A WELLSPRING OF SCIENTISTS

When it comes to producing science Ph.D.s, liberal arts colleges are at the head of the class. By CHRISTOPHER CONNELL

PHOTOGRAPH BY TODD BUCHANAN

WHEN IT WAS TIME TO DECIDE ON A COLLEGE, future Nobel laureate David Baltimore turned down Harvard and Cornell and elected to earn his undergraduate degree at Swarthmore College, a small Quaker school in Pennsylvania. ¶ Nobelist Harold E. Varmus graduated from Amherst College in central Massachusetts. ¶ And HHMI President Thomas R. Cech, who won the Nobel Prize in chemistry in 1989, says that "the intellectual cross-training" in the humanities and arts that he received at Iowa's Grinnell College made a profound difference in his life. ¶ Every scientist follows his or her own path, but how likely is it that future Nobelists will track in the footsteps of Cech and company to pursue undergraduate studies at liberal arts colleges? Judging from the trends, very likely. ¶ Liberal arts colleges have a long, prolific history of sending students on to graduate school and careers in science, both as front-line researchers and to serve as the next generation of faculty. They enroll about 1 in 12 undergraduates, but turn out almost 1 in 6 future Ph.D.s in science and engineering. Oberlin, Reed, Swarthmore, Williams, Wellesley, and similar schools that concentrate on undergraduate education and award few if any degrees beyond the bachelor's take pride in their ability to train future scientists—despite, or perhaps because of, their small size. "We have open doors," says A. Malcolm Campbell, a biologist who teaches and conducts genomics research at Davidson College in North Carolina. "The students come in, they ask questions, we get them into our labs. The students are not afraid of their teachers. Teaching is highly valued here,

"Intensity and fervor." *James Gentile (center left), with student scientists at Hope College, says the passion for teaching at liberal arts colleges mirrors enthusiasm for research at large universities.*

as is the mentoring and the hands-on access to research opportunities. It's the right mix."

"The cutting-edge science is done at the R-1 [Research 1, or major research] universities. No one would quibble with that," says James M. Gentile, recently appointed president of the Research Corporation, who has served as dean for the natural sciences at Hope College in Michigan. Regardless, Gentile says, "there are wonderful liberal arts colleges across the country where the intensity and fervor of teaching" is akin to the passion that scientists bring to the lab at research universities.

THE BRIGHT AND THE (NOT SO) BOLD

Skeptics suggest that liberal arts colleges' success in turning out scientists is attributable more to their admissions offices than their science faculty. At Reed College in Oregon, for example, the median SAT score for the class of 2007 was 1,359 (out of 1,600 points). The national average for entering freshman was 1,026. "It's not like we turn coal into diamonds. They come in bright," says Peter J. Russell, a Reed biology professor. "Basically we channel them … [and] stimulate them to perform at their highest level."

Channeling is an important function of the liberal arts colleges. With small student-faculty ratios and courses in which professors know every student by name, these schools are adept at steering students into the sciences and other rigorous majors.

What liberal arts colleges may do best is to open a path for students too diffident to push their way forward. Consider molecular biochemist Manju M. Hingorani, who joined Connecticut's Wesleyan University in 2000. She specializes in DNA replication and repair, publishes regularly, and collaborates with HHMI investigator Michael E. O'Donnell at the Rockefeller University in New York. Hingorani says the attention that faculty lavish on the undergraduates at Wesleyan is unimaginable at a research university. "I'm here all the time. I'm here at 7 in the morning. I'm here at 8 at night. I'm here on weekends. It's not just me, it's most professors," says Hingorani. The undergraduates whom she remembers from her teaching assistant days were "the ones with initiative, willing to knock down the professor's door if that's what it took. At Wesleyan, we have so many students who are a bit more tentative—bright, even brilliant, students who maybe just need to be in a class with only 10 students so that they can speak up and say, 'OK, I have an idea.'

New worlds. *Wellesley chemist Nancy Kolodny found her career path as an undergraduate at the college.*

"The bright and bold," says Hingorani, "they'll do great anywhere. It's the others who are bright but maybe not so bold who benefit the most from places like this."

Small colleges often turn students on to research. "Students here often don't know about research as a career," says Nancy H. Kolodny, a professor of chemistry at Wellesley College in Massachusetts. "It's our responsibility that they find out about it as early as possible." A Wellesley alumna, Kolodny took chemistry to fulfill a distribution requirement, then spent

SMALL COLLEGES MAKE BIG INVESTMENTS

Rather than compete head-on with the major research universities, small colleges cultivate a unique niche.

Liberal arts colleges often spend hundreds of thousands of dollars to set up new science-faculty hires. Manju M. Hingorani, a molecular biochemist at Wesleyan University, says that the college lavished upwards of $300,000 on her equipment and a similar amount on renovating her lab, inherited from a retiring researcher. But Wesleyan's investment quickly paid off when Hingorani won a five-year, $1 million grant from the NIH.

Wellesley College President Diana Chapman Walsh says that steep start-up costs are a fact of life for liberal arts colleges serious about having science faculty combine teaching with research. "We need to help them get started because we know it's harder here" to land large research grants. The Wellesley College Science Center, which underwent a major renovation in 1991, boasts two nuclear magnetic resonance spectrometers, microcalorimeters, two electron microscopes, and a high-powered laser—all kept in steady use by faculty and undergraduates. Walsh says that the success of Wellesley's science faculty in securing research grants "has affected the larger culture of the college. The social scientists have gotten wind of it and now they want to do more hands-on research mentoring of students."

Many small colleges, in much the same spirit, have replaced cramped science buildings that dated from the Sputnik era. Williams College opened a new science center in 2000. Haverford College opened its new Koshland Integrated Natural Sciences Center in 2002. In 2003, Mount Holyoke College completed Kendade Hall, which cleverly links existing lab space and other academic buildings into a unified science center. A similar center at Swarthmore, which opened this past spring, connects the science and math departments. All these centers cost their colleges tens of millions of dollars.

It's a fact of life, however, that research universities are always going to have the advantage of newer, bigger, and better equipment, simply because "research-intensive universities are fundamentally different from small liberal arts colleges in their mission and focus," says Shirley M. Tilghman, president of Princeton University and a former HHMI investigator.

Nevertheless, if they wish to do science well, small colleges "must decide whether they are willing to make the investment in infrastructure to provide the environment for science to prosper," says Tilghman. "If not, they cannot turn around and expect the faculty to be competitive." —CC

JASON GROW

two summers in a lab with other Wellesley students, courtesy of the National Science Foundation. "If I hadn't gone to Wellesley or another small liberal arts college, I never would have gone into research," says Kolodny.

