Should Doctoral Education Change?

Ever since the mathematics job market started to sour, there has been talk of revamping doctoral education in mathematics. Various reports have addressed this issue, one of the first being "Educating Mathematical Scientists", produced in 1992 by the Board on Mathematical Sciences (BMS) of the National Research Council (NRC) and written by a committee chaired by Ronald G. Douglas of the State University of New York at Stony Brook. More recently, the NRC Committee on Science, Engineering, and Public Policy, chaired by Phillip A. Griffiths of the Institute for Advanced Study, released a report recommending changes in graduate education in all areas of science and engineering. A report based on a workshop on graduate education, organized by the National Science Foundation, is due to be released soon.

Does doctoral education in mathematics need to change? Interviews with nearly twenty mathematics faculty in institutions across the country show that while there is a great deal of concern about the employment difficulties new doctorates face, there is little consensus about exactly what kinds of changes should be made in doctoral programs in order to address this problem. Generally it appears that few departments are making radical changes in their doctoral programs.

The discussion about doctoral education in mathematics has generated a wide variety of suggestions for change. They range from requiring a course outside the mathematics department to requiring a minor in a different subject, from taking a course in computing to learning a computer language, from developing the ability to communicate with researchers in other areas to offering hands-on industrial internships. There has been talk of revamping the structure of the mathematics doctorate to get students started more quickly in research. For example, the preliminary examination, commonly taken in the second year of graduate study, could be eliminated. Instead of preparing for the exam, students would start working on a problem right away to accumulate the background they need to work on the problem.

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None of the faculty interviewed for this article indicated that their departments were considering such dramatic changes, and most believe that attempting to institute such changes on a uniform basis is neither feasible nor desirable. In fact, rather than calling for major changes in doctoral programs, most reaffirmed the importance of providing Ph.D. students with a solid background in pure mathematics.

George Papanicolaou of Stanford University notes that although his department is rather small, there is on the Stanford campus a wide variety of mathematical activity, from the business school to the electrical engineering department. "The mathematics department, being small, sees its role as maintaining the core areas"—analysis, algebra, geometry, and topology. "You can't fool around with that," he says. Across the country, at North Carolina State University in a very different kind of mathematics department with a booming program of industrial linkages, R. H. Martin, chair of the department of mathematics, expresses much the same view: "We need to keep a focus on the basic principles of mathematics."

Worries about the Job Market

Most departments are confident that they provide high-quality education in mathematics. But, shaken in recent years by their students' employment troubles, they have been forced to ask hard questions about whether they are producing doctorates who are able to navigate successfully the changing seas of today's job market. To what degree should the job market drive changes in doctoral programs? On the one hand, slavish following of job market trends is probably unwise. "If you are doing job training and there are no jobs, then it is appropriate to change your program in response," remarks Douglas Kurtz, head of the mathematics department at New Mexico State University. "But if the goal is to provide education and intellectual development, then why would you change the best system of graduate education in the world?" On the other hand, ignoring the job market is not a solution either. As Ronald Douglas puts it, "A doctoral program is not a vocational program, but people need to be able to use what they learn to get jobs."

To what degree should the job market drive changes in doctoral programs?

In one way or another, the job market is affecting just about every doctoral program in the country. Papanicolaou says that Stanford graduate students are very "employment-conscious" and, even without encouragement from faculty, will "buy insurance" against unemployment by taking courses outside of the mathematics department. The Stanford department is not contemplating any changes to its doctoral program, except to "teach students how to benefit from the environment" at Stanford. "I think that not so many changes are needed as people perceive," Papanicolaou remarks. "Most of the graduate programs I know of work fairly well. But we should be concerned that we produce students that can get jobs."

The reports on graduate education often speak of "broadening" doctoral training. Without more specifics, this recommendation comes under the heading of motherhood and apple pie. "How can one disagree with more and wider knowledge?" asks Robert Zimmer, associate provost for research and education and former mathematics department chair at the University of Chicago. "It's a question of how you do it—specifically what you gain, and specifically what you give up." Those interviewed for this article said they would never discourage students from taking courses outside their area of specialization. But many expressed views similar to that of David Vogan of the Massachusetts Institute of Technology. "What we ask people to do in the four years or so of getting a Ph.D. in mathematics is extraordinarily difficult," he notes. "I don't think we can ask people to become mathematicians in a reasonable amount of time and at the same time give a lot of attention to things outside of mathematics."

Many different ideas have been proposed under the rubric of "broadening" doctoral education, from, for example, having students specializing in geometry take a course in algebraic topology, to offering a minor in a subject to which mathematics can be applied, such as computer science, physics, or electrical engineering. But rather than planning a "perfect set of courses," argues William James Lewis, chair of the mathematics department at the University of Nebraska at Lincoln, departments should aim to educate students as scholars who can learn what they need when they need it. Departments should cultivate in students "the ability to learn and the interest in being a research scholar, so that when they need to know some algebraic topology they learn some algebraic topology—but they don't necessarily have to have taken a course in it." By emphasizing this approach, doctoral programs could also get students into working on research problems sooner.

