying the historical roots of the original work?
2. Interactions of advanced labs with undergraduate research programs and preparation for quality NSF-REU experiences are increasingly important. To accomplish this end, some departments are strategically spreading advanced laboratory experiences (including analytical and computational skills) over two or three undergraduate years—often in a project mode that is well integrated into several undergraduate physics classes.
3. While advanced labs clearly depend on good equipment that works well and reliably, it remains important to also pass on the spirit of "making from scratch" and to nurture the troubleshooting experience. How does one best achieve this needed balance? Many current students lack the craft and construction skills assumed in the past, while adaptive computer skills (including interfacing of instruments) are strong and acquired quickly.
4. As students increasingly prepare for varied careers, pedagogical goals of advanced labs should reflect these broader perspectives. Student writing and oral presentation skills grow in importance, especially as they may relate to communicating with a broader audience. Applied physics, engineering physics, and other interdisciplinary perspectives increasingly broaden the undergraduate curriculum. Advanced laboratory work in areas such as applied optics, metrology, fluids, acoustics, and nuclear engineering is increasingly needed, and industrial support of advanced laboratory and undergraduate research facilities can play a role in an era of limited NSF support for physics education.

In a sense we see that advanced laboratories represent a microcosm of the many pressures on physics education today. Nevertheless the physics education community simply must rise to meet the challenges of these varied experiences at a critical juncture of the undergraduate years. Δ

Dick Peterson is university professor of physics at Bethel University and a former president of AAPT. He has worked with advanced labs in optics for many years, has led AAPT's Lab Focus '93, and has received the APS prize for research with undergraduates.

Teaching by the Polls

A history lesson on student response systems and undergraduate physics

BY JANE CHAMBERS

In one of many classroooms today some physics instructor is standing before a whiteboard working out an inclined plane problem to demonstrate Newton's three laws of motion. The students are following the instructor's calculations on a large projector screen. Afterwards, a multiple-choice problem, similar to that which the instructor has just solved, is displayed on the screen. The students have five minutes to work the problem and select the correct answer. Each student enters his or her choice on a handheld electronic keypad. Moments later the screen displays a bar graph representing the distribution of student responses.

Based on the distribution of right and wrong answers, the instructor as well as the students can gauge the quality of learning that has taken place during the class.

The use of keypad response systems as a tool for assessing teaching and learning during a class session is nearly commonplace in any well-equipped physics classroom. The reason for its popularity, according to many proponents of the system, is that the technology fosters interactivity and student engagement; thus, students are likely to learn more.

As far back as the early 1970s, educators sought ways to make physics teaching more interactive. Before the widespread use of the electronic keypad system, flash cards were a popular innovative technique.

The first known use of a response system to teach physics was at Cornell University, more than 35 years ago. With a $1,000 grant from Cornell's former Center for Improvement of Undergraduate Instruction to purchase materials and $700 from the physics department, in addition to "free" labor from the university's Lab of Nuclear Studies, an instructional lab technician, and his children, physics professor Raphael Littaur built a student response system (SRS) to be used in his introductory physics course. "Not knowing of any commercial offerings at affordable prices, I decided to build my own," Littauer said in an email. "The total cost ($1,700 plus labor) for a 206-seat classroom was trivial compared to the $70,000-plus that I later heard Skidmore [College] used to fund their 40-seat SRS made by General Electric."

The first commercial offering geared toward classroom use that Professor Littauer can recall was Classtalk, which was marketed by Better Education, Inc. in the early 1990s as "a new interactive classroom communications system." Eric Mazur implemented such a system in his physics classroom at Harvard around 1993 to promote interactivity, leading to his widely read book, *Peer Instruction: A User's Manual*. Many educators refer to Richard Hake's article in the *American Journal of Physics* in 1998, which reported on a study that proved the effectiveness of interactivity in the classroom.

The design of student response systems has evolved from the clunky box of the 1970s to the sleek, wireless versions ubiquitous in physics classrooms today.

The first systems were hard-wired and often homemade in classrooms. Clickers, or wireless keypad systems, made inroads in the '90s as technology evolved, using infrared (IR) or radio frequency (RF) technology to send student responses to questions from the instructor. A receiver collects and records the responses on a screen at the front of the classroom. The instructor gets immediate feedback and the students in turn can see how everyone else responded to questions.

As the technology has improved, use of clickers has skyrocketed in schools and universities all over the country. Manufacturers such as e-instruction, of Denton, Texas, report increasing sales each year. “I can assure you that the market has grown significantly since we started selling the product back in 2000,” commented Darren Ward, vice president of sales.

The earliest use of wireless keypads in the physics classroom likely was in 1992 or 1993. At that time Illinois Institute of Technology physics professors Leon Lederman and Ray Burnstein adapted the RF Fleetwood keypads for instructional use. These were the first commercial clickers—they were expensive, used radio frequency, and had a high range.

By the late ’90s, technology improved and the Classtalk system and other wired systems became obsolete, replaced by infrared wireless clickers. In the last few years, inexpensive radio frequency (RF) clickers have become available, taking over the IR models, according to Burnstein.

As an example, physics senior instructor Michael Dubson, at the University of Colorado, said he read Mazur’s book in 1997 and that got him started on the road to interactivity, using ConcepTests with colored cards in a few physics and astronomy classes from 1998 to 2001. In 2002 Dubson said his department started using infrared H-ITT clickers (chosen for the low cost to students) in a freshman physics class. Their use increased, but was limited because of the expense and difficulty of maintaining the permanent receivers in the lecture halls, he said. The H-ITT clickers, with infrared technology, required a number of receivers in the classrooms, all in line of sight with the clickers. In fall 2006, Dubson tried out RF iClickers (developed by physics professors in Illinois and sold through Holtzbrinck Publishing) in a large freshman class, as did an astronomy professor. By spring of 2007, clicker use has exploded at CU, with 10,000 students in 60 classes using them across the campus. This fall, the H-ITT will be officially abandoned and the iClickers will become the campus standard, Dubson said, meaning the campus support staff will train and support them. He said iClickers, which students buy like a textbook for $30, were chosen because they have the simplest design, with 5 keys A to E, so they can be used in any class and for any subject. ∆

A Progressive History of Response Systems

Cornell University, 1970s: Prof. Raphael Littauer installs his own homemade personal response system, with hard-wired response boxes installed on chair backs of Rockefeller Hall.

Illinois Institute of Technology, 1993: Profs. Ray Burnstein and Leon Lederman adapt a radio frequency, wireless keypad system made by Fleetwood, offering wide range and reliability, for their physics classes.

AAPT Summer Meeting, 1994: A Workshop is offered by Better Education, Inc., manufacturer of Classtalk, a “new interactive classroom communications system.”

Rutgers University, 1995: Physics Prof. Joel Shapiro introduces a hard-wired personal response system he built and installed himself and was later described at the AAPT Summer 1996 Meeting in a paper. After 2001, technology intervened and IR systems became commercially available. Rutgers installed an educue PRS system, but it was not as reliable as his own system, Shapiro said, and in fact it was a step backward because it did not have direct feedback to the students that their response was received. At the present time, he said, the university is going to replace PRS with more reliable and inexpensive RF systems. The use of clickers has grown at Rutgers, he said, moving into the chemistry, economics, genetics, and a number of other departments.

Kansas State University, 1995: Physics Professors Dean Zollman and David Johnson install a wired computerized personal response system supplied by Classtalk, a more sophisticated system than simple clickers, allowing all types of responses. Over the years, KSU has continued to grow and experiment with interactive systems, moving to pocket PCs (PDAs), which use wireless Internet connections, in 2004. Zollman and Professor Sanjay Rebello presented a paper at the Winter 2005 AAPT meeting on “The evolving classroom response system at Kansas State University: Classtalk, PRS, & PDAs.”

Harvard University, 1997: Prof. Eric Mazur’s book *Peer Instruction: A User’s Manual* is published.

University of Colorado at Boulder, 2002: H-ITT clickers are used in an introductory physics class by Michael Dubson. 2003: “Physics for Poets” class taught by Carl Wieman and Katherine Perkins uses the clickers for student multiple-choice questions.

Interactive Whiteboards: Technology for Learning

BY JANE CHAMBERS

Interactive whiteboards are a modern tool used to increase students' engagement in the classroom, improving their retention and their enthusiasm for learning. First manufactured in the early 1990s, the interactive whiteboard is simply a touch-sensitive screen working in conjunction with a computer and a projector. Used throughout industry, educators are the largest single group using the technology.

Interactive whiteboards are used in the classroom to manipulate text and images, make notes in digital ink, view websites or demonstrate software, create digital lessons, and allow students to make presentations. Students may write or draw on the screen with their fingers or a pen tool. Teachers may write over websites or other digital documents on the screen, and also highlight important sections with underlining or colors. Notes that are written on the whiteboard can be saved and sent out to students by email, to help in their studying for tests.

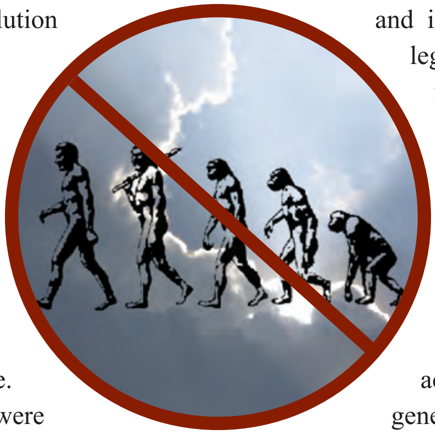
The technology is also helpful in reaching out to visually- or hearing-impaired students, or students with other special learning needs. Students with visual impairment, but some sight, can benefit from extra large text on the screen and manipulating the objects themselves. The touch-sensitivity and interaction with the screen are helpful for a wide variety of students. According to recent research, the interactive whiteboards bring excitement to the classroom and are instrumental in motivating students to learn and keep coming to class. ∆

Unintelligent Design

A slightly different version of this essay originally appeared in the *Northwest Arkansas Times*, on October 15, 2005.

BY ART HOBSON

The evolution wars continue. One recent skirmish was in Pennsylvania, where 11 parents brought suit against the Dover Area School District after its school board became the first in the country to instruct teachers to inform students of "gaps and problems in Darwin's theory" and to teach "other theories of evolution including intelligent design." The trial opened in federal court on September 26, 2005, and ended on December 20, 2005, with a victory for evolution education.



A former school board member's testimony provides insight into intelligent design (ID) ideology. She described the board meetings where the new policy was adopted as similar to a revival. Scripture was quoted, speakers told people how to accept Jesus Christ as their personal savior, and attendees muttered frequent amens. The new policy was adopted by a vote of six to three. Dissenters were called atheists, asked if they were "born again," and told they were "going to hell."

ID is the latest strategy in a campaign to compel science teachers to teach religious dogma in science classrooms. The previous creationist approach was based on a literal reading of Genesis and insisted that Earth was only a few thousand years old and that all biological species were separately created by God. ID dresses creationism up in new clothing, arguing that living things are "irreducibly complex" in the sense that if one vital part is removed they won't work at all, and that such structures must have been "intelligently designed."

Creationists have labored for decades to portray evolution as a "theory in crisis," and they've had considerable success in persuading Americans that there is indeed a real debate here and that it's only fair to teach "both sides." I'm all in favor of teaching both sides whenever two sides actually exist, but teaching the ID "theory" of biology is like teaching the stork theory of childbirth. There is no scientific controversy here. Evolution is supported by literally millions of experiments and has been settled science for over a century. Nobody supports creationist notions in science journals or at meetings, despite scientists' natural tendency to search for weaknesses in established theories.