REAL SCIENCE

Access to faculty is easier at small liberal arts campuses than at most R-1 universities, says molecular biologist Shirley M. Tilghman, the president of Princeton University and a former HHMI investigator. "In addition," she says, "students in small liberal arts colleges aren't spending their time with disgruntled eight-year graduate students terrified they won't get their Ph.D.s and five-year postdocs terrified they won't get a job."

When A. Malcolm Campbell was finishing graduate studies at the Johns Hopkins University, a professor bluntly warned him, "Don't go into teaching. You'll go brain dead." Campbell ignored the advice, headed to Macalester College in Minnesota, and later joined the faculty at Davidson College, where he has found a balance between the classroom and the laboratory.

While most newly trained scientists emerging from Ph.D. programs and postdoctoral fellowships at major research campuses elect to stay within that universe, scores make the decision that Campbell made.

> **"Every science course I took at Swarthmore—and there were a lot—had a lab associated with it. That is unheard of."** —Joseph Takahashi

Teaching at top liberal arts colleges allows them to do important research, although at a slower pace than in the hothouse R-1 university world.

Reed College avidly recruits faculty with such interests. With 1,340 students—a quarter of whom major in math, science, or engineering—Reed hires faculty with a research interest as well as a passion for teaching, then provides the infrastructure that allows them to do both, according to biology professor Peter Russell. "We have a fully fledged stockroom and two assistants to prepare our labs," he says. That means Russell, who experiments with budding yeast, can spend time in the lab talking with students about "the serious stuff, not telling them how to pour gels."

At California's Harvey Mudd College, all 700 undergraduates study science or engineering and are eager for collaboration. "I've had students from four departments in my lab—biologists, chemists, physicists, and engineers," says Elizabeth J. Orwin, a professor of engineering and biology. In her research on growing cells that may one day constitute replacement corneas, "I've got students not only working on the tissue, but also trying to get the matrix material. We've got engineers building a bioreactor so we can grow these things with the same physical, mechanical, and chemical stimuli that they have in the eye."

"At a bigger campus, I couldn't take any risks or do anything that would lead to my not publishing," Orwin says. "A place like [this] gives you the opportunity to explore things you might not do at an R-1 university."

One by-product of professor-student collaboration is that faculty scientists often publish papers with undergraduates as coauthors in peer-reviewed journals. Because most liberal arts colleges have few if any graduate students or postdocs, "we have to bring undergraduates into that niche" for laboratory research, says Scott F. Gilbert, a professor of biology at Swarthmore. Admittedly, it's a slower process. "It takes a long time before you get a paper out," says Gilbert.

Thomas Wenzel, a professor of chemistry at Bates College in Maine, says that "the research I am doing at Bates is of similar quality to the work I did during my Ph.D. thesis at the University of Colorado, and the students are not frustrating me. They make my job worthwhile." Wenzel advocates getting undergraduate students involved in research right away. "I do semester-long projects in my first semester general chemistry class right off the bat instead of weekly, boring three-hour experiments. That way, they get really engaged."

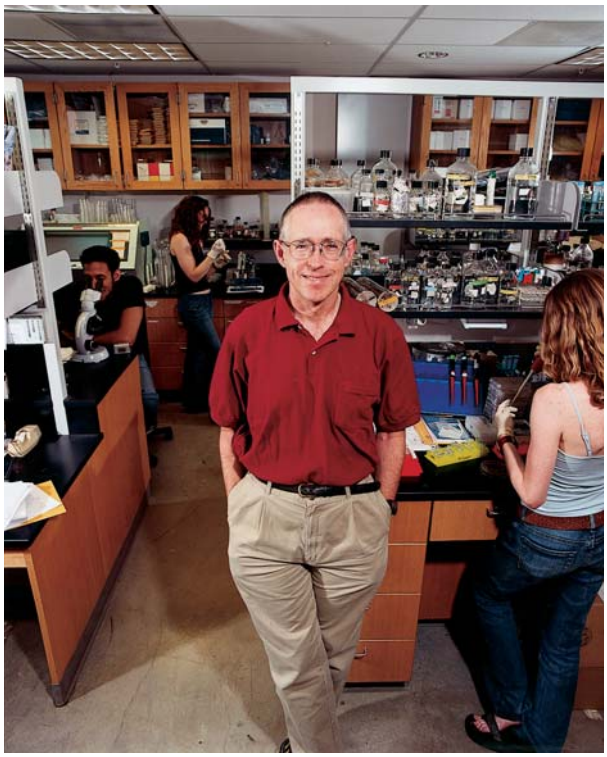
PREPARATION FOR LIFE

For some students, that engagement turns into a lifelong passion. Renowned scientists who are alums of liberal arts colleges often remember their undergraduate days with fondness, and they speak highly of the education that prepared them for life in the laboratory and the public arena. HHMI's Cech attributes part of his scientific success to his study of the humanities and arts at Grinnell. "In addition to whatever exposure one gets to undergraduate research at these places," he says, "maybe it's the liberal arts education as a whole that gives you the broad-based education needed to be an imaginative scientist."

David C. Page, an HHMI investigator at the Whitehead Institute for Biomedical Research, remembers Swarthmore's honors program and seminars as key to his personal and professional growth. "You were given a topic and some suggested readings and expected to show up and discuss the topic intelligently. That meant we needed to be completely comfortable with the library and with critically analyzing and digesting the scientific literature without someone holding your hand. This made me better able to take on new intellectual pursuits with minimal supervision."

Another HHMI investigator, neurobiologist Joseph S. Takahashi at Northwestern University, is still struck by the fact that "every science course I took at Swarthmore—and there were a lot, like 16—had a lab associated with it. That is unheard of." In a course taught by physiologist Kenneth Rawson, Takahashi became fascinated with circadian rhythms, a topic he pursues to this day.

Harold Varmus, president of Memorial Sloan-Kettering Cancer Center, in an article written more than



ROBBIE MACLAREN

Faculty hires. *Biologist Peter Russell says Reed College recruits faculty who want to blend research and teaching.*

a decade ago for an Amherst publication, said that in a small liberal arts college students can learn "the arts of exposition and criticism that scientists often wait too long to learn. Most scientists spend an extraordinary amount of time reading, writing, and speaking, for which imagination, critical analysis, and clarity of expression become more important than any technology."