Doctoral Programs Evolve

Doctoral programs in mathematics are always evolving, in many different ways and for many different reasons. Some departments are energetically exploring ways to offer their students, as the NRC report puts it, "a broader range of academic options". "We're taking the report very seriously," says Ronald Anderson, chair of the mathematics department at Texas Tech University. The department, which has a strong applied flavor, has initiated a dialogue with chairs of science and engineering departments and the deans of engineering and of the graduate school to see what can be done to broaden doctoral education in mathematics. "I believe graduate education is very good in this country, and I don't think we need to make wholesale changes," Anderson explains. But he believes graduate education can be strengthened and job opportunities widened. Some of the mechanisms his department is exploring include joint teaching with other departments, training grants in cooperation with other departments, and cross-listing of courses.

At North Carolina State, the mathematics department is making changes partly to give doctoral students wider career opportunities and partly in response to a new intellectual stimulus: the influx of high-tech firms into the Raleigh area. Largely through the efforts of H. Tom Banks, who heads the NCSU Center for Research in Scientific Computing, the department has built a burgeoning program of linkages between the mathematics department and local industry. They have established contacts with a materials manufacturer, a toxicology institute, the computer giant IBM, the North Carolina Department of Insurance, and other organizations. Graduate students take part in research projects in which they work in groups with faculty and industry researchers. Chair Martin reports that the department has recently seen an increase in the quality of students applying to their doctoral program.

Other departments are contemplating few changes. J. J. Kohn of Princeton University points to the establishment of an applied mathematics group in the Princeton mathematics department some fifteen years ago as "a new direction for us", motivated by the increasing connections of mathematics to other areas. But as for the basic core program in mathematics at Princeton, "I don't think there will be drastic changes but we will continue to adjust our program as required by the new environment." And few would argue that Princeton, which attracts excellent students and is highly successful in educating them, ought to undergo major changes. Similarly, Wilfried Schmid of Harvard University says that the system of graduate education in mathematics in the U.S. is working "quite well", and he does not see Harvard making any big changes in what it does.

Highly selective programs like those at Harvard and Princeton have an advantage in that they have been largely insulated from the worst vagaries of the job market. In fact, Schmid reports that recently a number of Harvard mathematics doctorates have taken positions outside academia, even when they had good academic prospects. "It was perfectly clear that those who hired these people knew what a Ph.D. in pure mathematics is, and they wanted people with this background," he points out. "I very much doubt that these employers would prefer students trained more broadly but less deeply."

Teaching a Priority

In at least one respect there has been widespread change in doctoral programs in mathematics: Just about all of them are paying much more attention to developing the teaching skills of graduate students. "Teaching is all-important at the moment," declares Papanicolaou. "Everyone knows it, from the deans to the graduate students. Our students earn their keep by teaching. The department monitors their teaching extremely carefully—we tutor them on it. The students are extremely concerned that they do well at it and get good evaluations.... If you can't teach, the chair of the department will be on your back."

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Departments across the country are establishing mechanisms to insure that their graduate students become good teachers. The mechanisms vary in emphasis and style, from orientation workshops, to seminars on educational issues, to mentoring programs, to videotaping of classroom lectures. But all are aimed at responding to two pressures: demands from administrators, teachers, and parents that faculty not compromise teaching to focus on research and demands from academic employers that new doctorates have a sound background in teaching. Attention to teaching also helps those aiming for industrial jobs, where the ability to communicate is critical.

Some also believe that it is essential for mathematics Ph.D.s to acquire computing skills. In today's world, says Douglas, "it's crazy for anybody to get a Ph.D. in mathematics and not have some understanding of computers." Industrial positions often require computer programming skills. In addition, with the widespread use of computers and calculators in introductory mathematics courses, new Ph.D.s taking academic jobs are increasingly expected to have some facility with this technology. Although many students pick up such skills in graduate school, Douglas believes that if one looked carefully, one would find "a substantial minority, and even a majority in some places, who know very little beyond e-mail or typing a paper."

Foreign Students

One of the most sensitive issues associated with graduate education is that of foreign students. For the past several years, the percentage of Ph.D.s in mathematics going to non-U.S. citizens has been over 50%. The increase in Ph.D. production can be largely attributed to foreign students; between 1986 and 1994, the number of doctorates going to U.S. citizens increased 30%, while the number going to foreigners increased 56%.

Foreign students tend to be especially talented and well prepared, and they make important contributions to the mathematical life in departments. And, had the numbers of foreign students leveled off or dropped, the mathematical community may well have had too few doctorates to fill the available positions. But what seems at first glance to be a win-win situation for foreign students and U.S. mathematics departments is not so simple. For one thing, some departments worry about spending U.S. taxpayer money to support foreign students on teaching assistantships. Some foreign students come to this country with funding from their home countries, but a great many do not.

This financial concern points to a larger question: Have mathematics departments abdicated their responsibilities toward U.S. students? Some say they have. "You can bring students from abroad with all the skills you want," says Raymond Johnson, chair of the mathematics department at the University of Maryland at College Park. "You don't have to think about what changes need to be made to attract American students. We've turned off so many American students to mathematics, minorities and women in particular." Reaching out to such students would necessitate changes in graduate programs, says Johnson, especially in providing an environment in which students can work well and thrive.