The evidence for human evolution is especially impressive. The fossil evidence stretches back over six million years and includes some 20 different species of two-legged human ancestors since we branched off from the apes, leading gradually from ape-like creatures to Homo sapiens. Genetic dating methods that trace the genetic similarities between humans and apes also point to a divergence about six million years ago. Specific human genes are known to be currently evolving under the influence of Darwinian natural selection. Two of these are genes that act on the human brain. One of these variant genes emerged about 37,000 years ago and is now present in 70 percent of humans, and the other arose only within the past six thousand years and is now present in 30 percent of humans.

ID is one of those so-called scientific theories that are "not right" and "not even wrong." ID is certainly not right. For example, one of the favorite creationist challenges is the development of the eye. Only an intelligent designer, they argue, could have created such a brilliant and complex arrangement. But the eye betrays its evolutionary origin with a tell-tale flaw: The retina is inside out. The nerve fibers that carry signals from the retina's light-sensing cells lie on top of those cells and have to plunge through a large hole in the retina to get to the brain, creating the eye's blind spot. Any intelligent designer would be offended by such a clumsy arrangement. The human eye was not designed; it was inherited as the result of long-term evolutionary development. The eyes of all vertebrate animals are linked with our invertebrate relatives that have only simple eyes that detect light but can't form an image. In fact, molecular studies have recently found a direct link between the genetic structures that control primitive invertebrate light sensors and those that control sophisticated mammalian lens structures.

ID is "not even wrong" because it's not a scientific theory at all. In the first place, whenever the theory comes up against a structure that's difficult to explain, it claims that the "designer" made it. Ascribing some phenomena to supernatural forces puts ID entirely outside the realm of science. Although science neither denies nor affirms God, the foundation of the scientific age is the use of reason and natural causes to explain natural phenomena, in contrast to the pre-scientific view that natural phenomena are caused by gods and demons. If we admit supernatural causes into science, we can kiss science goodbye.

Furthermore, ID has no positive content. There is no ID theory, no ID evidence, there is only a collection of spurious objections to evolution. ID offers no opposing scientific explanation for the diversity of life, except to say "the designer did it" in certain cases.

Creationists are a puzzle. They presumably believe that God created the universe. Why then can't they accept the beautiful evidence that is written in the fossils, in our genes, and indeed in the heavens, evidence that is observed daily by scientists everywhere? Our highest natural faculties, namely our brains, attest to the theories that this evidence inspires. Surely, this evidence and these theories concur with whatever design God might have for life on Earth. Thus if the universe is created by God then creationism, by trying too hard to squeeze the universe into its own narrow orthodoxy, might be the ultimate heresy. Δ

Art Hobson is professor emeritus of physics at the University of Arkansas, Fayetteville.

Share Your Opinion

This article does not necessarily represent the views of this magazine. The mission of *Interactions* is to foster an open discussion on any issue of particular interest to the physics education community. That means representing all points of view.

If your observations, insights, and judgments differ from those reflected here, we welcome your feedback.

Send comments to: interactions@aapt.org.

Tracking the unintelligible designs of an anti-science movement

BY MARTHA HEIL

Despite a verdict handed down in December 2005 by a Pennsylvania court that upheld the role of science, the anti-science movement has not retreated (see "Creationism and Public Policy").

Attempts to push intelligent design continue, but in the wake of the Dover, Pa., case, school districts now have reason to pause before conforming their science curriculum to the creationist agenda.

It appears that any setback caused by the Dover decision has prompted the "intelligent design" movement to reinvent itself as a campaign advocating for the teaching of evidence for *and against evolution* and other scientific theories, popularly billed as "teaching the controversy." Presented as a critical analysis of two competing theories, this new position purports to represent the midpoint between secular science and personal religious beliefs.

The problem with this argument, however, is that there is no credible scientific evidence against evolution, and that any "gaps" or problems in the theory are being amplified by those whose objections to evolution are based solely on religious dogma.

The movement is also pressing for protections for teachers who choose to teach the so-called competing theories.

These attacks are aimed primarily at evolution, but they also affect other disciplines, including physics—from cosmology to radioactivity.

A survey conducted by the National Science Teachers Association three years ago indicated that 30 percent of those teachers surveyed felt "pushed to de-emphasize or eliminate evolution or evolution-related topics from their curriculum."

Fortunately, the science community has not retreated, either. Science societies are offering their members' expertise and other resources to help teachers, local school boards, and concerned citizens confront this movement against science education and literacy. Δ

Martha Heil is senior editor/strategic planner for the American Institute of Physics.

Creationism and Public Policy

2006

Ohio
The Board of Education considers a proposal to formally define "critical analysis" as a challenge to the validity of evolution. The proposal is introduced by a board member who supports the teaching of intelligent design.

South Carolina
Four out of the five candidates for superintendent of education believe that "critical analysis" or "intelligent design" should be a part of the science curriculum.

Michigan
An amendment to a bill would require teachers to provide evidence "for and against" evolution and students to "critically evaluate" scientific theories.

Alabama
Two bills are introduced that would protect the rights of teachers "to present the full range of [sic] scientific views." The bills stipulate that students should not be "penalized in any way because he or she may subscribe to a particular position on any views."

Maryland
A bill is introduced protecting teachers who present the "full range of scientific views, including intelligent design."

2007

Kentucky
A "Creation Museum," funded by a major anti-science group, Answers in Genesis, is scheduled to open.

Missouri
The "Science Education Act," slated to be introduced by the state legislature, would prevent teachers from teaching "consensus of scientific opinion" and theory, by requiring them to teach only "verified empirical data". Theories, including evolution, would be subject to "critical analysis."

Louisiana
Basing their decision on a survey clearly biased against evolution, a local school board unanimously approves a policy allowing teachers to teach evolution "only [as] a theory."

Mississippi
A proposed bill would require the teaching of creationism along with a school-board mandated teaching of evolution.

Texas
A creationist-majority school board will form a committee to refine science standards in 2008.

For more information on intelligent design initiatives, visit the National Center for Science Education website at NCSEweb.org.

The Student-Minded Professor

An award-winning professor offers tips and techniques for effectively teaching the introductory physics course

INTERVIEW BY DARYL MALLOY

Bruce Barnett
Johns Hopkins University

Matt Payne

Arguably, many professors are free to select for themselves from among differing curricula and teaching approaches, but how would you define the ideal physics curriculum and pedagogy for undergraduate students?

The ideal undergraduate physics curriculum and teaching approach cannot be simply defined. Both depend upon the background, preparation, and goals of the professor and student. What and how one tries to teach someone who wants to be a physics major is different from what and how one tries to teach someone who wants to go to medical school, and what and how one teaches a student who has a good math background is different from what and how one teaches a student who does not.

At some level one could say that once one has defined the goals and background of the student, the best teaching approach would be "Socratic," i.e., a one-on-one interaction between the professor and the student with lots of demonstration equipment to let the student interact with actual physical objects. Unless the student is prepared to hire an individual tutor, which none are, then this is not really a practical approach.

Moving up, then, one would say that having a professor and only a few students in a class, again with lots of demo equipment available, would be the next best thing. This could be much like the "studio physics" approach that a few universities try (see "Lighting the Fire," page 16). Often this approach is rather conceptual and may or may not actually improve the student's ability to solve problems, and it frequently ends up covering less material in a given amount of time than one would like or need.

In most universities, certainly at [Johns Hopkins], one has "boundary conditions" on the possibilities for how a class is taught, and often, certainly this is true in my case, the result is that there is a large group of students, ranging from 100 to several hundred, who are to be instructed by a professor with help from graduate students who run smaller "conferences." The professor gives several lectures per week to all of the students together in one room while the graduate students have a group of about 20 students for a one-hour class once a week.

Clearly, this does not give the students as much close contact with the teacher as do those methods with the smaller classes: Socratic, studio, conceptual, etc. But there are many ways to teach these larger lecture courses, some of which I believe are more effective and some that are less effective. If one is doing introductory general physics, be it for engineers, pre-meds, calculus-based or non-calculus based, one wants to make the lectures interesting and keep the students engaged. In a Socratic method one can get instant feedback from the student by asking a question. In a large lecture one can use a student response system—a "clicker" through which the professor can ask a question and get an immediate response to keep the students involved and to see if they are keeping up. One can use demonstrations and have the students come to the front and participate in the demo. One can walk up and down the aisles to get closer to the students to become more "real" to them.

There are several methods for doing homework. One can have homework written on paper and handed in to be graded. Or one can use web-based homework systems which give instant responses. Each have benefits and deficiencies. I prefer the web-based system, but it must be combined with the grad students and professor having lots of office hours.

Furthermore, as soon as one has two or more students, one must decide how fast to teach the material. Does one teach the best students, with other students falling somewhat behind? Does one teach the worst students and risk the better students being bored? Does one teach to the level of the average student? For each method how do you get students to spend the appropriate time on your course in addition to working on other courses?

So, your original question does not have a single or simple answer because the “best” method would be strictly one-on-one teaching, which no university can do.

In this issue I write about the studio classroom and suggest that a likely consequence of the growing use of technology-based, active learning will be the demise of the traditional lecture approach to teaching physics. Would you agree?

No, I don’t think so. One could say that all a student really needs to learn physics is in the textbooks that students have had for decades or centuries. But the students aren’t able or willing to sit by themselves and learn the material. The new technologies will enable students more interaction and feedback, but there is still something motivating about having a real person performing and/or lecturing in front of you.

Based on your extensive experience in the classroom, what personal qualities and professional skills are essential for effective physics teaching at the college and university level?

You must be interested in the student and interested in your subject. You must try to make a person-to-person connection with the students in the audience. Care about the students and make sure the students know that you care. Don’t lecture to the board. Look the students directly in the eye while you talk. Try to speak in a normal conversational style to them, not in an artificial “lecturing” style. Don’t be aloof. Get them involved in the lecture. For example, include them in the exhibition of the demonstrations. Walk up the stairs into the audience while you are speaking so you get closer to them. Go up and talk to and be near the students in the back row.

The Maryland Association of Higher Education selected you as its 2007 Outstanding Faculty Award recipient largely because of your innovative approach to teaching introductory physics. How would you describe your teaching strategy? And why is it so effective?

Of course, I don’t really know why the MAHE selected me for the award, but I suspect it was somewhat for my teaching of introductory physics, but it may have also been for my attempts at teaching through many other venues too. In my introductory physics teaching I have introduced new demonstrations and new electronic feedback systems into my lectures and web-based homework and computers into the conference sections. But much of teaching is a question of personality and approach. For example, I always try to let the students know that I care about them as individuals and how they learn. I tell them that I am available to them during office hours and also at other times at their convenience. Aside from the introductory physics lectures, however, I have been involved in developing workshops with high school teachers to improve their knowledge and also have initiated and supervised the annual JHU Physics Fair, where we try to bring physics to the general public. And, finally, being at Johns Hopkins, I have had many graduate students who also needed to be “taught.” So I expect that the MAHE looked not just at my introductory physics courses but also at my other many attempts at teaching when they selected me for this award.

> **One must try to make a person-to-person connection with the students in the audience. Care about the students and make sure the students know that you care.**

The popularity of those TV crime dramas featuring clever and attractive forensic scientists notwithstanding, the tenor of public attitude and the direction of U.S. education policy suggests a crisis in science literacy among the general public and a lack of national support for a more rigorous science education.

I don’t watch the TV shows so I really can’t say. I could, on the other hand, comment about the government. It seems to me that the federal government used to take scientific input on important public questions seriously, but recently it seems that the government makes many scientific decisions based upon the politics of interest groups, and will ignore real scientific input if it does not agree with the political decision desired.

If you could share your love of physics and teaching in just 50 words, how would you?

It is important for our society to base its decisions on truth, not on falsehoods and superstitions. The well being of this and future generations requires us to understand our interactions with nature and the environment. To the extent possible I want to extend and expand that understanding. Δ

This Old Classroom

The large-enrollment course might well be the best way to *teach* introductory physics. But is it the best way to *learn* it?