Varmus, who majored in English at Amherst and also obtained a master's degree in literature at Harvard University before finding his way to medical school, called himself "a confirmed proponent of prolonged adolescence and career indecision."

David Baltimore, now president of the California Institute of Technology, agrees that it's better to devote a good part of one's undergraduate years to unconstrained exploration, which is a bit more likely, even expected, at a small liberal arts school: "This is one time in your life

WHERE DO FUTURE PH.D.s COME FROM?

The National Science Foundation (NSF) keeps track not only of how many doctorates U.S. institutions award each year, but also where the recipients earned their undergraduate degrees. The NSF's latest tally shows that liberal arts colleges continue to excel at this enterprise. Although they enroll approximately 8 percent of four-year college students, from 1996 to 2002 their graduates earned 15.5 percent of the Ph.D.s awarded.

The top 25 research universities, meanwhile, produced five times as many Ph.D.s as the top 25 baccalaureate institutions—but they also enrolled five to ten times as many students.

For example, the University of California, Berkeley, which reserves prime parking spaces on campus for the eight Nobel Prize winners on its faculty, produced 2,234 undergraduates who earned science and engineering Ph.D.s from 1996 to 2002, more than any other institution. Berkeley enrolls almost 24,000 undergraduates. Oberlin College, which led the baccalaureate schools with 417 science and engineering Ph.D.s, enrolls fewer than 2,900.

The NSF data also show that the same highly selective four-year colleges remain at the head of the class in producing science Ph.D.s. Indeed, these schools have become even more productive since the NSF's 1996 report, *Undergraduate Origins of Recent (1991-95) Science and Engineering Doctorate Recipients* (NSF 96-334). From 1991 to 1995, graduates from the top 25 baccalaureate colleges earned 3,686 science and engineering Ph.D.s, for an average of 737 a year, and from 1996 to 2002 graduates from these schools earned 5,648 science and engineering Ph.D.s, or 807 a year. The accompanying charts tell the story in raw numbers.

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Top 25 "research universities" that were baccalaureate origins of 1996–2002 science and engineering (S&E) doctorate recipients, ranked according to total S&E doctorates

Rank	Name	S&E total	Physical sciences
1	University of California, Berkeley	2,234	1,794
2	Cornell University, all campuses	1,730	1,362
3	University of Illinois at Urbana–Champaign	1,488	992
4	University of Michigan at Ann Arbor	1,478	1,143
5	Massachusetts Institute of Technology	1,331	821
6	Pennsylvania State Univ., main campus	1,256	889
7	University of Wisconsin–Madison	1,237	1,030
8	Harvard University	1,213	1,160
9	University of California, Los Angeles	1,139	958
10	University of Texas at Austin	1,134	893
11	University of California, Davis	1,031	876
12	Texas A&M University, main campus	961	725
13	Stanford University	939	786
14	University of Minnesota–Twin Cities	903	669
15	Purdue University, main campus	901	557
16	University of California, San Diego	860	737
17	Michigan State University	831	687
18	University of Florida	818	610
19	Virginia Polytechnic Institute and State Univ.	805	521
20	University of Pennsylvania	783	639
21	Yale University	781	731
22	Princeton University	780	631
23	University of Washington–Seattle	768	613
24	Rutgers the State Univ. of NJ New Brunswick	765	610
25	University of Virginia, main campus	763	603
Total, top 25		26,929	21,037
Total, all "research universities"		50,631	40,244
Top 25 as a percent of all "research universities"		53.2	52.3

Top 25 "baccalaureate colleges" that were baccalaureate origins of 1996–2002 science and engineering (S&E) doctorate recipients

Rank	Name	S&E total	Physical sciences
1	Oberlin College	417	417
2	Swarthmore College	368	368
3	Carleton College	357	357
4	Wesleyan University	319	319
5	Williams College	292	292
6	Wellesley College	257	257
7	Reed College	251	251
8	Smith College	235	235
9	St. Olaf College	228	228
10	Grinnell College	227	227
11	Pomona College	216	214
12	Bucknell University	213	213
13	Bryn Mawr College	196	196
14	Vassar College	196	190
15	Colgate University	189	187
16	Amherst College	187	187
17	Haverford College	185	185
18	Mount Holyoke College	179	178
19	Franklin & Marshall College	175	175
20	Barnard College	174	174
21	Macalester College	171	170
22	Bowdoin College	166	166
23	Bates College	154	154
24	Allegheny College	150	149
25	Furman University	146	144
Total, top 25		5,648	5,633
Total, all "baccalaureate colleges"		17,097	16,313
Top 25 as a percent of all "baccalaureate colleges"		33.0	34.5

Source for tables: National Science Foundation, Division of Science Resources Statistics

when you can get broad experience and develop those things that are not standard scientific capabilities."

NIFTY FIFTY

Intellectual hothouses such as Swarthmore, Reed, and Oberlin have produced science Ph.D.s in significant numbers for decades, and more recently other liberal arts colleges have been doing so as well. Some benefited from a buyer's market for new science Ph.D.s in the 1970s and 1980s, when limited opportunities at the major research universities led more young academics to consider careers at smaller colleges, where they could combine teaching with research.

When Oberlin College organized a group of liberal arts colleges in 1985 to seek more government and foundation support for their science programs, they were dubbed the "Nifty Fifty." That number has since grown. When the Research Corporation released its 2001 *Academic Excellence* study of undergraduate science research, it counted 136 public and private colleges that were endeavoring to combine serious research with committed teaching.

The approach of getting undergraduates into labs with faculty, not only as mentors but also as research partners, no longer is exclusively the province of highly selective, private liberal arts colleges. It has now caught on with a growing number of other private and public colleges as well.

Mark Jacobs, long a star on the biology faculty at Swarthmore College, was wooed by Arizona State University (ASU) in 2003 to become dean of its Barrett Honors College. ASU's honors students "are just as smart as the Swarthmore kids," says Jacobs. "You've got to invent a way to get the kids into labs, and that's what we're trying to do." Few universities offer labs with every science course the way Swarthmore does, and fewer still have full professors teaching those labs, he notes. "Undergrads are a lot more ready and willing to embrace real research than lots of older-style professors would ever believe. The old conception that students are bothersome fleas that have to be flicked off the professor's hide is breaking down," says Jacobs.

