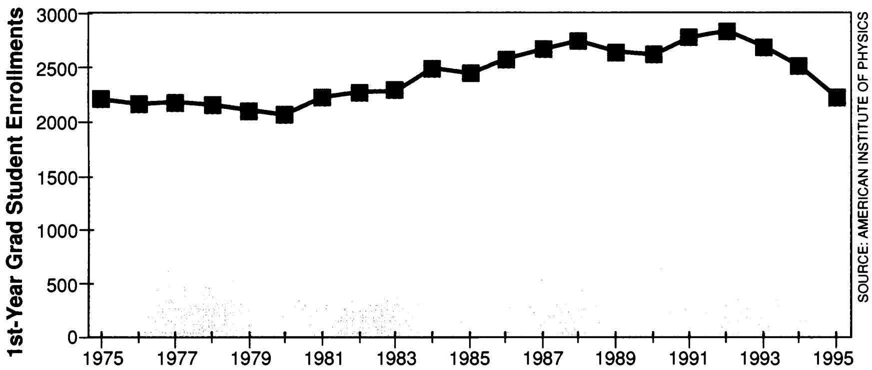
to less-than-stellar applicants. And at the University of Michigan, B. A. Taylor, chair of the mathematics department, says, "I think we're using 'birth control' ourselves by being more selective."

One place where the bullet seems clamped firmly between the teeth is the Board of Regents of the state of Ohio. Several years ago the board decided that the costs of graduate training were getting too high. "We've been very concerned that over the last 5 years the state subsidy for Ph.D. education has gone from 8% to 11% of the total subsidy for all higher education," says Garrison Walters of the Board of Regents. The board has therefore ordered reviews of all state-supported Ph.D. programs over the next couple of years. Ultimately, there will be caps on how many students get trained. Meanwhile state subsidies are frozen at the 11% level until the review—designed to assess the productivity and quality of each program—is completed.

Data-gathering. Like Ohio, most institutions are looking for better information before they take action. Says Charlotte Kuh, the new head of NAS's Office of Science and Engineering Professionals: "Biting the bullet when you don't have data is not a very good idea." One of the most glaring voids in any report to date concerns people a few years after they've gotten their Ph.D.s—the time when traditionally they would be settling into a "permanent" position. Such information will be considerably more illuminating of the state of the scientific job market than are simple unemployment figures.



Breeding fewer physicists. Since 1990, first-year enrollment in graduate physics programs has declined.

But more projects are in the works. The most extensive is a survey just launched at the University of California, Berkeley, which has a Mellon Foundation grant to do a follow-up survey of 1500 people in five fields who got their Ph.D.s between 1983 and 1985. And smaller initiatives are going on at other schools such as Cornell, where biology department chair Peter Bruns says he's commissioning someone to do "an analysis of where our students end up and what they think of their training."

The definitive answer to the Ph.D. population problem, however, may ultimately be as elusive as the definition of appropriate Ph.D. employment. As Representative Sherwood Boehlert (R–NY) asked at a recent congressional hearing on Ph.D. training, referring to two colleagues with Ph.D.s in engineering and physics: "Are they underemployed because they're members of Congress?" The rhetorical question was posed, ironically, as Boehlert was justifying planned cuts in federal science spending.

–Constance Holden

CHANGING DOCTORATES

Grad Schools Preview the Shape Of Ph.D.s to Come

When revamping its graduate program hit the top of the agenda at Northwestern University's biochemistry department, based in Evanston, Illinois, in the early 1990s, it did several things that would have been unthinkable a scant 10 years earlier. The department halved its intake of students and told new entrants they were expected to finish their degrees in 5 years, rather than the usual six to seven. And in what seems the ultimate act of self-sacrifice, the department abandoned its own recruitment program in favor of a broad-based effort that draws students to a variety of life and physical science departments.

But these changes are not going to weaken the department, says biochemistry chair Richard I. Morimoto; they will—he hopes—make it a biochemistry hotbed for the 21st century. "It took us a while to realize that we can't train students the way we were doing," says Morimoto, who got his Ph.D. in 1978. "We're in a different era"—an era that can no longer count on the continuous expansion made possible by massive build-ups of federal research money during the Cold War.