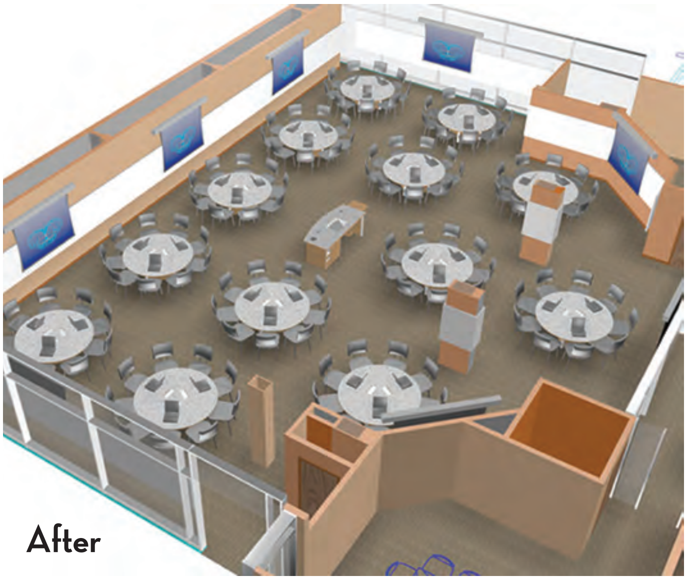
BY DARYL MALLOY

Once, John Belcher was a lead scientist for the Voyager spacecraft program. That was more than 30 years ago. His children were away in college, and he decided it was time to embark on a new challenge. So, Belcher went back to school.

He joined the faculty of the physics department at the Massachusetts Institute of Technology, teaching the introductory course in electromagnetism to first year students. At MIT, all undergraduates take at least two semesters of physics—the large-enrollment courses, which feature upwards of 600 students. Although he became a highly regarded lecturer, according to student evaluations, John Belcher had a problem. The introductory physics sequence typically had a 40 to 50 percent attendance rate by the end of the term and, perhaps more troubling for an institution where nearly all its entering students possessed strong math and science backgrounds, the failure rate was around 10 percent or slightly higher. “Whatever you think of the pedagogy of large lectures,” Belcher said to me, “if students aren’t coming, it’s a problem.” But the solution that Belcher proposed to improve student performance may, eventually, alter not only how we teach undergraduates physics but also whom we teach.

Generally, large-enrollment introductory science courses consist of three distinct elements: lecture, recitation, and the

Old School Model: The teacher represents the all-knowing “sage on stage,” who pours out knowledge to his “passive receptacles.”



New School: The TEAL studio classroom constitutes the student-focused approach. Round tables foster group interaction, and the teacher workstation is not the focal point of the room.

Matt Payne

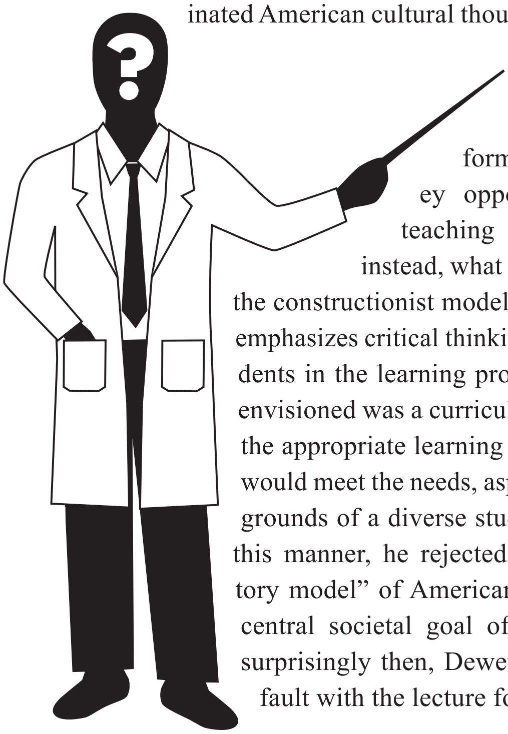
laboratory. Jack Wilson, a former officer of AAPT, called the introductory science courses taught at large research institutions "an intimidating experience." In 1997, Wilson wrote:

> Many efforts to improve undergraduate courses work from an assumption that there are "good lecturers" and "bad lecturers," and that students can learn more from the "good lecturers." The strategy then is to improve the "bad" or replace with the "good." Providing good lectures is obviously superior to providing poor lectures, but there is little evidence this leads directly to increased learning.

Something Old

Wilson was saying, in effect, the transfer of information does not presume the transfer of knowledge. Of course, Wilson was one of many educators to observe the particular shortcoming of the lecture-recitation model. In a 1984 article in *American Zoologist*, E.P. Volpe points out that "the inability of students to appreciate the scope, meaning, and limitations of science reflects our conventional lecture-oriented curriculum with its emphasis on passive learning." Volpe was arguing for a new pedagogical model in which "students become interested in actively knowing, rather than passively believing."

And Volpe's argument echoes one expressed by John Dewey, the famous education reformer and one of the principals of the early 20th century progressive movement in American education. Adherents to this view typically support a different pedagogical approach known as "active learning." Since the ideology of a more liberal, or less formal, way of teaching dominated American cultural thought, active learning is once again the orthodoxy of a new education reform movement. Dewey opposed authoritarian teaching methods, favoring instead, what philosophers called the constructionist model of learning, which emphasizes critical thinking and engages students in the learning process. What Dewey envisioned was a curriculum—coupled with the appropriate learning environment—that would meet the needs, aspirations, and backgrounds of a diverse student population. In this manner, he rejected the existing "factory model" of American education and its central societal goal of assimilation. Not surprisingly then, Dewey also found much fault with the lecture format, especially in regards to the teaching of science. *In Democracy and Education*, he wrote:



> Pupils begin their study of science with texts in which the subject is organized into topics according to the order of the specialist. Technical concepts, with their definitions, are introduced at the outset. Laws are introduced at a very early stage, with at best a few indications of the way in which they were arrived at. The pupil learns a "science" instead of learning the scientific way of treating the familiar material of ordinary experience. The method of the advanced student dominates college teaching; the approach of the college is transferred into the high school, and so down the line, with such omissions as may make the subject easier. The chronological method which begins with the experience of the learner and develops from that the proper modes of scientific treatment is often called the "psychological" method in distinction from the logical method of the expert or specialist. The apparent loss of time involved is more than made up for by the superior understanding and vital interest secured. What the pupil learns he at least understands."

And he went on:

> Since the mass of pupils are never going to become scientific specialists, it is much more important that they should get some insight into what scientific method means than that they should copy at long range and second hand the results which scientific men have reached.

If it is so easy to find fault with the lecture model, what, then, explains its persistence? The method was designed to transfer data, instruction, ideas, etc., from an "expert" to large numbers of people assembled together in a specific place, at a specific time. Critics of this approach like to point out that the lecture serves only as a vehicle for the delivery of information—but it is not influenced by or adaptive to the manner in which that information is received, interpreted or implemented. "I became a great lecturer," John Belcher said to me. "But my students weren't learning much."

Consequently, around the early 1980s an alternative teaching method emerged in the physics education community and began to challenge the prevailing lecture-recitation model. Endorsed by science education reformers and supported by cognitive and educational research, this new model—active learning—is purportedly more than a mere delivery mechanism; rather, it is a "tool" for improving comprehension and performance. Unlike lectures, active learning is intended to engage students intellectually (and physically) by introducing them to a media-rich learning environment, collaborative learning, and an inquiry-based curriculum. One way to think about how the two methods differ would be to call lecturers unilateralists and active-learning instructors, multilateralists. But it still doesn't explain what is preventing the widespread adoption of the active-learning approach by the large research institutions—especially if, as numerous studies have shown, active learning is truly superior to the large-enrollment lecture?

According to a 2004 *Science* article: "[I]t may seem surprising that change has not progressed rapidly nor been driven by the research universities as a collective force. Instead, reform has been initiated by a few pioneers, while many other scientists have actively resisted changing their teaching." Richard Panek, author of *The Invisible Century: Einstein, Freud and the Search for Hidden Universes*, offered a possible explanation in a 2005 *New York Times* article: "the large lecture survives, in part, because it is cost-efficient."

History might frame the progressive education movement as a war of ideologies, and if history is correct, it explains why Dewey never realized his vision on a large scale. Perhaps Dewey would have succeeded had he been an economist, not a philosopher. For what rarely factors in a century-old, national debate on education reform is that the so-called factory model makes good economic sense, despite its limited pedagogical value, and shifting to a more "progressive" alternative (i.e., active learning) means abandoning the financially feasible large-enrollment lecture.

One way to think about how the two methods differ would be to call lecturers unilateralists and active-learning instructors, multilateralists.

Something Borrowed

Six years ago, MIT engaged in an experiment to create a multi-sensory learning environment that would support a new way of teaching the freshman physics course. The new pedagogy would be driven by the principles and techniques of active learning. John Belcher spearheaded the initiative. The goal was to replace the traditional lecture-recitation with a "studio physics" course dubbed the Technology Enabled Active Learning (TEAL) Project.

Studio physics is a pedagogical model developed at Rensselaer Polytechnic Institute (RPI). From 1988 to 1993, RPI created a variety of courses that emphasized cooperative learning and made extensive use of technology. Jack Wilson, who was a provost at RPI, writes: "The re-engineering of the course led directly to a redesign of the facilities." RPI completely renovated seven classrooms. The task of the physics instructor in such a setting is to act as a mentor and guide. Students work in teams of two or four. The chairs are arranged in a semicircle to facilitate class discussion. Twenty to 40 percent of the session is typically devoted to computer-based exercises; the balance comprises group activities, class discussions, and hands-on experiments. A studio classroom is specifically designed to foster social interaction, which means, in Wilson's words, rather than separating the functions of lecture, recitation and laboratory, the instructor can move freely from lecture mode into discussion, ask the students to discuss their results with their community neighbors, and then ask them to describe the results to the class.

If the description of a studio classroom recalls students engaging in a lively debate at the campus coffeehouse, it is precisely the point: studio physics embodies the basic idea in constructionist theory of learning as a social function rather than solely a mental process.

TEAL is intended to serve as "a model of undergraduate science courses for large groups of students at MIT and possibly elsewhere." Belcher, together with the development team, built two, specially designed studio classrooms.

Both classrooms feature 13 round tables, with three computer monitors atop each table; 12 video cameras and 12 projection screens surrounding the room; a teacher workstation located in the center of the classroom; and a personal response system (PRS).The major expenditures included the costs for construction and the computer-controlled video projection system. Funding the project wasn't the central problem. (The National Science Foundation, Microsoft, and others provided financial support.) The challenge was finding adequate classroom space.

Belcher attributes the layout of the room to insights gleaned from the development of another studio classroom developed at North Carolina State University, under the direction of Robert Beichner, known as the Student-Centered Activities for Large Enrollment Undergraduate Programs (SCALE-UP) project. SCALE-UP is the product of a four-year, multi-phase process. The room contains six circular tables (seven feet in diameter), with three laptop computers on each table. There are ceiling mounted video projectors, whiteboards, and a wireless microphone system. Round tables are used to facilitate group interaction.

Beichner and his colleagues describe their experiences converting a traditional classroom into a studio/workshop in a report titled “Research-Based Reform of University Physics.”

Something New

I locate Building 32. It is an awkward shaped complex designed by renowned architect Frank Gehry and named the Ray and Maria Stata Center for Computer, Information, and Intelligence Science—a cubist-inspired vision standing in stark relief to the neoclassical and modernism dominating the MIT campus. It is moments before three o’clock in the afternoon of an oddly temperate New England February. I enter the Stata Center and walk downstairs to room 082. I have come to MIT on this Thursday afternoon to observe TEAL in practice; and, on Thursdays, Physics 8.12T: Electricity and Magnetism (E&M), Section L08, meets from 3:00 p.m. to 5:00 p.m. Room 082 is one of two studio classrooms located on campus. The other one is housed in a different building.