California State University at Fullerton and Western Washington University also exemplify public colleges that engage their undergraduates in research. After three decades at the University of Colorado at Boulder, Arlan Norman became dean of the College of Sciences and Technology at Western Washington University, which has 12,000 undergraduates. Norman says Western Washington endeavors to get science majors "working side by side with faculty who are experienced teachers and researchers. There is not the hierarchy of mentorship that often exists in primarily research institutions, where the undergrad works with a grad student, much of the grad student's work is supervised by a postdoc, and the postdoc reports to the faculty lab director."

So the liberal arts college model of science education and research is spreading. At Wesleyan, Manju Hingorani says of her 14-hour days in class, office, and lab: "I am very tired, but I am so happy. I see the faculty and students committed to science and more research money around me, and at many other institutions as well. It is a very exciting time."

Cancer researcher Thomas R. Tritton, president of Haverford College, once suggested that an inexpensive way to gauge the vitality of scientific research on a campus was to walk by the labs at 11:30 p.m. and see how many lights were on. For now, liberal arts colleges are keeping their laboratories' lights burning. H

JASON GROW

FACULTY ROLE-MODEL

A Mentor and Four Students

There is no "middleman" in the science labs at Wellesley.

Is this heaven? *When Mary Allen joined the Wellesley faculty, she marveled at how much time colleagues spent with undergraduates.*

Microbiologist Mary M. Allen works with Wellesley College undergraduates unraveling the mysteries of cyanobacteria, perhaps the oldest oxygen-producing organisms on earth. "There's no middleman in our laboratories—no postdocs or graduate students between me and my students," says Allen. For decades, Wellesley has produced more scientists than all but a handful of other liberal arts colleges.

When Allen joined the Wellesley faculty in 1968, she marveled at how much time colleagues spent with undergraduates. "I thought I had died and gone to heaven. It was just fantastic," she recalls.

The faculty-student collaboration process at Wellesley requires patience. "The undergraduates take three years to do what a postdoc probably could do in a year, but the quality is the same," says Allen, a past president of the Council on Undergraduate Research. Three of her students became Beckman Scholars—recipients of $17,600 scholarships from the Arnold and Mabel Beckman Foundation for research over two summers and the senior year. In interviews, three Wellesley graduates and a senior spoke about their mentor.

Keren Lisa Witkin '98 graduated this spring from UC Berkeley with a Ph.D. in molecular and cell biology. She didn't envision a career in science when she entered Wellesley, "but in my first year I took 'Intro to Cell Biology' and loved it." The summers in Allen's lab were "a lot of fun," Witkin recalls. "We were a tight group. Mary was always encouraging." She calls Allen "a phenomenal mentor."

Witkin wrote her undergraduate thesis on heat-shock response in cyanobacteria, and she and Allen presented a poster on that work at the VI Cyanobacterial Workshop in Pacific Grove, California, in July 1998.

"That was one of the best parts about doing research as an undergraduate," Witkin says. "It was very unusual to go to meetings with undergraduates. Mary took two of us. We got to present our research in front of all these real scientists. The experience was amazing."

Jean Jing Huang '01 arrived at Wellesley knowing she wanted to study biology. "I had great mentors in a public elementary school in Brookline, Massachusetts. A friend and I won the science fair in sixth grade," she says. "We developed a test for lead in paint, and we went around town testing the paint in the library and other places."

Huang worked in Allen's lab during the summer after freshman year, looking at acid shock. Allen "was there when I needed help, but she wasn't telling me what to do. That was the best part, because I developed confidence," says Huang. The students even had keys to the lab, allowing them to work with a buddy late at night and on weekends.

"This project was very forgiving," she says. "I tried a lot of experiments. I'd take a course and learn about some technique, then try it with the cyanobacteria. Since we weren't looking for any one result, it could develop in all these different, interesting ways. We used NMR [nuclear magnetic resonance] spectrometers and all sorts of instruments, and we collaborated with other labs on campus." Huang, who became Allen's first Beckman Scholar, wound up presenting a paper at a microbiology conference in Barcelona and was the lead author of a paper published in the *Archives of Microbiology*.

"I really saw the best of what science was all about at Wellesley," says Huang, a third-year graduate student in biology at the California Institute of Technology. "The only model I saw was a successful professor." [HHMI, recognizing that graduate students and postdoctoral fellows may also serve as mentors, supports programs that train them in teaching as well as research at both colleges and universities.]

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>
> **—Jean Jing Huang**

Katie Shea '03 was bursting to do science, thanks in part to mentoring from her high school biology teacher, when she arrived at Wellesley from rural New Hampshire. She became Allen's second Beckman Scholar. (The third, Sogole Moin, class of 2005, received the honor just this spring.)

Allen "had an open-door policy. If things weren't going right, you'd ask her questions. She was floating in and out of the lab all the time," says Shea. Allen and other professors also met jointly each week with the students working in their labs, sharing progress reports and offering suggestions on how to deal with bottlenecks.

Shea took up the acid-stress work in her junior year, presented posters at American Society of Microbiology meetings in Salt Lake City and Washington, D.C., and graduated *summa cum laude*. She is now at Dartmouth Medical School, with her cap set toward pediatric oncology.

"I definitely want research to be part of my career," says Shea. "That's one aspect of oncology—your research can coordinate well with your clinical skills."

Tam-Linh N. Nguyen '04 came to Wellesley from Pennsylvania as a premed major, but soon switched to biology. When the opportunity came to work in Mary Allen's lab, Nguyen embraced it. "I found that I really, really liked being in the lab, I liked working with instruments, I liked doing science," she says.

Nguyen picked up the acid-stress work where Katie Shea left off. "They've already done so much work on this, I am a successor," she says. "But I feel like I'm contributing something to their project." If things fall into place, eventually a paper will be published with all the participants' names on it.

The young researcher says "Professor Allen is so approachable and so down-to-earth, she doesn't intimidate any of the students. I can talk with her about my problems. I talk to her about all sorts of things." They even discuss the progress of her sister Michelle, who just finished her freshman year at Wellesley.

Perhaps Allen has an eye on Michelle for the lab, too? "Possibly—or my sister has an eye on her," Nguyen replies. "If you want a mentoring relationship like that, you can't just sit around waiting for it to come to you. You have to go out and find it." —CC

CAMPUS CULTURE

The Faculty's Greatest Passion

At Swarthmore, the road to a Ph.D. starts in Bio 1 and 2.