The Northwestern exercise is in response to a refrain that is ringing across the country. It's one that calls for shortening the number of years of Ph.D. training, which has crept up to about eight in some fields; for broadening the requirements for a Ph.D. to create a more versatile researcher; and even for changing the way graduate students get funding, to free them from dependence on a single faculty member, who may keep them in the lab longer than necessary. While there's been a lot more talk than action so far, a few schools have begun to reshape their curricula to respond to today's realities.

Changing times. When Morimoto was in graduate school, most doctoral students expected to follow the career paths of their academic advisers and to become tenured professors. Now fewer than half can expect such a course. This situation has spawned a great deal of rhetoric and self-examination by universities and the government agencies that support their research (see p. 135). Mark Wrighton, former provost at the Massachusetts Institute of Technology and now chancellor of Washington University in St. Louis, says the feeling is that doctoral training is too long, too narrow, and not well connected to the concerns of the outside world. "We need to focus more on the needs of students to prepare them for independent careers," he says.

Until recently it was possible for academic Ph.D. scientists to spend their entire careers pursuing one narrowly defined subject. A chemist, for example, could study the structure of compounds using a single technique—such as computer simulation or nuclear magnetic resonance or x-ray crystallography—while barely being familiar with the other two. Now, however, it's become clear that the best structural chemists must be comfortable with all available techniques.

"Broad-based training that fosters movement to another more or less related field may be a necessity for future employment," says Ned Heindel, a chemist at Lehigh University in Bethlehem, Pennsylvania, and past president of the American Chemical Society (ACS).

The National Science Foundation (NSF) pressed this theme last June when its Mathematical and Physical Sciences Directorate held a workshop, involving about 80 scientists, to consider possible new directions for graduate education. Says one of the conference's organizers, retired IBM research director John Armstrong: "There was quite remarkable consensus. We recommended that moves be made to broaden the intellectual content of Ph.D. training, to develop mechanisms for shortening the time to the Ph.D. exam, and to use off-campus experiences as an option during training." Last summer's report of the National Academy of Science's Committee on Science, Engineering, and Public Policy reached a similar conclusion: "A world of work that has become more interdisciplinary, collaborative, and global requires young people who are adaptable, flexible, as well as technically proficient."

Broadening training. These are bold visions, but what of the reality? Northwestern's biochemistry department is one of the few places where changes have already taken place. Now many students seeking Ph.D.s in the life sciences are recruited to an umbrella program that requires them to take courses in several aspects of biology, including biochemistry, anthropology, biomedical engineering, and molecular biology. Immunologist Sue Pierce says that "our students are fearless, because they hear about carbohydrate chemistry and structural biology along with their major subject. They know there are other branches of science that are not alien cultures."

The program, known as the Interdepartmental Biological Sciences Program, began in September 1994. Students undergo about a year of general preparation before they are asked to commit themselves to a particular field. The program involves scientists in both basic and applied research, which means students get to focus in detail on biological mechanisms as well as explore processes that can function on a large, commercial scale. Students are also exposed to a range of work opportunities via "career events" that bring recent graduates back to campus for seminars. Visitors this year will include a high school teacher, a unit administrator from the biotech company Genentech, a lab head from Abbott Labs, and a faculty member at a nonresearch university.

Larry Pinto, the first director of the program, says it has attracted a lot of high-quality applicants. And because the intake has been reduced, he adds, the quality of those who actually make it into the program is absolutely superb. The program has not yet produced any full-fledged Ph.D.s, but Morimoto says the students in it

For more info on this topic, see *Science*'s Next Wave World Wide Web site: **http://sci.aaas.org/nextwave/**

A Marketable Master's

Late last August, Northwestern University graduated its third class of master's degree students in biotechnology, and, if the pattern established during the program's first 2 years continues, all 35 graduates should now be gainfully employed, at annual salaries of about $45,000. "All of our students have had jobs 1 month after graduation," boasts the program's associate director, Alicia Loeffler.

Northwestern's biotechies are still an unusual phenomenon. "Science fields are grossly underrepresented among master's degrees, because people regard the Ph.D. as be-all and end-all," says Daryl Chubin of the National Science Foundation. But that could be changing. "With the exception of the physical sciences, the master of science degree is on a high growth curve" in institutions across the country, says educational writer and researcher Sheila Tobias of the Research Corporation, a private research institute in Tucson, Arizona. Even that one exception may not last long: Recently developed master's programs in physics and optics at the University of Rochester, and in physics and engineering at Cornell University, suggest that inroads are being made in physical sciences as well. Chubin adds that master of science degrees are increasingly being offered, "particularly in combination with other kinds of degrees," such as business degrees.