The instructor is an enthusiastic MIT lecturer named Peter Dourmashkin, whose lesson today concerns Gauss’s Law. Dourmashkin opens the session with six “PRS questions,” which he displays on the projection screens in succession. The 108 or so students in attendance respond by using their assigned hand-held keypads, popularly known as clickers. For instance, one of the questions asks: Do you [the student] take notes in class? 1) Yes, on lecture [PowerPoint] printouts. 2) Yes, in “traditional” way. 3) No.

Moments later, a histogram appears on the screen showing the distribution of responses, in percentages. The class majority indicate that they take notes in the traditional manner. Also, according to the chart, more students select answer number 3 over number 1.

The teaching plan seems to follow the guidelines established by NC State’s SCALE-UP project. That is, the two-hour session is structured as a series of short (five to 20 minutes) discrete activities: presentations (mini-lectures), visualizations, demonstrations, PRS questions and group problem solving, and desktop experiments.

During the presentations portion of the session, Dourmashkin discusses concepts such as a point charge, electrical fields, flux, and the symmetry of Gaussian surfaces. During the presentation, Dourmashkin derives formulas; calculates the magnitude of an electric field (“What technique do we use to solve this problem,” he asks); and succeeds (in my view, anyway) in transforming the abstraction of Gauss’ Law into a visually concrete concept with the aid of a device called an electrostatic field apparatus. He writes a problem on the whiteboard labeled number nine. (My field of vision is obstructed but I watch his image on the screen.) He then moves to whiteboard number eight to perform the calculations—he presses a button along the wall, activating the camera positioned on the number eight whiteboard—some of the screens now display the problem and some, the solution. Nearly an hour has passed; and, after the presentation and demonstration and derivations and example problems, Dourmashkin introduces another PRS question:

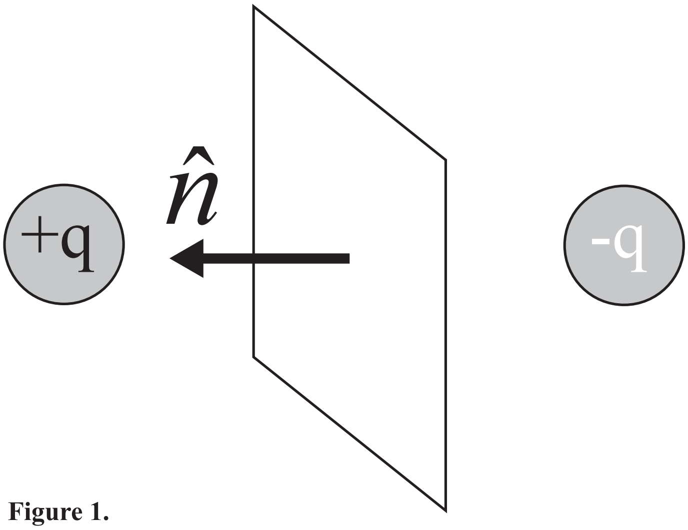


Figure 1.

> The flux through the planar surface [see Figure 1] (positive unit normal to left):
>
> 1. is positive.
> 2. is negative.
> 3. is zero.
> 4. I don’t know.

Dourmaskin gives the class approximately four to six minutes to solve this problem. Some students appear to use less than a minute of the allotted time to key in their answer and some discuss the problem with another student or students before choosing. The movement of the bar graphs demonstrates the fluidity of how knowledge is transmitted from one student to another during the group discussion, until almost the entire class knows the correct answer is number two (negative). After briefly summarizing the key issues and concepts represented by the problem, Dourmashkin proceeds to the next question. (If, say, 50 percent or more, depending on the nature of the question, continue to choose the wrong answer after further group discussion, then "meaningful learning" has failed to happen, and Dourmashkin would have to reconsider the effectiveness of his presentation.) Immediately following another PRS question, the class takes a ten-minute break, and despite my not having participated in any of the group discussions or solving a single problem, I too welcome any pause in the action, however brief. I recall what another TEAL instructor, named Eric Hudson, said when I talked to him about four months earlier: "When you walk into a TEAL classroom there is a dynamic that is absent from the lecture setting." But he somewhat, perhaps, is understating the actual effect.

Something New

In fall 2001, the development team introduced a small-scale, or experimental, version of TEAL for the freshmen E&M course. Most of the students who participated in the prototype class said they would recommend it to other students. But a full-scale implementation, in spring 2003, met with mixed reviews. "Students expressed both positive and negative attitudes," notes a study conducted to evaluate TEAL. In fact, 150 students signed a petition denouncing TEAL and calling for a halt to its proposed expansion. "8.02 TEAL does not provide us with the intellectual challenge and stimulation that can be expected from a course at MIT," the statement reads. "We feel that the quality of our education has been compromised for the sake of 'trying something different.' We strongly advise that the traditional 8.02 course be reinstated as soon as possible."

Belcher and his colleagues had set out to improve learning and performance in an introductory physics course, and they succeeded. "The net gain and relative improvement of TEAL students' conceptual understanding has been found to be significantly higher than that of the control group [students taking the traditional lecture course]," concludes an assessment study, titled "How Does Technology-Enabled Active Learning Affect Undergraduate Students' Understanding of Electromagnetism Concepts?"

The view offered in the petition recalls Dewey's observation that "the method of the advanced student dominates college teaching." Hence, the choice of words such as "intellectual challenge" and "quality." The problem with the "lowering-standards" argument, however, is it assumes studio physics in particular and pedagogical reform efforts in general are merely about retooling time-honored methods and practices to accommodate underachieving students. It's not. Physics reform, purportedly, has less to do with making physics accessible to all students regardless of background or motivation and more to do with sustaining the future viability of the physics discipline.

"Many people don't see science as a subject that's interesting or relevant to their lives, which is why it's easy to sweep it off to the fringes of our cultural discourse and leave it there," writes Kristin Abkemeier, an "ex-physicist" who has created a website devoted to science and culture and art, called *Radioactive Banana*. Abkemeier started the site to encourage people to think about science "by showing how thinking like a scientist is fun, how opening oneself to a different way of seeing the world makes your life richer."

I once asked asked Eric Hudson if TEAL will produce a future Nobel Laureate. "I certainly hope so," he replied. Will it increase the number of physics majors? "I don't necessarily care if we don't produce more physics majors. I want to produce people who are science literate."

Perhaps, the more significant contribution of Jack Wilson, Robert Beichner, John Belcher, and the other pioneers of studio physics will not have been inspiring the classroom of the future but rather having removed the walls that promise to further isolate the physics classroom from the core educational experience of tomorrow's undergraduate students.

Daryl Malloy is managing editor of Interactions. *Send comments to dmalloy@aapt.org.*

Editor's Note: The MIT Physics Department and the TEAL Project were featured at the workshop "Achieving Systemic Reform in Physics Teaching at Leading Research Universities," organized by AAPT in 2006. Fifty-one physics professors attended the forum from 28 universities, including Johns Hopkins, Princeton, and Yale. Public universities included the University of British Columbia, UCLA, University of Colorado at Boulder, University of Illinois at Urbana-Champaign, Universities of Michigan and Minnesota, as well as Cal State-Long Beach, Ohio State, Michigan State, and Penn State. The presentations and discussions focused on teaching effectively to large sections of introductory physics courses, training tutors, and engaging research faculty from across departments in teaching reform.

The Apprentice Physicists

Providing meaningful research opportunities to undergraduates can be a challenge, but it is possible, and well worth the effort. One general relativity teacher explains why.

BY THOMAS W. BAUMGARTE

Involving undergraduate students in research on general relativity can be simultaneously difficult and extremely rewarding. The difficulties come in more or less three closely related categories, none of which should come as a great surprise: the limited background of typical undergraduate students, the difficulty of finding an appropriate project, and the limited time available for research. By writing about these issues, based on my experience at Bowdoin College, I risk stating the obvious, but perhaps my observations are nevertheless a useful starting point for discussions. Another issue with which I have sometimes struggled is the fact that students may carry out the research as part of a credit course. The rewards of working with undergraduate students, on the other hand, may be less self-evident, and should definitely be a part of these discussions.

Limited background

Carrying out meaningful research in general relativity obviously requires a solid understanding of the subject. A rigorous introduction to general relativity, however, is not very often offered as part of an undergraduate curriculum.

Clearly, the situation differs widely from institution to institution: some places may offer an undergraduate-level introduction to general relativity; at some universities undergraduates can also take graduate-level courses; while other places may offer a Physics First course, or only a qualitative introduction, or no course in general relativity at all. Until recently, for example, the relativity course at Bowdoin covered special relativity and some concepts of general relativity, but introduced only very few of the mathematical tools and did not develop the field equations. A typical student interested in becoming involved in research on general relativity, then, rarely had a solid understanding of the subject.

Adding to the problem, research in general relativity typically requires knowledge that exceeds the material covered in a graduate-level course. Numerical relativity, for example, also requires an understanding of decompositions of Einstein's equations as well as of computational physics and numerical algorithms.

To address this issue I found it necessary to offer both extra support to students to learn this material, and to limit my expectations. In terms of offering extra support, I offer an independent study course on general relativity. In this course students read a textbook on general relativity more or less independently, and I meet with them weekly to discuss problems or questions. Offering such a course makes better use of our time if several students take it simultaneously. I have found it useful to offer such a course during the spring term, to prepare students who start research in the summer.

In terms of limiting expectations, I also believe that it is adequate for undergraduate students to have a more limited understanding of a project than one would expect from graduate students. For example, when assigning a project on initial data, one would certainly expect a graduate student to be able to derive the constraint equations in the particular decomposition adopted in the project. For an undergraduate student, however, it may be sufficient to have a more qualitative understanding of how the equations are derived, as long as the student has the mathematical tools to manipulate the equations themselves.

Research as a credit course

Typically undergraduate research comes in one of two kinds: the students carry out the research as a research project during the summer, in which case they may be paid a stipend; or they work on the research during the academic year, in which case they often enroll in an independent study course and earn academic credit. At Bowdoin, the research may lead to an honors project that entails writing a thesis as well as an oral presentation.

A problem with research as a credit course is that as supervisors we have to give academic credit for the students' progress on the research project. Clearly, every research project is very different and it is difficult to formulate well-defined uniform goals or objectives—other than completion of the project. Unlike in typical lecture courses, it is therefore very hard to come up with suitable and objective criteria for assigning a letter grade.

In anticipation of this difficulty I talk about this issue with every student before he or she signs up for an independent study. I try to formulate my expectations as clearly as possible and discuss the level of time commitment that I expect. Having such a conversation may also help students anticipate their schedules accordingly.

Choosing the Right Subject

Probably the most difficult aspect of involving undergraduates in research on general relativity is identifying a suitable project. Such a project has to meet a number of criteria: it must be sufficiently simple and limited in scope so that a student with very limited background and experience can solve it; it should be interesting, because otherwise it is not worth the effort or our time; but it also shouldn't be too interesting, because otherwise somebody else is likely to do it before the student can finish it. My personal goal is to have students work on projects that may lead to publishable results, even if it is a very short paper.

There are different types of projects that meet the above criteria. A personal favorite is one that is completely self-contained, so that the student can see it through from beginning to end. Needless to say, these projects are hard to come by. As an example, I had one student study spherically symmetric shells of non-interacting particles in circular orbit, and compare criteria that different research groups had used to identify circular orbits for binary black hole systems. Spherical symmetry is probably a very good starting point, but of course there is only a very limited number of interesting problems that can be done in spherical symmetry.

Another possibility, at least in numerical relativity, is to have students use or modify existing codes to explore certain effects. For example, I have had students use a code that models rotating neutron stars to find the maximum allowed mass of differentially rotating neutron stars for different equations of state.

Yet another possibility is to have students study a model problem that perhaps is not even general relativistic in nature, but illustrates some aspects of an effect that is also encountered in general relativity. In one example that I particularly liked, students rewrote Maxwell's equations to illustrate numerical stability properties that are encountered when Einstein's equations are manipulated in an analogous way.