SWARTHMORE COLLEGE, FOUNDED during the Civil War by Quakers who wanted a coeducational alternative to Haverford College, has always been fertile ground for training scientists. Among liberal arts schools, it was second only to Oberlin College in the number of science Ph.D.s produced between 1920 and 1976. The latest statistics from the National Science Foundation (NSF), for 1996–2002, show that Oberlin and Swarthmore are still first and second.

Some science Ph.D.s, no doubt, are born. But others are made, and a visitor to this campus can practically watch them being hatched in Bio 2—or, more formally, "Biology 002: Introduction to Organismal and Population Biology"—as Julie Hagelin, an expert on how birds use plumage ornamentation to attract mates, lectures on natural selection and how insects decide their optimal group and territory size. Between slides, she peppers the audience with questions. At the lecture's start, Hagelin tosses cotton into an aquarium containing a colleague's Siberian hamsters. At the end of class, she flips a switch so that an overhead camera projects the result of the animals' industry: a cozy nest built of fluffy cotton and pine shavings. While some students slam notebooks and bolt for the exits, others in this class of 100—gargantuan by Swarthmore standards—stream up the aisles for a closer look or to pose additional questions.

Hagelin team-teaches Bio 2 with three other biology professors; each also spends one afternoon a week in the lab with the students. In much the same manner, four other biologists team-teach "Biology 001: Cellular and Molecular Biology" in the fall. Students emerge from this pair of courses not only familiar with biological concepts from genetics to microbiology to ecology to behavior, but also on a first-name basis with most of the biology faculty.

Some students enter Swarthmore with physics or philosophy or political science in mind until Bio 1 or 2 essentially realigns their brain cells. And this is clearly a long-lasting realignment, as almost half of the college's biology majors go on to obtain doctorates in science.

For example, Aaron Strong, now a junior, arrived from Maine thinking about astrophysics, "but that changed the first week I was here." When Hagelin mentioned last year she was looking for students to do summer fieldwork studying crested auklets on an island in the Bering Sea off Alaska, Strong needed no second invitation. "He sent me an e-mail saying, 'I've wanted to go to the Arctic since I was five years old,'" recalls Hagelin. "I could see right away he was passionate about what he does. That's just the kind of student you want at a field site, where things don't always go the right way."

Strong spent winter break at Auburn University in Alabama, learning how to isolate bacterial DNA from bird feathers, and is one of three students working alongside Hagelin this summer on St. Lawrence Island, inhabited by a few hundred Siberian Yup'ik Eskimos and hundreds of thousands of birds, including the crested auklet, a monogamous seabird that produces a tangerine scent during courtship.

The Bio 1 and 2 experience tends to realign faculty brain cells as well, with similarly positive results. These classes are a far cry, says Hagelin, from "the cattle-call courses" at a large state university where she taught as a postdoctoral fellow, "with the cell phones going off and people reading newspapers during class. Here it's almost like they are little goldfish nibbling at my feet, wanting more and more and more."

DAVID GRAHAM

Teamwork. *Swarthmore students do lab work in groups, says Amy Cheng Vollmer, "because complex problems are solved by teams."*

PARKING EGOS AT THE DOOR

Swarthmore President Alfred H. Bloom says that the college hires faculty with a passion for combining teaching and research, and helps them stay current by granting paid sabbaticals every seventh semester.

> **"We've developed a culture of making sure our students have research experiences."**
>
> **—Carl Grossman, Swarthmore College**

Professors must tailor their research, however, to fit the fabric of a liberal arts college. "You can't do certain types of projects that require a full graduate team," notes Bloom, "and you can't do projects that require unbelievably costly equipment. But you can do a lot of exciting, important, and innovative interdisciplinary research." Toward that end, the school opened a new $77 million science center this spring.

Biology chair Amy Cheng Vollmer says that Swarthmore faculty are "willing to park their egos at the door" and see their success in their students' triumphs. Physics professor Carl Grossman agrees. "We've developed a culture of making sure our students have research experiences," says Grossman. He chooses experiments for his nonlinear-optics research lab "that combine entry-level work and get students thinking about what they can do in graduate school."

Two recent physics majors were able to extend that thinking on Rhodes scholarships. Matthew Landreman '03 spent two college summers in labs at the University of Minnesota and the Santa Fe Institute, courtesy of the NSF's Research Experience for Undergraduates program; his next two summers were spent in the spheromak (plasma ring) lab of Swarthmore plasma-physics professor Michael R. Brown. Now at Oxford, Landreman remembers not only exciting experiments in the lab, but also "a great number of excellent barbeques" at Brown's home. "I got to know other faculty well, even those with whom I never had a class," he says.

Jacob J. Krich '00 is pursing a Ph.D. in physics at Harvard, after three years studying mathematics during his Oxford sojourn. Krich's mentor was physics professor Peter Collings, who has done pioneering work in liquid crystals. "He explained advanced concepts of physics to me in a wonderful, patient manner," Krich recalls. "He was always a bright spot in the lab. Peter helped me through the hard parts and got me farther than either of us expected." Krich won an Apker Award from the American Physical Society for physics undergraduate research.

Even students who ace advanced placement science are encouraged to take one of the introductory biology courses, if only to hone an ability to write lab reports as though they were being submitted to the journals *Cell* or *Nature*. They also do this lab work in groups, says Vollmer, "because complex science problems are solved by teams rather than by single people."

The cutthroat competition often found on college campuses, especially in courses frequented by premeds, is less evident at Swarthmore, says cell biologist Elizabeth A. Vallen: "The kids here are driven internally, but they are amazingly kind and helpful to each other." Not once has a student asked Vallen if a topic covered in class would be on an exam.

"Students get excited any time I talk about what the end of knowledge is," says neurobiologist Kathleen Siwicki. "Our students sense that there's plenty of interesting science to be done"—in her own lab, for example, where she works with *Drosophila melanogaster*, or fruit flies. "We study learning and memory, and changes in the brain that are responsible for changes in behavior. We're working at a slower pace, naturally, because the students have lots of other commitments and don't work full-time in the lab," says Siwicki. "The most exciting part of the teaching experience here are those afternoons in seminar. The students select the papers and literature they want to read. Something goes on in those seminars that empowers them to think of themselves as scientists."

Several of Siwicki's students paid tribute to their mentor at the most recent Darwin's birthday party, an annual biology department event, by decorating cupcakes with icing that depicted two *Drosophila* a-courting.

FRUITS OF RESEARCH

To other institutions wishing to emulate Swarthmore's success at grooming scientists, President Bloom urges them to hire faculty "who treasure the work with undergraduates, and to change the criteria for promotion and tenure so that inspired teaching is rewarded."

