ties, 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."

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

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JOHNSON & JOHNSON

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

—Robert Gussin

years ago and tend to get deep into their research "almost immediately." They are not exposed to a broad range of approaches to scientific questions.

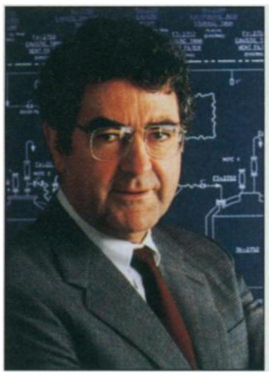
Gussin is not alone in this assessment. "Many departments have minimal course requirements, require no minor field of study, and have exams mostly focused on a student's major research area," says Mary Good, undersecretary for technology of the U.S. Department of Commerce, who taught materials science at Louisiana State University for 25 years. As a result, pharmacologists come out not knowing anything about clinical trials, for example, or polymer chemists have no background in biochemistry. For this reason, Gussin says he would like to see a lot more Ph.D. programs "where biologists interact with chemists, bioengineers with biologists."

Industry sources also say biology students in particular sometimes arrive loaded with techniques like gene splicing or cloning, but short on fundamentals. "There's a tendency for graduate education to become focused on what's fashionable," says Ed Penhoet, chief executive officer of Chiron Corp., a biotechnology firm in Emeryville, California. But "tools change. In the long run the skills to fall back on are a very strong understanding of the field."

EASTMAN KODAK

"Most academic training is not tailored to prepare students for industrial R&D."

—James Pearson



CHIRON CORP.

"For most students, it's a great mystery ... doing science in an industrial environment."

—Ed Penhoet

Playing a team game. Related to this capacity is the ability to do research as part of a group. "In some ways Ph.D. training is a very solo kind of experience. Your name goes on your Ph.D. with your thesis adviser's and that's it," Feuer says. "You get to industry and find out most people these days are working in teams." Shorter product development times have also heightened the need for teamwork, notes Anders Hedberg, a molecular pharmacologist who heads science education at Bristol-Myers Squibb Pharmaceutical Group in Princeton, New Jersey. That's another reason why Gussin likes multidisciplinary graduate programs.

Business sense. Some notion of how a company works would be another valued tool in the Ph.D. arsenal. "The Ph.D. today is basically out there selling their work to the businesses," says Tom Parent, a recruiter for General Electric (GE) Corporate Research and Development in Schenectady, New York. At GE, scientists need to be able to explain their work to business managers and muster their support. At DuPont, says recruiter Dave Berlien, a Ph.D. must "relate their work to satisfy customer needs," which means working with customers and suppliers. That requires not just business savvy but also good communication skills.

Industries also need scientists "who can manage budgets," says John Ryals, vice president of Ciba-Geigy's agricultural biotech center in Research Triangle Park, North Carolina. Taking courses in such areas as accounting would help. So would some exposure to intellectual property issues, Pearson says. "You can't mandate business courses, but you can recommend or make available to students the opportunity," says toxicologist Jeff Handler of SmithKline Beecham Pharmaceuticals in King of Prussia, Pennsylvania.

Cross-fertilization. At present, industry people say, there's not a lot of business sense in science graduate school programs. "Some faculty are very savvy about industrial life, and their students are very attractive to us," says Greg Bottger, manager of external technology for Kodak, but many professors do little to acquaint students with the ways of the business world. People like Bottger and Penhoet hope to see this change with more cross-fertilization: industry scientists who do teaching stints at universities. Penhoet, for instance, is teaching a new course at the University of California, Berkeley, this fall on biotechnology that he says will be "geared toward an industrial perspective." The course will cover biotechnology from research programs through commercial processes, clinical development, and follow-up after marketing, Penhoet says.

Learning on the job. But as this kind of cross-fertilization is still fairly uncommon, some companies are coming to grips with these issues themselves by offering internships so graduate students can get a better feel for life in the private sector. Barbara Mohl, a recruiter at Squibb, points to an arrangement her company has with nearby Princeton University, which sends molecular biology students down the road to Squibb's lab to do their doctoral work.

Many companies are also adding graduate student and postdoc slots to internship programs once reserved for master's or bachelor's students. Electronics giant Hewlett Packard of Palo Alto, California, started a program within the last 2 years that offers research internships for first-year graduate students through postdocs, from summer stints to 6-month stretches.

Going too far? Not everyone, however, is keen on an extremely industry-oriented Ph.D. It's a "somewhat dubious notion" to assert that it's the "right job of a Ph.D. program" to prepare people for industry, says Peter Meyers, director of graduate studies in physics at Princeton. You need to know how to do research properly, he adds, before you can begin to think about commercializing discoveries: "We're trying to train people to do research, and they can do that in any venue." And Rutgers University mathematician Felix Browder, a member of the NAS committee on graduate education, acknowledges that such changes "could weaken the scientific strength of a program."

Echoes of this view can be heard even from people in industry. Penhoet, for one, thinks the best training for industry is a sound technical background and that a good scientist will have no trouble picking up business and other skills later. "I'm very negative about programs which are practically oriented," he says.

Penhoet does, however, think graduate schools should do one thing better: make it clear that many future Ph.D.s will find work not as university professors but in such positions as market analyst, science writer, high school teacher—or industrial researcher. "For most students," concludes Penhoet, "it's a great mystery ... doing science in an industrial environment." But as a large number will wind up in that environment, he continues, it's one scientific mystery that few can afford to leave unexplored.

–Jocelyn Kaiser