Matt Payne

Probably the most difficult aspect of involving undergraduates in research on general relativity is identifying a suitable project.

Time constraints

One great challenge that we face when carrying out research projects with undergraduate students is time constraints. These constraints are of two types: undergraduates have a certain fixed amount of time to graduate; and undergraduates have to take classes and can only devote a small fraction of their time to research. Both of these aspects are very different from what we might expect from graduate students. Advanced graduate students devote all of their time to research and do not graduate until the research has come to a reasonable stopping point or conclusion.

The last weeks or months before impending graduation are often filled with many distractions. While we would hope that students focus on their project during that time, tie up loose ends, and finish their theses, the reality is likely to be quite different. Add to this a more or less severe case of senioritis, and progress may come to a grinding halt.

Even without these adverse effects of impending graduation, the productivity of undergraduates during the academic year can be quite low. This is very understandable, of course, since their prime responsibility is to take classes and do well in them. Taking classes means that there are regular deadlines—such as homework sets, midterms, and finals. Research projects rarely come with fixed deadlines and therefore may easily end up as a low priority.

The Baumgarte Index

Number of students who have worked on research projects with Baumgarte since he arrived at Bowdoin in 2001: **7**

Estimated percentage of these students who were juniors: **43**

Estimated percentage of seniors: **57**

Number of students who have co-authored at least one paper with Baumgarte: **5**

Number of students who have given talks at Eastern Gravity meetings: **3**

Number of research projects ongoing: **2**

The best time to do research with undergraduates, then, is the summer. In fact, I usually ask students who would like to work on an honors thesis with me to spend the summer prior to their senior year working on their thesis project. Unfortunately that precludes the student from enrolling in an NSF REU program, which could also be a very valuable experience. Instead, I suggest that they apply for REU programs for the summer before their junior year. The down-side of this plan is that most REU programs prefer rising seniors over rising juniors.

I also request honors students to spend at least one week of their senior year's spring break at Bowdoin. Luckily Bowdoin College has a two-week spring break, so that spending one week here does not rule out a more typical spring break. However, during that time students often have to visit perspective graduate schools as well, which again takes priority over finishing an honors project.

To encourage students to stay focused during the academic year, it helps to have regularly scheduled meetings—perhaps once or twice a week—and to discuss in each meeting what should be accomplished by the time of the next meeting. I have also found it useful to tell my students what level of time commitment I expect. Formulating these clear expectations makes it less awkward to assign a letter grade, as discussed above.

While there are constraints on the students' time, there are constraints on our time as well. Given the amount of training and tutoring that undergraduate students typically need before they can complete a meaningful project in general relativity, it would often take us less time to do the problem ourselves. This observation raises the question, of course, of why we involve undergraduate students in our research in the first place. We would all hope that being involved in a research project provides a very valuable educational experience to the student, but I would argue that working with undergraduates may also be very enjoyable and rewarding for the supervisor.

Rewards

Having discussed all of the problems, challenges, and potential pitfalls of doing research in general relativity with undergraduate students, it may come as a surprise that I find it profoundly rewarding to involve undergraduates in my research. For these students this is usually the first exposure to serious research, and they choose to do this because they think it is "cool." Unlike graduate students, many of whom have already made acquaintance with the frustrations of never-ending and possibly irrelevant research projects, undergraduates enter a new and exciting world and therefore are often extremely motivated.

Whether or not this holds for every student may depend on the institution. At Bowdoin, the completion of a senior thesis is not required, so that only the truly interested and motivated students become involved in research. At other institutions where a senior thesis is required, it may be more of a challenge to find a project for every student, and to motivate every student to bring the project to a meaningful conclusion.

Nevertheless, I believe that working with undergraduates provides the opportunity to work with highly motivated and appreciative students. To further boost the students' motivation, I have found it very useful to bring them to conferences. For students the attendance at a conference is exciting, and learning that there is a whole community that works on related subjects and uses the same language can be an exceptionally motivating experience. The regional relativity meetings provide a very useful forum for this purpose: they are informal, inexpensive, and if students have already completed a sufficiently interesting project they can even give their own presentation.

Finally, working with undergraduates has led me to work on some small projects that otherwise I probably would not have undertaken. As it turns out, some of those projects proved to be quite enjoyable and surprisingly rewarding. Working on a simple and transparent problem that yields some useful insights can be very satisfying, and may provide a welcome break from other more complicated and involved projects. Δ

Thomas Baumgarte is associate professor of physics at Bowdoin College and adjunct associate professor of physics at the University of Illinois at Urbana-Champaign.

This article was adapted from a paper written by Baumgarte, originally published as "Some Thoughts on Involving Undergraduate Schools in GR-Related Research," presented at the 2006 AAPT Topical Conference in Syracuse, NY. (www.aapt-doorway.org)

Examples of Student Co-Authored Papers

A.M. Knapp, E.J. Walker, T. W. Baumgarte; "Illustrating Stability Properties of Numerical Relativity in Electrodynamics," *Phys. Rev.* D 65, 064031 (2002).

M. L. Skoge, T. W. Baumgarte, "Comparing Criteria for Circular Orbits in General Relativity," *Phys. Rev.* D 66, 107501 (2002).

I. A. Morrison, T. W. Baumgarte, S. L. Shapiro, V. R. Pandharipande, "The Moment of Inertia of the Binary Pulsar J0737-3039A: Constraining the Nuclear Equation of State," *Astrophys. J.* 617, L135-L138 (2004).

Undergraduate Research at Tennessee Tech

FROM ONE REMARKABLE DEPARTMENT COMES AN UNLIKELY OUTCOME

Engaging students in funded research projects when they are undergraduates has a significant impact on the students' educational accomplishments and career choices. The Physics Department at Tennessee Technological University is a case in point. Tech's physics department, which only offers the bachelors degree in physics, has been steering students toward graduate degrees and careers in physics since the late 1970s. As a regional, predominantly undergraduate university in a state not known for generously funding higher education, one might not expect to find a program that has sent a string of students on for Ph.D.s in physics at places like Georgia Tech, University of California at Berkeley, Yale University, Michigan State University, Rutgers University, Indiana University, Duke University, and North Carolina State University; but this is just what has happened.

The Department made a strategic, deliberate decision in the late 1970s and early 1980s to build a research specialty among its faculty. Owing to the make-up of its faculty's interests at the time, nuclear physics was selected as the area of focus. New faculty positions and replacement faculty members were recruited with significant qualifications and experience in this physics subfield.

An abrupt turnabout in student outcomes came when TTU physics majors were offered the opportunity to engage in research under the guidance of the TTU physics faculty on projects at accelerator facilities at Argonne National Laboratory, Florida State University, Oak Ridge National Laboratory, Institut Laue Langevin at Grenoble and others. Sustained research supported by the Department of Energy's Division of Nuclear Physics was key to making this happen.

While the number of Ph.D. degrees awarded in the nuclear sciences has been steadily declining over the past decade nationally, eleven TTU graduates have attained Ph.D.s or are in graduate school in this subfield alone. Currently, TTU physics graduates hold faculty or staff positions at major national laboratories and institutions, including Brookhaven National Laboratory, Oak Ridge National Laboratory, University of New Mexico, and Vanderbilt University. Graduates from Tech's physics program have won a Presidential Early Career Award for Scientists and Engineers (PECASE), are contributing to research at Brookhaven's Relativistic Heavy Ion Collider, and hold positions such as that of Deputy Director of the Marshall Space Flight Center in Huntsville Alabama.

From an unlikely regional public university has come an unlikely result. Like many physics departments, TTU has a rigorous curriculum. What distinguishes TTU's undergraduate physics program from many others is the importance the physics faculty place on giving students the opportunity to engage in cutting-edge nuclear research throughout their four-year undergraduate education. Δ —**John Mateja**

John Mateja is the director of Undergraduate Research and Scholarly Activity at Murray State University and chair of the Division of Physics and Astronomy at the Council on Undergraduate Research.

A Physics Makeover

From insights gleaned over many years in an undergraduate physics classroom, the author argues that the introductory course is outdated. The time has come to revise the physics syllabus.

BY DONALD F. HOLCOMB

Over the past 45 years there have appeared many imaginative designs for college physics courses geared to non-science students. But the typical syllabus for courses aimed at science majors has basically remained unchanged for the last 50 years. The physicist's stock in trade is to question the range and validity of the current models used to describe how Mother Nature works in this world and in the wider universe. But the dramatic changes, both within physics itself and in its relationship to the world around us, have had only a marginal effect on the organization and content of the mainline introductory physics course. Perhaps the time has come for the physics teaching community to examine this situation. To which, the reader may respond, "But this syllabus is time-tested. Why should we change?" Here are a few of my reasons:

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Too many topics are covered. An academic year is too short a period to effectively teach all the physics material included in the traditional syllabus. To illustrate this time constraint, Rosanne diStefano, the evaluation director for the Introductory University Physics Project (IUPP), devised the 360-Hour Sum Rule, which demonstrates that over the period of an academic year the amount of time the typical student has available to spend on physics (in class or lab, studying, taking exams, etc.) is 12 hours per week for 30 weeks, or a total of 360 hours.

The range of physics material keeps growing, but we lose our central raison d'être if we sacrifice depth for breath. "Overpacking" the physics syllabus with "just one damned thing after another"—as an IUPP student once remarked—leads to incomplete mastery of the subject.

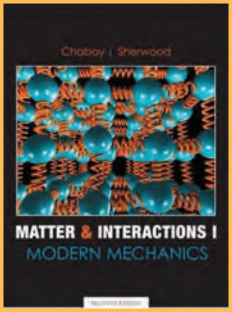
The current, standard-model syllabus reflects a 1950 physics worldview. Although the standard model has been updated, new topics are simply draped across the existing skeleton. This "classical" (a word with little meaning to today's physics students) structure has, in many cases, been left untouched by evolutionary ways of thinking about physics content or about physics teaching, which have developed over the past 60 to 70 years. Even the terminology is dated. How is a student to make sense of a scene in which the physics of 100 years ago (e.g., Einstein's world of 1905, early quantum physics, etc.) is characterized as "modern"?

The syllabus and instructional materials are largely detached from the life experiences of present-day students. The worldview of students today has been formed against a backdrop of TV, computers, lasers, satellites, the Internet, and an abundant array of electronic gadgetry, not by yesterday's mechanical machines, analog devices, outdoor games, and the like.

Physics Education Research (PER) has given us better insight into how students learn physics. The fruits of this work have given us a number of simple and robust guideposts for improving the effectiveness of physics teaching. But it appears to me that, in spite of its broad and productive work, PER has seldom focused in a deeply probing way on whether the standard-model syllabus provides the most effective pathway to the learning results we seek. Most PER work tacitly accepts the current model as given and focuses instead on better ways to teach within the confines of the status quo.

There are, of course, a few exceptions. One, for example, is *Teaching Physics with the Physics Suite*, by Joe Redish of the University of Maryland, which contains a couple of chapters that

On Matter and Interactions



A couple of decades of intensive research on student learning have led to new approaches in teaching introductory physics that place students at the center of the interactive process of inquiry (which are gradually spilling over to advanced and graduate courses as well). Teaching physics seems most effective when the student is engaged in doing physics and explores problem solving in ways commensurate with how physicists generally solve problems. The reform has by and large focused on the process of teaching.

The content of intro biology and chemistry courses has changed dramatically, while the content in calculus-based intro physics courses has not. But there are models of content reform. One such model is the *Matter and Interactions* introductory, two-semester curriculum that is in use in the calculus-based course taken by engineering and science students at North Carolina State University, Purdue University, and the Georgia Institute of Technology, as well as some smaller schools. (NCSU also offers a distance education version of this curriculum for in-service high school physics teachers, to give them a contemporary view of introductory-level physics.)