Too often, the value of such teaching "is discounted as contrary to the seriousness of a research institution," says Bloom.

Five honors seniors bring their slides one morning to summarize their projects for a visitor. Seeta Sistla plans to pursue a Ph.D., while Stephanie Cross, Emily Ford, Matthew Goldstein, and Renuka Nayak aim to acquire joint M.D.-Ph.D. degrees.

"I'll be over 35 before my first job," says Cross, one of the cupcake decorators. "I knew from the start that I wanted to do biology. But there's a passion here at Swarthmore. It's in the professors and students."

Ford worked with biology professor Colin Purrington on a study of the evolutionary bias of handedness in twining vines; 90 percent of vines advance in a counter-clockwise manner.

In a Stanford lab last summer, Goldstein studied the potential of statins (cholesterol-lowering drugs) to suppress proliferation of T cell lymphoma. He is also a left-handed pitcher with a close-to-90-miles-per-hour fastball who cocaptained the Swarthmore baseball squad.

Nayak said studying *Drosophila* (fruit flies) "helped me see how research is done. It's all about asking questions. I came in really shy. Research has given me more confidence."

Seeta Sistla, of Albany, New York, arrived intending to major in philosophy but was converted by Bio 1 and 2. She hopes to publish with Purrington and plant physiologist Mark Jacobs (now dean of Barrett Honors College at Arizona State University) results of her research on plant vascular regeneration.

—CHRISTOPHER CONNELL

THE STUDENT EXPERIENCE

Striving to Succeed

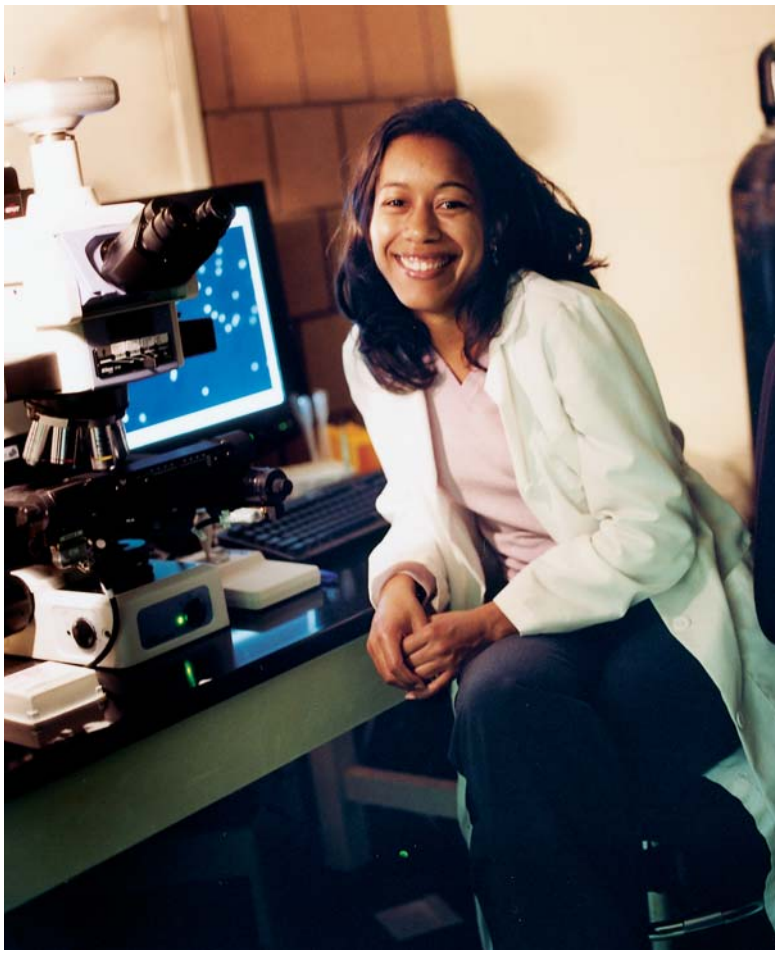
Traditionally minority and majority colleges alike offer benefits to students, and faculty, of color.

Erica Martin earned her undergraduate biology degree at Spelman College, a small, historically African American college for women in Atlanta. The 32-acre campus wasn't crawling with famous research scientists, and some specialized courses the M.D.-Ph.D. student wishes she could have taken—anatomy, for example—weren't offered. But Martin wouldn't trade her undergraduate years at Spelman for anything.

"We were nurtured and challenged there," she says. "We learned hands-on, with constant feedback. They taught us to pay attention to details and to think outside the box. Academically, it was as rigorous as any research university. It was also like a family. Everybody knew my name."

After Spelman, Martin finished two years of medical school at the University of Maryland, Baltimore (UMB), when she switched to a neuroscience graduate program there, and is now in her third year of that program. After she earns her Ph.D., Martin will return to the university's medical school to complete her M.D. She wants to do clinically oriented research on the effects of ischemia, or reduced blood flow to the brain, which often occurs during cardiac arrest and stroke.

Medical school was quite an adjustment for Martin after four years at Spelman, where her largest class had 40 students. At UMB, she found herself in classes of 150. Some of her classmates from research universities had already taken



CHRIS HARTLOVE

Fast track. *On course to earn her Ph.D. and M.D., Erica Martin says she got a strong start in science as an undergraduate at Spelman College.*

courses in anatomy, histology, and electrophysiology.

But Martin took it all in stride. "Spelman prepared me mentally to do the work," she explains. "I understand how to use resources to find things out—how to learn. And maybe most important, it gave me self-confidence. So if a professor here doesn't know my name, I'll walk right up and introduce myself and ask a question."

Martin participated in a math and science magnet program at Montgomery Blair High School in Silver Spring, Maryland. For college, she considered two branches of the University of Maryland system, including the flagship at College Park, before settling on Spelman. "At historically minority colleges and universities, you are among other minorities who are striving to succeed," says Martin, adding that Spelman is known for its dedication to helping minority females succeed.

> **"Academically, [Spelman] was as rigorous as any research university. It was also like a family. Everybody knew my name."—Erica Martin**

Martin almost went to College Park because she loved to play soccer and they had a good women's team, while at Spelman there was none. Instead, she chose Spelman and spearheaded a women's soccer program there. "So I got the best of both," she says with a grin.