DEWEY HENTGES

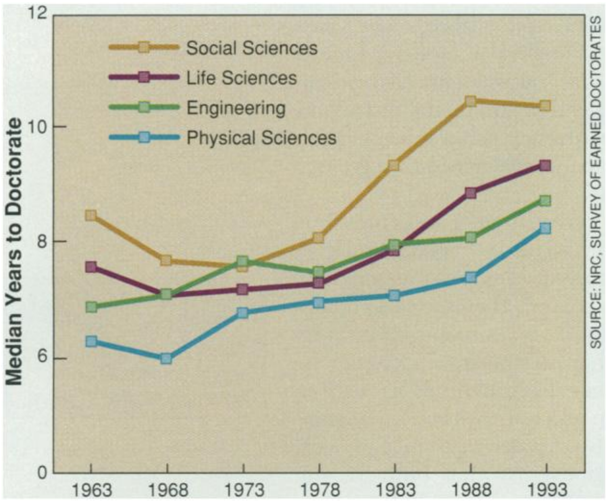
Jobward bound. Northwestern's master's graduating class in biotechnology is ready to hit the ground running.

Master's programs are also sometimes tailored to equip students with specific skills that are in demand in the geographic area where the university is located. The University of Rochester, for example, is a good place to learn optics, because Rochester is home to Kodak Corp. And when Catherine Propst left her vice-presidential position at Abbott Labs, in a suburb of Chicago, to build Northwestern's master's in biotechnology program, she had in mind preparing students for work at major pharmaceutical firms such as Abbott.

Propst claims that some very talented Ph.D. graduates lack "corporate survival skills," such as building and working in teams, figuring out budgets, and understanding state and federal regulations (see p. 133). So she designed the biotechnology program to require coursework in business as well as in scientific techniques and research.

Indeed, it was a desire to master such commercially valuable skills that lured Chris Faraday—who already has a Ph.D. in botany—into a brand new, 1-year master's degree program at Cornell's School of Business that was explicitly designed for those with scientific backgrounds. His doctoral training, he says, gave him general technical and analytic abilities. But, he says, "I believe I need specific managerial and financial skills to get ahead."

–A.S.M.



A longer journey. In many fields of science, the total time to degree has crept up past 8 years (gauged by years post-baccalaureate).

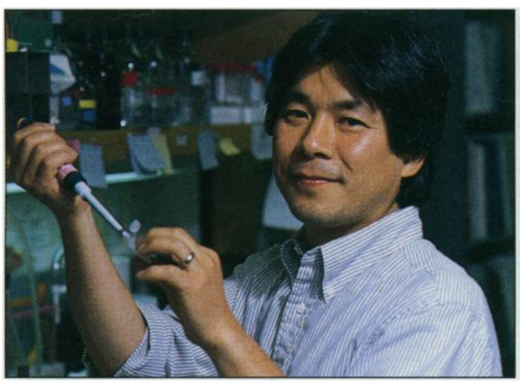
are getting the strong message that there will be a wide variety of career opportunities open to them.

Crossing boundaries. While one way to broaden training is to expand the coursework and seminars students take before they commit to thesis research, another strategy is to have doctoral thesis research that itself spans several fields. Indeed, some universities are encouraging the development of interdisciplinary programs that span both department and college barriers.

Until a few years ago, most boundary-crossing efforts were done on an ad hoc basis by an interested faculty member or intrepid student. Indeed, the California Institute of Technology was a pioneer in relatively uncharted territory when, in the late 1980s, it launched a program on computation and the neurosciences, which studies the interface between neurobiology, electrical engineering, computer science, and physics.

But now interdisciplinary programs, although still unusual, can be found with increasing frequency. Last year, the University of Wisconsin, Madison, started a multidisciplinary program in geological engineering that involves geology, physics, and several engineering departments. At the University of Maryland, a doctorate in molecular biology is being coupled with a master's degree in technology management. At the University of California, Berkeley, faculty members are planning a new School of Information Management and Systems, which will couple segments of the former School of Library Sciences with computer sciences. And next year, Washington University will accept its first students in a new, multidisciplinary program in biomedical engineering. Says Washington University's dean of engineering, Chris Byrnes: "This is one of few programs to bridge three colleges ... Arts and Sciences, Engineering, and Medicine."