For some, the intro content is deemed less important to worry about than the process, as long as the main physical principles and models, applicable in a large spectrum of courses, are well grasped. As such, most calculus-based intro courses still comprise similar content, classical mechanics and classical E&M, adopting almost the same ideas and applications developed in the 1700s and 1800s. But the question arises whether such topics are attractive to this new generation of students and lead to competent knowledge relevant to our rapidly changing world—especially when this is the only and last physics course that most students take.

The *Matter and Interactions* curriculum (developed by Ruth Chabay, Bruce Sherwood at NCSU; the textbook is now in its second printing by J. Wiley & Sons, 2007) emphasizes the reductionist nature of physics, that from a small number of fundamental principles plus simple atomic models of matter one can explain a wide range of physical phenomena. The two-course sequence (*Modern Mechanics*, and *Electric and Magnetic Interactions*) deals with macroscopic phenomena from a microscopic perspective, brings to the fore the atomic character of matter, connects physics with chemistry, and introduces students to computational physics (through the open-source VPython 3D programming environment). An added feature is that the two volumes are thin and light paperback editions. Δ

—Toufic Hakim

attempt to probe the underlying elements of human cognition. Serious attention to such issues may be helpful in achieving a major reconstruction of the standard model syllabus.

Teaching Non-Physical Science Students

In most introductory physics courses, the textbook plays a central role in establishing the syllabus. At the present time, most widely used textbooks for the non-calculus-based undergraduate course closely follow the calculus-based syllabus used for engineering and physical science majors (with exception to two relatively new texts for engineering/physical science students: *Six Ideas That Shaped Physics*, by Tom Moore, and *Matter and Interactions*, by Ruth Chabay and Bruce Sherwood). The commonality of the two syllabi is derived from the tacit assumption that the "carry away" needs of the two groups of students are the same. My view is that they are not the same. The non-calculus course typically attracts students majoring in the biological sciences such as pre-meds, as well as students from a wide array of other disciplines—from architecture to philosophy—fulfilling general graduation requirements. Consequently, their needs can be vastly different.

The non-science student should carry away from his or her physics course a knowledge of and confidence in the attitudes, methods, and tools for doing science. They should possess (to use a now common, but nevertheless rich phrase) "habits of mind"—meaning, the attitudes, judgments, and skills (including mathematics)—that anyone who is trained in the quantitative sciences must bring to a new problem or a new domain of interest. Many physics teachers, including myself, believe that these methods and attitudes are most clearly seen in physics. Inculcating these habits should be at the forefront as we develop models for new syllabi.

Revising the Standard Model Syllabus

To design the major changes I'm thinking about will require participation from a diverse group of college and university physics teachers. But, just to get the conversation going, I'll give three examples of modifications to the standard model syllabus that seem natural to me.

- **The atomic world.** Nearly all students who come into the undergraduate physics course will have encountered the microworld of atoms, electrons and molecules in substantial detail in previous science courses, in high school or in a previous college course. It is natural to include a review and extension of that world in the early part of the college physics course. Such an introduction would then permit natural connections to that microworld as one works through the remainder of the course.
- **The power of conservation laws.** Current syllabi do, of course, focus attention on use of the energy conservation principle. But, particularly for students in the non-calculus course, it is natural to strengthen the focus on energy flow processes in biology, physiology, geology, thermodynamics, and in mankind's collective life on Earth.
- **Exponentials.** Many aspects of human development and culture can be modeled with exponential functions—be it energy usage, population growth, or measuring the ages of biological specimens through carbon dating. The physics teaching community could do our students a favor by helping them gain a better sense of how to identify and handle exponential processes.

Being faithful to the 360-Hour Rule will, of course, require truncations elsewhere. I'm sure that buried not too deeply in the minds of many teachers of undergraduate physics lie dissatisfactions with the standard model syllabus similar to mine. I welcome communications. Δ

Donald Holcomb is professor emeritus of physics at Cornell University.

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Diving into the Physics Classroom Feet First

BY ERIK CHRISTENSEN

While growing up on the outskirts of Pittsburgh, Pa., never in my wildest dreams did I even consider becoming a college physics professor! My career aspirations were singularly focused on serving our nation in uniform. My dreams became a reality when I was appointed to the U.S. Naval Academy in Annapolis, Md. Four years later, I graduated with a B.S. degree in Ocean Engineering and was commissioned as an Ensign in the U.S. Navy. I spent the next 23 years on active duty as an Engineering Duty Officer and a Deep Sea Diver serving our great nation in a variety of shipboard and ashore assignments all over the globe. Along the way, the Navy sent me to Massachusetts Institute of Technology (M.I.T.) for three years, where I earned dual graduate degrees in Mechanical and Naval Engineering. My last Navy assignment before retiring was as the Commanding Officer of the Navy Experimental Diving Unit in Panama City, Fla. where I oversaw the Navy's biomedical diving research and evaluation program.

To celebrate my Navy retirement, my wife and I spent a year touring on our bicycles. We put everything in storage and flew to New Zealand. We then spent nine months cycling to every corner of that incredibly picturesque country. Upon our return to the United States, we continued our adventure by cycling from Los Angeles to Orlando. Needless to say, our 7,500-mile bicycle odyssey was an adventure of a lifetime.

After spending several months searching central Florida for the ideal place to settle, we spent a full year designing and building our dream home. But shortly after moving in, I became restless being retired and started to look for new challenges. Remembering how colleagues in the past had often told me that I would make a good instructor, I decided to "try out" teaching. So, I inquired at the local community college, South Florida Community College, about becoming an adjunct instructor. It didn't take long until I was assigned to teach my first class in developmental mathematics. I immediately found the experience extremely rewarding and personally satisfying. Near the end of my first semester, my students signed a petition asking the college to rehire me for the following semester so that I could teach them the follow-on math course. That was a major motivating factor in my decision to continue teaching. When a full time instructor position opened up a year later, I applied and was selected as the new physics instructor.

I have just completed my second year of teaching introductory physics. I am the sole physics instructor teaching three levels of physics (calculus-based, algebra-based, and conceptual) at my institution located in a rural setting with an annual enrollment of approximately 3,000 students. I have found the experience immensely rewarding and I couldn't be happier doing what I am doing! But it has not been all fun and games. Let's face it, physics is a difficult subject for students to learn and it also is a challenging subject to teach. I have had to rely heavily upon the organizational and personal discipline skills that I developed during my Naval career. My training as a Navy Deep Sea Diver and Salvage Engineer have helped me immensely with the detailed preparation and planning required for classroom activities. A diver must methodically prepare for each dive and then remain fully cognizant of his environment and equipment throughout his dive—the same is true in the classroom. In my prior life as an on-scene salvage engineer, I had to think on my feet and rapidly react based on sound reasoning and attention to detail. I now use these skills when responding to changing situations in the classroom and when interacting with my students. My broad-based training and practical field experiences as a registered professional engineer have enabled me to easily tackle the broad range of topics that are covered in the one-year physics sequence.

Being the lone physics instructor at my college with no other post-secondary institution in my county has presented me with many challenges. There is no one locally to whom I can turn when I have a physics-related question or problem. Thankfully, it was recommended to me to join the American Association of Physics Teachers (AAPT). That has proven to be the single most important reason for my current success. Whenever I attend local AAPT section meetings, I always return home with a list of new ideas to implement. Thankfully, my college places a high priority on professional development and so I have been able to regularly attend physics-related workshops throughout the academic year and during the summer.

After my first semester teaching physics, I became extremely frustrated at my students' ability to conceptually understand the material that I had spent hours preparing and then so eloquently presented during class lectures. Very quickly, it became obvious that the traditional lecture method that I grew up with simply did not work when teaching physics to the Millennial Generation. I spent my summer vacation attending two extended workshops dealing with activity-based learning; a three-week High School Physics modeling workshop on mechanics hosted by Florida International University (FIU) and the Activity-Based Physics Faculty Institute hosted by the University of Oregon. Both of these workshops provided me with hands-on training, introduced me to active learning strategies and peer-based learning, and provided me armloads of material to use in my classroom. I have never looked back! Since then, I have attended several NSF-funded workshops and each one has helped develop my pedagogical approach and inspired me to try new methodologies. Eager to implement new strategies, I have been continually modifying and evolving my instructional pedagogy to better suit my students' capabilities and needs. My classroom learning strategy is to make my students responsible for their own learning. I help equip them with the basic tools and scientific approaches, but then want them to build upon that foundational knowledge to understand, rather than simply memorize, basic principles and to see how they might apply in our daily lives. I currently strive to develop an activity-based, peer-learning environment which I enrich with online components using our Desire To Learn (D2L) course management system. I have found the use of tasks inspired by physics education research (TIPERS) and whiteboards to be among the most successful tools that I have integrated into my class. Since everyone does not learn in the same manner, having multiple avenues available for different types of learners is a real bonus. I think I am making a difference. Student attendance in my classes is always above 90 percent and my students actually say that they enjoy coming to my physics class!

It is a real honor to be able to serve my community and help equip future leaders with the ability to think critically and analyze problems using a sound science-based methodology. My retirement certainly is not what I would have ever dreamed of, but there is nothing I would rather be doing right now! Δ

In his last job, Erik Christensen served as the "lab rat" for the evaluation of new diving equipment for possible military use.

Shifting Paradigms

What does it take to revitalize the undergraduate physics curricula? The author suggests ways faculty and department chairs can build effective and lasting reform.

BY CATHY MARIOTTI EZRAILSON

Enrollment is down in your introductory physics classes, so your department establishes a committee to identify possible causes and devise viable solutions. Clearly, something about the course is not working, but what? Where should the committee begin?

If this problem seems familar, that's because during the 1990s the number of physics bachelor's degrees conferred by U.S. colleges and universities fell nearly 25 percent, from approximately 5,000 to fewer than 4,000 by the end of the decade, according to a 2003 report by the American Institute of Physics. An estimated 350,000 undergraduate students take introductory physics each year, and about one-half of them take the calculus-based course. But only about three percent of the approximately 175,000 students who enroll in calculus-based introductory physics actually take a further physics course, and about one percent eventually graduate with a physics bachelor's.

Many university physics professors think the purpose of teaching physics is to prepare first-year university students for research in physics. For them, structure is the most important element of the curriculum and pedagogy.

But if the purpose of the undergraduate introductory course is to weed out all but the better prepared and least distracted prospective physicists, then the curriculum is doing what it was designed to do: produce no more than 2,000 or so physics majors each year. One the other hand, if the goal is to draw more students into the physics discipline, then maybe it is time to reform the introductory undergraduate course and upgrade the accompanying instructional materials. Increasing physics enrollment, however, poses a different sort of challenge: How do we teach physics effectively to a larger student population, not just the physics majors, whom we find easiest to teach?

> **"[Those] who teach physics are the ones who were able to learn physics through traditional physics teaching. Whether the operative phrase is 'in spite of' or 'because of' is an open question."**

No Half Measures

The impetus for changing a curriculum typically arises in response to a variety of factors, including the availability of new information and the widespread acceptance of new ideas and ways of thinking. Curriculum changes can result from adopting new technologies that alter the way work is done and knowledge is discovered. Similarly, addressing the educational needs of an increasingly diverse student population can also drive curriculum changes. In fact, this issue has prompted curriculum reform efforts at many universities.

Among the most far-reaching and innovative efforts in physics teaching reforms has been the *Harvard Project Physics Program,* published in 1970, and its predecessor, the PSSC physics course, designed by the Physical Science Study Committee in 1957. Early research in this area focused mainly on student learning, difficulty with mathematics, and with the perception that physics is a difficult subject beyond the comprehension of most people.