A friend's younger sister now is facing the choice Martin made nine years ago. "She's considering Spelman or New York University, and I'm offering my advice, whether she wants it or not. I've told her she should go to Spelman."

TOUGH CHOICE

With two undergraduate degrees from two very different kinds of schools—Morehouse College and the Georgia Institute of Technology—Keith Howard knew he wanted to teach at a small liberal arts college. "The mentorship I received and my interactions with professors were much more meaningful at Morehouse than at Georgia Tech," he recalls.

For Howard, the tough choice after graduate school (at Vanderbilt University in Nashville, Tennessee) was whether to teach at a historically minority institution like Morehouse or one where his African American face tended to stand out.

"I had offers from both predominantly white and predominantly black institutions," the mathematician recalls. "My final decision was based on where the resources were available that would enable me to further my research interest in mathematical modeling."

He chose Kenyon College in Gambier, Ohio, a school where only 12 percent of the 1,550 students are minorities. Not only did Howard receive the necessary resources from Kenyon, but he also knew the territory. Having worked there for a year as a dissertation fellow, he says, "I had already integrated myself into the department and the institution."

Howard has found that being one of only a few minority faculty members has nurtured collegiality with other colleagues of color. And, both a plus and a minus, he is asked to serve on numerous committees dealing with diversity issues. "These are labors of love, but they are also very time-consuming," he observes.

At a historically minority college such as Morehouse, undergraduates find themselves in a familiar community, and the faculty serve as role models. Colleges such as Kenyon lack the numbers of black students necessary for a sizeable subculture to emerge, creating an environment that can be intimidating to the few black students there, Howard says.

Yet, in a way, that makes his role even more significant. "At a school like Kenyon, every faculty member of color has a huge impact on students," the assistant professor of mathematics points out.

—JENNIFER BOETH DONOVAN

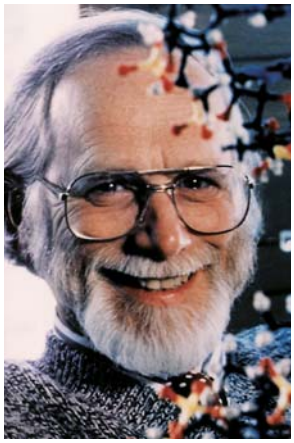
UNIVERSITY OF CALIFORNIA, SAN FRANCISCO

THE NOBELIST

Expect the Unexpected

An eminent investigator's perspectives on the best preparation for a life in science.

J. Michael Bishop, chancellor of the University of California, San Francisco (UCSF), gave his 2003 autobiography the wry title *How to Win the Nobel Prize: An Unexpected Life in Science*. Bishop, who shared the 1989 Nobel Prize in physiology or medicine with Harold Varmus, grew up in rural Pennsylvania, a minister's son, and went to Gettysburg College. "Every new subject that I encountered in college proved a siren song. I imagined myself a historian, a philosopher, a novelist, occasionally a physician, but never a scientist (in part because I then had no idea of what a scientist might do)," he wrote. He saw "nothing of research. Gettysburg was a small liberal arts college that valued creativity, but in those days provided no opportunities for laboratory research, nor did it occur to me at the time that it should."



Value added. *J. Michael Bishop says that liberal arts colleges "know how to prepare science students for graduate school."*

Nevertheless, "it was adequate preparation, a suitable stepping stone to the next level of sophistication that I encountered at Harvard Medical School," he says in an interview. "But recall that I was starting from a primitive base. That was a long time ago. It appears to me that the contemporary liberal arts colleges of first rank know how to prepare science students for graduate school, and offer much more to boot."

> **A liberal arts education is "a wise course of action, both as a credentialing device and a test of motivation."—J. Michael Bishop**

But are graduate students from the liberal arts colleges as well prepared as those who studied, say, across the bay at UC Berkeley, when they come to UCSF, an institution that ranks among the country's leaders in biomedical research?

"By and large, yes," replies Bishop, "especially if they have worked in a competent research lab during summers. Some colleges have alliances with research-intensive universities to facilitate this. And some students take a year or two after college to obtain extensive experience in a research lab before applying to graduate school."

The chancellor says that he remains "a great fan of liberal arts education. By all indications, this is a wise course of action, both as a credentialing device and as a test of motivation. Such students seem always to do well in our programs at UCSF. I recommend it."

—CHRISTOPHER CONNELL

THE PROFESSOR/RESEARCHER

Right Where They Belong

Combining the pleasures of teaching and research at small liberal arts colleges.

Roberta R. Pollock is a product of research universities. As an undergraduate, she studied biology at Emory University in Atlanta, graduating *summa cum laude*. She went on to earn a Ph.D. in immunology at Harvard University and did postdoctoral fellowships at Albert Einstein College of Medicine and Columbia University's College of Physicians and Surgeons. But since 1989, Pollock has been teaching biology at Occidental College, a liberal arts campus in Los Angeles with about 1,900 students and 135 faculty.

Nurturing. *Roberta Pollock says "I love teaching undergraduates in small classes, and playing a role in their intellectual growth."*

The author of some three dozen papers, Pollock has continued her research in immunology and at last count had authored seven papers since joining Occidental, three of them with undergraduate coauthors. An HHMI grant to Occidental helped the college equip her lab. "My research has progressed much more slowly than it would at a research university," she admits, "but I love teaching undergraduates in small classes, getting to know them, and playing a role in their personal and intellectual growth."

Pollock also likes the accessibility of colleagues from other scientific disciplines, as well as those in the humanities and social sciences. She values the college's willingness to let her work half-time when her children were very young, and its support for innovative ideas. With help from Occidental's HHMI grant, Pollock developed a course on gender and science in which she explores the historical role of women as scientists, the status of women in science today, and whether women and men conduct science differently.

After 15 years, Pollock is sure that she's right where she belongs. "I wanted to combine teaching and research and have them both count toward tenure," she explains. "Occasionally, when I go to a professional meeting, I regret that I am not accomplishing as much in research as I would if I had chosen to be at a research university. But I am helping students decide what they want to do with their lives, and that is so satisfying."

At Occidental, Roberta Pollock likes the accessibility of colleagues from other disciplines, in the sciences and beyond.

THE BEST JOB EVER

Barely more than half Pollock's age and just finishing his first year on the biology faculty at Austin College in Sherman, Texas, Lance Barton couldn't stay out of the classroom even during his graduate school days at the University of Cincinnati College of Medicine, where the focus was firmly on research.