Another way to bring more interdisciplinary breadth to a graduate program is to broaden the faculty. At Purdue University in Indiana, professors are encouraged to seek new training through tuition subsidies and time off. They can get a new degree at Purdue, at a 75% discount in tuition, or travel elsewhere with a less comprehensive leave and tuition reimbursement offer. Purdue health scientist Randy Black, for example, who received his doctorate in psychology from Stanford University in 1978, got leave from Purdue to go to San Diego State a few years ago for a master's degree in public health, collapsing a 2-year program into one. The experience, Black says, "was invaluable in expanding my horizons." Now, he says, he can teach epidemiology from the perspectives of both a medical and social scientist.



Broader biochemistry. Northwestern University's Richard Morimoto covers a lot of ground overseeing a new, multidisciplinary program—and so do his students.

Shorter training. Even as training programs are being broadened, critics say they also need to be shortened. Between 1973 and 1993, for example, the average number of years of study it took to get a Ph.D. in the life sciences expanded from 5.5 to 6.8 years, according to the National Research Council (see chart). Many people believe that time to degree for most science doctorates can be shortened to between 5 and 5.5 years without sacrificing any depth. An added year or two in the lab may put a high polish on a thesis but is often not the best use of a student's time and resources, says Columbia University chemist Ronald Breslow, president-elect of the American Chemical Society. And, he adds, that extra time can lead to a destructive pattern of procrastination. Indeed, some argue that when it comes to thesis work, less can be more. "I hold the paradoxical view that shortening the time to degree helps students," says Armstrong. It gets them into the world of work sooner and reduces their anxiety, he claims.

One of the simplest and most effective ways to speed things up is through the judicious manipulation of financial support. Berkeley, for example, is offering fellowships to help students through critical times in graduate education—typically right before the qualifying exam and, later, during the last year of thesis-writing. This frees them up to focus on their studies and forget about teaching or part-time jobs for a while, says Maresi Nerad, director of graduate research.

But Berkeley administrators are willing to use sticks as well as carrots to move things along. Now, for example, the physics department is being encouraged to change its rules so that students take the qualifying exam by the end of the second year rather than waiting, as some have in the past, until their fourth year of graduate study. This should give students early feedback on their accomplishments and accelerate a student's involvement in a research program, says Nerad.

The price of change. People both at universities and at federal funding agencies are now talking about how to use graduate school financing to bring about some of these changes. Because many students are supported by federally funded research assistantships, where they are paid to carry out their supervisor's research program, they can be stuck in labs after they have ceased learning much and are basically being "exploited" as low-paid technicians, says Daryl Chubin of the Education and Human Resources Directorate at the NSF. "We must break the cycle of preparing students in the image of their university mentors," says Chubin.

One way to solve this problem, observes Heindel, is for the major funding agencies, such as NSF and the National Institutes of Health, to put more money into traineeships that are distributed to students by departments, or into fellowships, which go directly to students. These alternate modes of funding break a student's dependency on a lab director for financial support, observes Heindel. In this way, he continues, market forces can step in: "Those faculty who are successful in training students and providing opportunities for successful careers will attract the best students. Those who take advantage of students for their own research agenda, without regard to career opportunities, will be unable to continue to attract top-quality students." Washington University's Wrighton agrees, saying that "if we put more money in the hands of students, the faculty will respond."

Backlash. Some faculty members are already responding, and not all university researchers are thrilled about the prospect of some of the changes in the air. Shortening a student's academic career while at the same time encouraging the exploration of a broader range of subjects outside a thesis topic will, no doubt, limit time in a supervisor's lab. And some university researchers take sharp exception to the notion that such time is a period of graduate student exploitation.