More recent studies have compared the results of traditional and alternative methods. In one study, published in 1998, Richard R. Hake of Indiana University at Bloomington compared what students learned in traditionally taught physics classes to what others learned in a class taught in a more interactive "reformed" way. Students in the interactive sessions consistently scored better on the Force Concept Inventory (FCI), a test of conceptual understanding in physics designed by David Hestenes and Ibrahim Halloun, among others at Arizona State University.

Introductory Physics Reform Process

Expectations and instructional goals must be clearly communicated at the outset from physics professor to graduate teaching assistant to student for learning to succeed.

Input	Activities	Outcomes
Individual Instructor/Student Talents Best Practices Based on Physics Education and Educational Research Investigation of Models Drawn from Diverse Areas of Expertise	Goal Setting Instructional Design Program Synthesis Model Development Strategy/Model Testing Evaluation	Articulation of Course Elements Improved Teaching and Learning Practice Higher Achievement for all Students Realistic Course Expectations Final Evaluation and Applications

Also, Nobel laureate Carl Wieman is leading a multipronged study at the University of British Columbia to test alternative teaching methods in introductory courses. By varying class size, introducing new types of group work, adding interactive computer simulations, and refining the use of "clickers" (electronic devices for active learning), the University of British Columbia physics department will study many of the reform measures successfully instituted elsewhere and bring them together in new ways. Other ongoing research on effective teaching and learning of physics is being examined and studied through a myriad of methods and contexts at large and small universities and colleges around the world.

A national task force on undergraduate physics known as SPIN-UP, under the auspices of the American Association of Physics Teachers (AAPT), the American Institute of Physics (AIP), and the American Physical Society (APS), visited 21 undergraduate physics programs, mostly during the 2001 and 2002 academic years. The SPIN-UP team look at what these "thriving" departments were doing that led to a strong production of undergraduate physics majors in the face of a general decline in physics student enrollment, and three key themes emerged:

- Building a thriving undergraduate program involves more than curricular reform. It must also be challenging, yet supportive, and foster a strong sense of community.
- The department's commitment to reform is critical for change in undergraduate education. The faculty and administration's commitment can be measured by their willingness to experiment and to adopt alternative models.
- One size does not fit all when it comes to innovations in physics education, but there are some common elements that have proven to be successful across a host of different settings. The reforms must meet local needs and goals through coordinated and identifiable partnerships (professor, teaching assistant, student), while it gleans resources from many external sources.

Does Teaching Matter?

What constitutes good teaching? Are good teachers made or born? Are teachers solely responsible for their own teaching? What role does the institution play in improving teaching?

These excerpted comments, posted originally on "Angry Voices, Tomorrow's Profession, Physics Central, Expert Voices," online discussion groups where the challenges inherent in teaching physics are shared and explored, illustrate how assumptions about and expectations for physics teaching and student learning are not always made clear. Unfortunately, few opportunities exist for professors (and teaching assistants for that matter) to learn from or experiment with effective teaching methods:

"I thought things were going pretty well—that is, the students seemed to be paying attention and actually working through their difficulties. Of course, now that I'm finally grading some of their work I have an awful yucky feeling inside... Then you start to wonder, 'Maybe it's my fault. Maybe I just suck as a teacher.'"

"[Those] who teach physics are the ones who were able to learn physics through traditional physics teaching. Whether the operative phrase is 'in spite of' or 'because of' is an open question."

"In thinking about this activity called teaching, the following has occurred to me: The best we can do—either as individuals or as a university—is create the learning environment and then offer the opportunity for an education to those who choose to acquire it. But ultimately, the emphasis has to be on learning and not on teaching."

Physics Education Research (PER) tends to approach good teaching and learning as scientific problems to be solved. Physics education researchers have also shown that students' attitudes, beliefs, and expectations about the subject matter, the course, or even about learning itself can greatly influence the way in which they learn new material.

PER is rich with models addressing how students learn best, with excellent examples of what has been tried and worked or tried but didn't work well. These are valuable resources that have often been ignored or discounted as not rigorous enough or simply irrelevant.

But research into instructional strategies has shown that the traditional lecture format is not as effective as alternative modes of instruction requiring the active involvement of the students (e.g., active learning).

Research in the cognitive and developmental sciences has provided conceptions of learning processes. In fact, these research findings have been synthesized in the National Research Council report *How People Learn: Brain, Mind, Experience, and School*. Three fundamental principles of learning are highlighted in order to illustrate the basic commonalities and "ingredients" necessary for humans to learn:

1. Humans develop conceptions about how the world works. If their initial understanding is not engaged, they may fail to incorporate advanced concepts, reverting to their prior conceptions.
2. In order to gain competence in a subject, students must (a) develop a deep foundation of factual knowledge in that subject, (b) incorporate facts and ideas into an already-in-place conceptual framework, and (c) organize new knowledge in a context that facilitates retrieval and application.
3. A "metacognitive" approach can help students learn to take control of their own learning by carefully defining learning goals and by gauging their own progress.

Good learning is good teaching

Effective instruction relies on impeccable and explicit communication—from physics professor to graduate teaching assistant to undergraduate physics student. At the outset, the expectations and instructional goals must be made clear to all participants. Traditional in-class demonstrations, performed by the professor and watched passively by the students, have been shown to be of little value in increasing conceptual understanding. Active engagement of the students is necessary for increasing learning gains.

At the University of Maryland studies of expert problem solvers have shown that there is more to being a good problem solver than mastery of mathematical manipulation and a good knowledge of concepts. For many students in introductory physics, the idea that concepts are relevant to problems or that physics is more than a set of facts and equations to be memorized is missing. These difficulties do not necessarily disappear when students graduate with a degree in physics or even when they become graduate students in physics departments.

In his 1990 book, *Guide to Introductory Physics Teaching*, Arnold Arons stresses the importance of using explicit language in constructing knowledge, acquiring meaning, and in understanding.

Similarly, physics reforms, which according to Hake include an "Arons-advocated method of science education," are, in effect, concept-building reforms that abandon the standard passive student lecture in favor of a more student-focused approach.

The model used at the University of Minnesota, for example, encourages continuous interaction between the instructor and student—as well as between students, working collaboratively to solve problems.

Gordon Pask, an English psychologist who made significant contributions to instructional psychology and educational technology, developed the *Conversation Theory.* Originally intended to inform instructional design, Pask's theory identifies conditions required for concept sharing and describes a process known as "teachback," in which one person teaches another—a similar method is the think-pair-share process invented by Frank Lyman in 1981 at the University of Maryland.

Role of TAs

A study conducted at Texas A&M by physics department faculty Peter McIntyre, Teruki Kamon, Petra Sauer, Cathleen Loving, and the author comparing the instructional methods of physicists with those of novice physics graduate teaching assistants, found that although the physics professors showed superior content knowledge and problem-solving facility, the students seemed better able to articulate their difficulties to the TAs. These interactions formed the beginnings of a mentoring relationship that served as a vehicle for some graduate assistants to provide support to their students and to build a sense of community.

At the University of Colorado, Valerie Otero, Noah Finkelstein, and some of their colleagues have developed a program that engages both science and education faculty in the training of "Learning Assistants"—undergraduates whose role is similar to the traditional graduate teaching assistant in physics departments. Undergraduate learning assistants are hired to assist science faculty in making their courses student centered, interactive, and collaborative—factors that have been shown to improve student performance.

Toward Systemic Change

The problem of undergraduate physics is legion and multifaceted, and the solutions challenging. A partial adoption of reformed curricular elements won't lead to lasting change. Indeed, reforming the undergraduate course will require a change in paradigm. Only by a concerted and unified effort, bringing together communities who are open to working with each other toward innovative solutions that incorporate insights derived from cognitive and educational research, along with models adapted from other disciplines, will excellent, sustainable introductory physics teaching be assured. Δ

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Toward Physics Reform

What will you do to begin your reform process? How can the results of various reform efforts help to inform your task? Some practical steps:

1. Review your program. Retain what is working well.
2. Create an identity for your program so that it is guided by your department but functions much on its own.
3. Emphasize rigor but be informed by good teaching practice. Invite your local (or favorite) physics education researcher to lunch—and to give a seminar to inform your department.
4. Work collaboratively. Enlist your department of education as a partner. There is much to gain from years of research into effective teaching methods. (Invite them to give a seminar, too.)
5. Create a website and/or a blog to learn from the efforts of others.
6. Find additional sources of funding. Consider a program to train the next generation of physics teachers and join PTEC, a world of reformers and information on all types of physics teaching reform.
7. Develop institutional support and form partnerships—cultivate your colleagues who may have crossed this bridge in engineering, geology, chemistry, or others.
8. Build community: support and mentor your students actively, whether majors or not. Peer support helps, too. Respect students who may choose to teach physics.
9. Develop and model best teaching practices based on research.
10. Be open to change. Approach course reform as you would a physics research problem.

Help Wanted

What physics departments have done, can do, and should do to increase student enrollment and better prepare physics majors for the workforce.

BY KENNETH S. KRANE

The 1960s were in many ways a golden age for undergraduate physics education in the United States. Perhaps in response to the growing interest in space exploration, undergraduate physics enrollment grew so that an average of 5,500 bachelor's degrees were awarded each year during the 1960s, peaking at 6,000 by the end of the decade. This growth in undergraduate enrollment produced a corresponding growth in graduate programs—the number of doctorates awarded each year tripled during the 1960s, totaling 1,500 in 1970. However, in the ensuing decades, the growth rate in physics majors has fallen, despite the explosive growth in technology.

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In fact, undergraduate enrollment fell 25 percent before stabilizing at about 4,500 bachelor's degrees per year through the late 1970s. This decline occurred primarily at institutions that awarded master's or doctorates in physics. Curiously, during this same period there was nearly a 20 percent increase in the total number of STEM (science, technology, engineering, mathematics) bachelor's awarded; though more undergraduates majored in science and engineering, fewer majored in physics.

The '90s proved to be an even more critical period for undergraduate physics enrollment. Bachelor's degree production in physics declined by 25 percent, while STEM-related bachelor's rose by 15 percent. The number of physics bachelor's degrees fell to fewer than 4,000 each year between 1997 and 2000, which had previously occurred only prior to 1958. As a share of total STEM bachelor's degrees, physics fell from 5 percent in the late 1960s to 2 percent by 2000.

In response to what was clearly a crisis for the physics community, the National Task Force on Undergraduate Physics was formed in 1999 to stimulate the revitalization of undergraduate physics education in the United States. Rather than identify the causes for the decline in physics enrollment, the Task Force set out to identify and assess departments where enrollment had thrived despite the national declines.

One of the key elements characterizing thriving programs was the presence of flexible and diverse degree curricula. In the 1960s and 1970s, most physics departments offered only a single bachelor's degree curriculum, whose purpose was primarily to provide the rigorous background necessary for success in graduate school. Today many successful departments offer a range of degree alternatives: applied or engineering physics (including joint 3-2 engineering programs); specialized programs within physics (such as optics or materials science); joint degree programs with other academic disciplines (chemistry, computer science, business); and general programs for pre-service teachers, pre-law, and pre-medical training. These programs encourage students to think of physics more broadly as preparation for the workforce, rather than more narrowly as preparation for graduate school.

Remarkably, the decline in undergraduate physics enrollment abated in 1999, and bachelor's degree production grew to more than 5,100 in 2005, the highest total since the early '70s. Based on the sizes of currently enrolled junior and senior classes, these increases are expected to continue at approximately 5 percent per year for at least the next two years. The revival in physics enrollment was led by Ph.D.-granting institutions, which on average

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This article was adapted from Kenneth Krane's panel presentation at the first Symposium on Physics Education, organized by the American Association of Physics Teachers (Seattle, January 10, 2007).

> **These programs encourage students to think of physics more broadly as preparation for the workforce, rather than more narrowly as preparation for graduate school.**

awarded about half of all the physics bachelor's conferred in the United States in 2005 (see "Endpoint," page 52).