"I don't have any enthusiasm for formal limits" on foreign students, says Lewis. "But I think that one should realize that it's not in the best interest of the country that as we approach the end of the decade a majority of Ph.D.s in mathematics—hovering around 55%—are going to foreign citizens." One argument says that if foreign Ph.D.s stay in the U.S. and contribute to the nation, then the investment in them is warranted. Another argument says that if they stay here, they worsen the job market for Americans. And yet another says that if they return home, then they work for the economic competitors of the U.S. Lewis believes these arguments miss the mark. "It's the failure to encourage enough of our own students that's the problem."

In fact, the problem has roots below the graduate level. "If you look at why American universities are so good, and why the research infrastructure is so good it's because we've recruited the best people from all over the world," remarks Myron Allen, chair of the mathematics department at the University of Wyoming. "So I'm not sure that it's important for us to insist on U.S. graduate students. Where we have to cultivate U.S. talent is in the high schools and undergraduate programs. By the time they're entering graduate school, it's too late."

Will the Elite Departments Lead the Way?

One thing that would improve doctoral education is greater diversity across the landscape of all doctoral programs. Zimmer says that, at least until recently, there has not been much diversity in doctoral programs in mathematics. "Some are better or more prestigious, but there has been a lot of drive for everyone to do the same thing," he notes. That the system needs to change does not negate the value of the model for graduate education that has been common to many institutions—in fact, in many places it has been very successful, and it is important that this type of program continue. "However, it would be better if there were greater diversity, particularly if institutions really could articulate directions for themselves in which they would make real, positive educational contributions," he points out. "The specifics need to be reflective of the different programs—they shouldn't all look like a pale version of one model."

"There is a lot of uniformity, and even greater uniformity in the sense of aspirations of departments," agrees Douglas. During the site visits for the BMS report, his committee found that many departments had a vision of themselves as preparing students only for positions in research institutions—and they held onto this vision even in the face of evidence that their students were not getting such jobs. Indeed, the 1995 AMS-IMS-MAA Annual Survey shows that, among last year's new doctorates who took jobs in academia, less than half went to doctoral degree granting departments. "Departments need to be clear on what the program is about, what its goals are," he says, and they need to have realistic expectations about where the majority of their students will find jobs.

One reason for the uniformity is the tendency of departments to try to emulate the elite departments. Does this mean that there will be few changes in graduate education in mathematics unless the elite departments change? Views on this question differ. Says Johnson, "If we depend on the top departments to change, then nothing will happen. I think things are working quite well for them, so they won't change." Glenn Hopkins, chair of the mathematics department at the University of Mississippi, is not sure all departments would follow suit if the elite departments decided to change. But, he says, "It's hard for institutions like ours to lead the way… We need that moral weight behind us, or we'd be afraid that we would be accused of simply weakening the Ph.D."

What could help is for Ph.D. programs to develop clear goals that make sense given their faculties and local environments. Those that do not could be vulnerable to the grim calculus of university economics. "There will be fewer graduate programs" in mathematics in the years to come, says Douglas. "This will happen as universities look at where their strengths are and where they want to invest their resources. And in some cases it is the mathematics graduate programs that are too small or uneconomical." The recent NRC ranking of doctoral programs is certainly being scrutinized by university administrators who want to save money by weeding out ineffective programs. "No doubt some places should stop giving Ph.D.s," says Schmid. "But who is to choose which places?"

The tendency to try to emulate the elite departments points to a broader question of values in the mathematical community. Often students pick up an "informal curriculum" which says that getting a job outside of academia equals failure. Opinions differ on how strong this attitude is within the community. Some argue that students come to graduate school aiming to be professors, and if they fall short of that goal, inevitably there is disappointment. Considering that only about a quarter of new doctorates get jobs outside academia—and they are clustered in such areas as statistics and applied mathematics—it is natural that most graduate students expect to be employed in academia. Still, some believe that unless attitudes about nonacademic employment change, departments will never adequately address the need to prepare their students for a range of employment possibilities.

Everyone agrees that negative attitudes about nonacademic employment are counterproductive and should change. But in trying to bring about such changes in the culture of mathematics, some say, it is important not to throw out wholesale the existing values in the profession. Roger Howe of Yale University believes that some part of the culture will have to change, but it must be done carefully. "Although it seems that research in pure mathematics has been the dominant value in the mathematical community and it seems that perhaps it's been overemphasized, I think it's really a rather fragile situation," he says. Probably it could be destroyed much more easily than people realize, and it could be difficult to reinstate. The pressure against that kind of value is very strong in America."

In the end, doctoral education in mathematics may change not so much by a concerted effort to institute this or that reform, but rather by mathematics faculty responding to students in their programs. Amid all the talk of change, it is important to remember that the students are the raison d'etre for any doctoral program. David Vogan says he is "continually amazed" at the students that keep coming into mathematics, even given the difficult job market. "They show amazing talent and dedication," he remarks. "It's a challenge for us to make a system that lives up to the students in it."

—Allyn Jackson