One of them is Paul Bohn, chair of the chemistry department at the University of Illinois, Urbana-Champaign. He says that laboratory work is often extended for the benefit of students, not faculty—in order to give them additional skills or to offer a buffer between completion of thesis work and entry into a glutted job market. "We keenly feel a responsibility to help students make a smooth transition to productive lives," says Bohn. Frank Richter, professor of geophysical sciences at the University of Chicago, says graduate students are sometimes kept on in labs more out of charity than as cheap labor. "Some students that stay on the longest are often the least useful," he says. "Unfortunately, too few [of us] have the heart to tell such students 'You won't make it.' "

Still, many faculty members agree that a broader and quicker course of study is a reasonable remedy for today's graduate school ills, as are new ways of routing money to students. "I wholeheartedly agree with efforts to shorten the time to degree to about 5 years," says physicist Don Reeder of the University of Wisconsin. "Anything longer borders on exploitation." He also favors broadening training, although he notes that, if poorly planned, a shorter, broader education can be an inadequate education. And Richter would welcome changes in funding that would, for example, take money away from research assistantships and give it to departments in the form of traineeships. That, he says, would allow departments to make more significant investments in hot new research areas that require the collective talents of several faculty members.

There is also widespread agreement on the need to cultivate industrial relationships, says Richter: "We have made a mistake of minimizing and devaluing industrial opportunities. We're partly at fault for creating a culture that limits opportunities to academe." Indeed, the current discussion about graduate education is making people think much more about how the Ph.D. can best be applied in nonacademic careers, says Armstrong.

A flexible future. Armstrong also notes that all these changes—or potential changes—would give graduate schools tremendous potential for customizing their graduate programs to meet the particular needs of an institution and its students. Those schools that are close to industries and government research labs may, for example, forge more collaborations, while other university graduate programs may continue to be self-contained.

"A lot of experiments are being done across the country to see what works best," says Luis Proenza, Purdue vice president for research and dean of the graduate school. And so far one thing seems certain, Armstrong says: "One size does not fit all."

–Anne Simon Moffat

INDUSTRY VIEWS

A Business Blueprint: How to Build a Better Ph.D.

When chemist Bernice Feuer joined the chemical company Hoechst Celanese in 1982, most researchers there still worked "as solo individuals" on some basic research, as Feuer did the first half of her career at Bell Labs. But today, she says, the emphasis has shifted from "publishing and patents" to "pushing products through." The buzzwords at Hoechst are market payoff and teamwork, and she's had to shed her old projects and some old habits.

Feuer remembers one researcher, a few years out of graduate school, who couldn't make the transition. He refused to share his data, and he insisted on working alone. He came up with a new idea for making stronger textile fibers, and although company managers told him it was interesting, it was too costly for Hoechst to pursue. That's when he walked out. "He didn't know how to play with a team," she recalls, and "he had not ever had to deal with a business."

This lack of preparation is a lesson graduate schools should take to heart, Feuer says. A growing proportion of Ph.D. graduates are taking jobs in industry—35% of Ph.D. holders worked in business or industry 5 to 8 years out of graduate school in 1991, while only 26% did in 1977, according to National Research Council surveys. Says James Pearson, manager of Ph.D. recruiting for Kodak, "Most academic training is not tailored to prepare students for industrial R&D."

JOHNSON & JOHNSON

"[I would like to see more courses] where biologists interact with chemists, bioengineers with biologists."
—Robert Gussin

That training increasingly focuses on working alone on one narrow scientific problem for several years, says Mary Jane Osborn, microbiology chair at the University of Connecticut Health Center and a member of the National Academy of Science's (NAS's) Committee on Science, Engineering, and Public Policy. In the long run, this tends to reduce a Ph.D.'s flexibility. "People who've sat around 8 years doing the same thing tend to want to do the same thing more," says William Brinkman, vice president of physical sciences research at Bell Labs.

But today in industry, Ph.D.s need to be ready to learn new disciplines, work in teams, explain their research to nonspecialists, and understand the business impact of their work. And they need to be able to do those things right away. Here's a look at what people in various industries, from pharmaceuticals to manufacturing, think graduate schools should do to adapt.

A limber degree. One of the most sought-after qualities in industry is the ability to be flexible—to think about projects from the perspective of several disciplines and to be able to jump from one project to another. At a pharmaceutical company like Johnson & Johnson in New Brunswick, New Jersey, a project to develop a polymer-based wound-healing compound might involve researchers in surgery, metallurgy, mechanical engineering, molecular biology, and chemistry, says Robert Gussin, corporate vice president for science and technology. Yet in today's graduate schools, Gussin says, Ph.D.s take fewer courses than they did 15 or 20