Despite the rosy national picture, not all departments have shared in these increases. Among Ph.D.-granting departments, about one-third award no more than six bachelor's degrees per year; approximately 33 percent of both B.A./B.S.- and M.S.-granting institutions award only two or fewer bachelor's degrees per year.

Many departments have posted increases between 2003 and 2005 that are far above the national average for their category. Table 1 represents "honor roll" institutions with Ph.D.- and M.S.-granting physics departments that significantly exceeded the national average increases (respectively 43 percent and 17 percent) in their categories relative to the 1997 to 1999 base period. Table 2 indicates "honor roll" institutions whose highest physics degree is the B.A./B.S. (for which the national average increase was 19 percent).

This survey was restricted to Ph.D.-granting institutions that awarded a total of 20 or more physics degrees during the 1997 to 1999 base period and to M.S. and B.A./B.S. institutions that awarded a total of 10 or more. As a result, depart-

Highest Degree	Institution	Degrees/y 2003-05	Change from 1997-99
Ph.D.	Michigan State Univ.	19	+164%
Ph.D.	Univ. of California, Santa Barbara	36	+163%
Ph.D.	Univ. of Arkansas at Fayetteville	19	+148%
Ph.D.	Oregon State Univ.	19	+138%
Ph.D.	Univ. of California, Santa Cruz	31	+119%
Ph.D.	Univ. of Maryland, College Park	33	+118%
Ph.D.	Univ. of Massachusetts Amherst	19	+107%
Ph.D.	Univ. of Arizona	35	+100%
Ph.D.	Univ. of Minnesota, Twin Cities	27	+95%
Ph.D.	University of Florida	24	+92%
Ph.D.	Brown University	15	+92%
M.S.	Missouri State Univ.	9	+160%
M.S.	California State Univ., Northridge	11	+154%
M.S.	University of Memphis	8	+150%
M.S.	Cleveland State Univ.	10	+138%
M.S.	Ball State University	8	+130%

Table 1. Ph.D.- and M.S.-granting departments with the largest recent increases in physics degrees conferred.

Institution	Degrees/y 2003-05	Change from 1997-99
Cal Poly, San Luis Obispo	24	+243%
Univ. of Northern Colorado	12	+133%
Benedict College	10	+131%
Gettysburg College	8	+130%
College of New Jersey	12	+125%
University of Wisconsin – La Crosse	19	+124%
Shippensburg University	9	+117%
Whitworth College	9	+117%
North Georgia College & State University	7	+110%
Rowan University	7	+110%
Williams College	18	+104%
Jacksonville University	9	+100%
University of Wisconsin – River Falls	10	+94%
Murray State University	9	+93%
Humboldt State University	7	+91%
Trinity University	7	+91%
Dickinson College	13	+90%
College of Charleston	19	+87%
Lewis and Clark College	9	+86%

Table 2. B.A./B.S. institutions with the largest recent increases in physics degrees conferred.

ments with very small degree totals but very large percent increases have not been included.

It is important to keep in mind that the so-called "honor roll" departments recognized in Tables 1 and 2 were already above the median in their respective categories during the base period, and they built on their prior successes to grow even more successful. Nor is it a given that every successful program will continue to thrive: Of the 21 schools featured as case studies in the report of the National Task Force, one-fourth showed declines in enrollment and one-fourth showed increases below the national average in their respective categories.

Of interest, however, are the key elements that enabled these departments to achieve such stunning successes from 1999 to 2005. Before doing so, it is helpful to review some of the characteristics common to these thriving departments as identified by the National Task Force:

1. Sustained departmental leadership.
2. A clearly articulated mission and the vision to implement it.
3. A substantial majority of the faculty engaged in the undergraduate program.
4. Support from the college or university administration.
5. An active recruitment program.
6. Effective formal and informal advising; other informal faculty-student interactions.
7. Career mentoring.
8. Careful attention to the introductory courses.
9. Flexible degree programs for majors.
10. Undergraduate participation in research.
11. An active physics club and a commons room for undergraduates.

The key element missing from this list is the coherence and coordination that must be brought to these otherwise disparate elements. It is not enough to simply check off these characteristics; instead, it is important to evaluate how these elements work together to create an environment in which undergraduates can achieve success. For example, efforts to improve the introductory course complement recruitment activities, because the introductory course often attracts new majors to physics.

The recipe for contributing to the workforce has three steps:

1. Grow enrollment in the physics major.
2. Create diverse degree programs that prepare students for the workforce.

A SAMPLING OF "THRIVING" PHYSICS DEPARTMENTS

University of Arkansas at Fayetteville (+147%)

The department offers multitrack curricula for the B.A. (targeted at students with interests in medicine, law, business, or journalism) and the B.S. (professional, optics, electronics, computational, and biophysics). A physics education research program has raised faculty awareness of good teaching practices throughout the curriculum. The department builds a sense of community for the students through an active Society of Physics Students chapter, student lounge, research projects, and involvement of students in departmental outreach activities.

University of Wisconsin – River Falls (+94%)

Recruiting efforts at UWRF are enhanced by a close connection with high-school physics teachers from throughout the state due to a summer master's program for teachers. The physics department meets with university recruiters to provide them with good talking points about physics. An undergraduate lounge, an active SPS chapter (one of the 10 largest in the U.S.), and a strong emphasis on undergraduate research help provide a supportive environment for students.

University of Minnesota, Twin Cities (+95%)

Active recruiting among science and engineering majors, who take a common curriculum in the first two years, helps build enrollment. The department offers five tracks through the major: professional physics, engineering, computational, materials, and biomedical, along with numerous double majors (astrophysics, computer science, math). Undergraduate research, an active SPS chapter, and an annual awards program and graduation party make students feel part of the department. Group learning methods are employed in upper-level classes.

University of Northern Colorado (+133%)

Students serve as teaching assistants (lab and discussion section leaders in introductory courses, graders in courses at all levels) and have keys to the physics building for after-hours access. Continuing evaluation and reform of the curriculum, an undergraduate research requirement, and meetings with advisers every semester have contributed to the department's success. Attention to the general education science classes helps attract new physics majors.

Oregon State University (+138%)

A modularized junior-senior curriculum breaks the subjects into manageable pieces and encourages a sense of mastery of the material. The program ramps more slowly into the sophisticated and theoretical subjects of the traditional junior-year curriculum and leaves fewer students frustrated with its difficulty. Group interactions coupled with a multiplicity of approaches to problem solving (analytical, computational, graphical, simulations) prepare students who will eventually attend graduate school and those who will directly enter the workforce.

University of Massachusetts Amherst (+107%)

In 1998 the department established a five-year program to double the number of physics majors. Components of the program include early contact with admitted students (in the spring prior to their first year), enhanced contacts with two-year colleges, and active presence in the university honors program and in an advising program for undeclared majors. There is tight central coordination of advising, with each admitted class keeping the same adviser for four years.

Lewis and Clark College (+86%)

The SPS program is supported with $1000 annually from the department for its activities. Upper-division students serve as teaching assistants in the lower-division labs and thus get to know the newer students. Students in the advanced lab give departmental talks on their projects and then get taken out to dinner like a visiting speaker. An endowed summer research program often leads to presentations at meetings or publications in peer-reviewed journals. Flexible scheduling of advanced courses allows students to participate in semester abroad programs.

University of Florida (+92%)

Student evaluations of teaching and exit interviews with graduating seniors are used to advise the department about future teaching assignments. All admitted students with SAT math scores above 720 receive a letter inviting them to enroll in the introductory course for majors. Other departmental attributes include an active SPS chapter, student lounge, undergraduate research, and an aggressive advising program (which includes a monthly newsletter informing students about classes, jobs, and research opportunities).

3. Incorporate pedagogies that simulate problem-solving methods useful in the workplace.

It is not necessary to reinvent the wheel, nor can anyone argue that “it won’t work here.” The highly successful programs cover a range of institutional sizes and characters. Among these model programs are many examples of how to create a thriving undergraduate program with an increasing number of graduates who are well prepared both for graduate school and for careers in industry, government, military, K-12 schools, and other professions. Δ

Kenneth Krane is emeritus professor of physics at Oregon State University. He was co-director of a comprehensive study of 21 physics departments conducted during the 2001-2002 academic year to understand the characteristics of undergraduate physics programs that thrived during a time of general national decline in the number of physics majors. The study was supported by the ExxonMobil Foundation, AAPT, the American Institute of Physics, and the American Physical Society. It led to the publication of Strategic Programs for Innovations in Undergraduate Physics (SPIN-UP), edited by R. Hilborn, R. Howes and K. Krane; published and distributed by AAPT.

endpoint

Size Does Matter, Sometimes

When it comes to producing undergraduate physics majors, size varies from institution to institution and year to year, but department type is also a factor.

BY PATRICK MULVEY

Collectively, departments for which a bachelor's is the highest physics degree awarded make up more than two-thirds of all physics departments in the United States, but the much smaller number of Ph.D.-granting physics departments currently produce the greater number of physics majors.

During the 2004-05 academic year there were 756 departments in the United States that offered physics bachelor's degrees, with the number of students enrolled varying greatly depending on the type of department (i.e., whether a bachelor's, master's, or doctorate is the highest degree awarded). On the whole, the bachelor's-only departments tend to be small, with 65 percent of them conferring four or fewer bachelor's in the class of 2005. Only 48 percent of the master's departments and 21 percent of the Ph.D.-granting departments are this small.

Research universities generally have large undergraduate physics programs, and eight such departments conferred more than 40 bachelor's in the class of 2005.

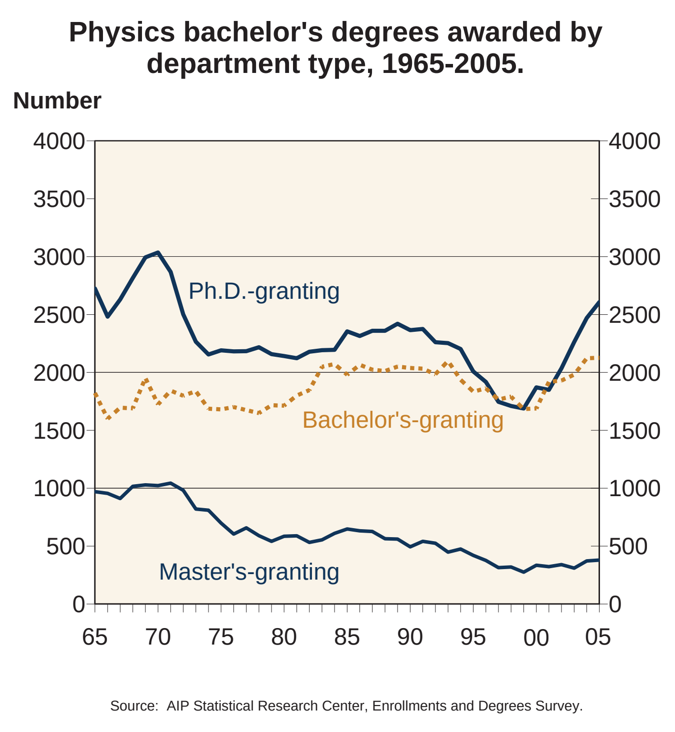
More than 50 percent of Ph.D.-granting departments awarded 10 or more physics bachelor's in 2005, compared with 18 percent of the master's departments and 11 percent of the bachelor's-only departments.

Patrick Mulvey is a lead research associate of the Statistical Research Center at the American Institute of Physics. More information on this topic can be found at www.aip.org/statistics.

Size of Physics Bachelor's Class by Department Type (class of 2005)

		Physics bachelor's degrees per department	
Highest degree awarded	Number of departments	Average	Median
Bachelor's	513	4.1	3
Master's	66	5.7	5
Doctoral	177	14.7	11

Source: AIP Statistical Research Center, Enrollments and Degrees Survey.


Physics bachelor's degrees awarded by department type, 1965-2005.

Source: AIP Statistical Research Center, Enrollments and Degrees Survey.