Barton found time to teach undergraduate biology at Cincinnati's College of Mount St. Joseph and to instruct middle school students in the Saturday Science Academy, an HHMI-supported outreach program at the University of Cincinnati.

As long as he stayed productive in the lab, Barton's mentor, HHMI alumni investigator John J. Monaco, Jr., didn't object to the graduate student's teaching activities, but others in his department "didn't think you could do both," Barton recalls. When he won the department's scientific award and an academic achievement award, "I think I changed a lot of attitudes," he says with a smile.

When Barton began looking for a faculty position, the largest school to which he applied had an enrollment of 2,200. He accepted an offer from Austin College, home to 1,300 undergraduates, because he liked the interdisciplinary nature of the faculty and their devotion to their students.

Barton is taken with a required course called "Integrated Science," cotaught by scientists and faculty from other disciplines, and with Austin College's January Term, three weeks between the fall and spring semesters when faculty and students can let their academic imaginations run wild.

He is also continuing his research on T cell immune response to viruses by collaborating with colleagues from the University of Cincinnati, and his students have opportunities to do research as well. He says that the faculty at the University of Texas Southwestern Medical Center at Dallas, home to four active Nobel laureates and only 70 miles away, "love Austin College students because they can think and have good lab skills."

If Barton had any doubts about his career choice, they vanished when he visited his undergraduate alma mater, Dickinson College in Carlisle, Pennsylvania, last year, and told biology chair John H. Henson that he too had decided to teach at a liberal arts college. "I told you when you were here that this is the best job ever," Henson replied.

"I only took three classes from Dr. Henson. He wasn't even my adviser, and I graduated five years ago," says Barton. "But he remembered me and my name."

—JENNIFER BOETH DONOVAN

DANNY TURNER

DAVID MCLAIN/AURORA

Alliances. *To extend her research, Hadley Horch (above) crafts strategic collaborations.*

THE PARTNERSHIP

Collaboration in the Name of Science

A college-university alliance proves to be win-win-win.

A product of Swarthmore College, Hadley Wilson Horch always wanted to teach at a liberal arts college. But as an assistant professor of biology and neuroscience at Bowdoin College, she found she missed the interaction with colleagues and the fast pace of discovery that characterized her graduate and postdoctoral days. She felt she needed to reconnect to the larger research community while carving out a productive niche for her own research.

She's solving these problems by linking up with Cornell University neuroscientist Ronald R. Hoy, an HHMI professor and Horch's postdoctoral adviser. Now Hoy and his former postdoc are collaborating to bring the tools of modern cellular and molecular biology to one of Hoy's pet projects, the regeneration of auditory neurons in crickets. Together they—and their undergraduate students—are revisiting questions that Hoy's research raised nearly 20 years ago, when the tools were not yet available to answer them.

It's a win-win-win situation. Horch gets to continue the research she began as a postdoc. In fact, she just won a $150,000 grant from the National Institutes of Health to pursue the regeneration work. Her students get to meet regularly with Hoy and the students in his lab, to do real science, and to see themselves as intellectual partners in a larger research project. And Hoy gets help with the molecular aspects of his research, freeing him to use the sophisticated equipment at Cornell to focus on the physiology of cricket neuronal regeneration. He also gets the stimulation of a dynamic dialogue with Horch about teaching undergraduates.

"I'm hoping to link up with several more faculty like Hadley to form alliances to build challenging research practices into undergraduate pedagogy," says Hoy. In 2002, he was named as one of 20 HHMI professors nationwide. Each HHMI professor receives $1 million over four years to develop innovative approaches to teaching undergraduate science.

Horch sounds a note of caution, though. "I think this collaboration works wonderfully with someone like Ron, who is truly interested in teaching and working with undergraduates. It might work less well collaborating with someone who rarely interacts with undergraduates." **— JENNIFER BOETH DONOVAN**

PRIVATE FINANCIAL SUPPORT

HHMI and Liberal Arts Science

$600 million in support of undergraduate science education.

HHMI supports undergraduate science education at major research universities and liberal arts colleges through separate invitation-only competitions. These competitions award four-year grants of up to $2.2 million to launch or sustain efforts to lure more students, especially minorities, into biology and other sciences; to get more undergraduates into laboratories; and to convince top scientists to bring to teaching the same passion and creativity they apply to their research.

In May, HHMI awarded almost $50 million to 42 baccalaureate and master's degree institutions—including many that are top producers of future science Ph.D.s. Two summers ago, it divided $80 million among 44 research universities for efforts to bridge the gulf between the lab and the classroom. The Institute also provides extensive support for K–12 science education, and two years ago it named 20 Hughes professors—prominent researchers who are each receiving $1 million over four years to practice and encourage great teaching.

HHMI has invested more than $600 million in undergraduate science education since 1988, making it the country's largest private source of such support. Why has the Institute—best known for the nearly $500 million in biomedical research it spends each year—made education such a priority as well?

"We saw a real need to connect science and the scientific community—hence research—more carefully with teaching," says Peter J. Bruns, vice president for grants and special programs. "With Hughes' name on it, this program challenges the community to think about education in the way that we think about science."

Bruns himself became a believer in 1989, when as a professor of molecular biology and genetics and director of the division of biological sciences at Cornell University, he was asked to lead the school's first Hughes undergraduate education grant. "Until that time I was pretty much the usual faculty member," Bruns recalls. "I did my teaching and enjoyed it, though it was not a major focus; I didn't develop programs or plans beyond my own course. But putting together the Hughes education proposal got my attention." Bruns and colleagues created the Cornell Institute for Biology Teachers, which enables faculty to work with high school instructors across New York State. That institute, with steady support from Hughes, is still flourishing and now also works with elementary teachers. Bruns left Ithaca in 2000 to lead HHMI's grants programs.

The liberal arts colleges that receive funding from HHMI tend to be repeat customers too. Most of the 42 liberal arts colleges that shared this year's nearly $50 million in awards were also selected in the 2000 round, and 10—Bates, Carleton, Haverford, St. Olaf, Smith, Swarthmore, Wellesley, Wesleyan, Williams, and Xavier of Louisiana—are five-time grant recipients. But 12 percent were chosen for the first time, and 29 percent were funded previously but not in 2000. The mix, Bruns says, "reflects the wisdom of an external, peer-review panel: We don't throw away the current people the next time we do something, and we're also not a closed shop." He added, "We recognize there are some things, like strong outreach to teachers, where it's important just to keep the wheels turning." **—CHRISTOPHER CONNELL**