A Wealth of Potential but an Uncertain Future: Today's Mathematics Departments

What does the future hold for today's mathematics departments? The Notices *asked three prominent department chairs to explore this question, and their thoughts appear below. Many of the issues raised here are being examined by the AMS Task Force on Excellence in Mathematical Scholarship, chaired by Morton Lowengrub of Indiana University. The Task Force is planning to release its report this fall.*

John B. Conway

We are in a period of change in the profession. Change that is fundamental and permanent. With the metamorphosis of the world economy and, in particular, the shifting of the United States's position in the world economy, changes are occurring in every sector of life. In recent years entire industries have faded to a shadow of their former glory, and American citizens no longer view continued increases of their families' fortunes as a given. In that atmosphere no one, including academia and mathematics, can expect to be spared fundamental shifts.

Compounding these problems is the electronic explosion. We have to believe that computers are going to continue getting smaller and faster. How long will it be before we have a 200 Mhz computer with 32 Mb of RAM that slips into a shirt pocket? When that happens many disciplines that presently require their students to take mathematics courses may begin to reconsider such a requirement. If what they want is that their students learn how to execute certain algorithms, I don't see why they should keep sending them to us.

The nature of the mathematics department ten years from now depends on how the mathematical community responds to this change. If you can predict that response, you can see what departments will be like. How the profession reacts to advancing technology, the coming of posttenure review, the assessment of effectiveness in the academic world, and the competition for mathematical talent will determine whether mathematics departments prosper or follow a path to the arcane.

The one force of change that we have any control over is technology. Of course we cannot control the technology itself, but we can decide whether to meet it as friend or foe. We have to embrace technology. I don't mean just tolerate it; embrace it and celebrate it! Let's face it. In our low-level courses we have been teaching students how to execute algorithms. We avoided the pain of trying to convey concepts and the meaning of mathematics to the great unwashed. This approach found its way into grade and high schools. (How did the teachers learn their mathematics?) Now calculators and computers can do those algorithms.

The professional mathematics community must adapt and learn how to best incorporate technology into instruction. With the existence of powerful, inexpensive computers, I see mathematics departments rethinking their entire curriculum. At least I hope they do. Otherwise we are out of business and will be replaced by buildings on the edge of campus that are filled with

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computers loaded with self-paced instructional software that leads the student through the steps of pushing appropriate buttons.

There is a dramatic upside to this. I think that proper incorporation of technology in teaching mathematics and an emphasis on teaching concepts and understanding implies smaller classes and the need for teachers with greater understanding of the subject. This might counteract some of the drive toward larger classes and more nondoctoral instructors.

It also means that mathematics departments must begin to act as their own ambassadors, sending diplomatic missions to their client departments. We have to understand what mathematics the other departments want their students to learn and start offering it to them. We should also try to persuade them that a greater understanding of the concepts is to their benefit. (This is not as difficult as you may think.) The alternative is that they will try to do it themselves. With technology, that may be more of a threat than ever.

One casualty of increasing accountability will be tenure as we know it. In ten years just about every state university will have a system of posttenure review in place. I am not sure of the form, and in fact there will probably be wide variation in the practice. Some will have a very mild form: problem faculty will be identified by the department head, and measures will be taken to correct the problem. If there is no improvement, the faculty member will be dismissed. Others will have five-year periodic reviews of all faculty. The review may be something like a promotion review, and some universities may waste everybody's time by writing for outside letters. Of course no academician will ever write a letter that will justify dismissal of a tenured faculty member, especially with most states having laws that make such letters accessible to the public.

Frankly, I'll be happy with posttenure review. Tenure is a great institution for protecting freedom of thought and expression. But unless there is a workable process for removing tenure, it is a guarantee of lifelong employment. As such it is indefensible. I have personally known mathematics professors who have spent a considerable portion of a semester lecturing on Norse sagas, have not shown up for their class, have cancelled classes after the Thanksgiving break, or have spent considerable lecture time staring at and mumbling to the chalkboard. Such people do not deserve our respect or the protection of tenure. Most would reform at the mere hint of review.

In the future, most graduate programs will be more specialized. The top ten or twenty programs will barely change at all, but the rest will begin to focus on a small number of well-defined research areas. To be a mathematician you need to know mathematics from several different areas, but most departments cannot afford to have heavy representation in all the areas. As a result they will pool their resources and focus on building research groups in four or so parts of mathematics, while hiring just enough faculty in other areas to maintain a diverse graduate curriculum. The core areas will offer their courses every year, and the others will be offered every other year.

External funding for individual research will decrease even further. The National Science Foundation (NSF) is tending toward funding more group research activities than individual grants. There appears to be widening support for institutes, conferences, and infrastructure. With increasing numbers of mathematicians significantly using computers in their research, however, there will be an increase in NSF support for equipment.

As a partial compensation, more mathematics departments will become involved in fundraising. It will be difficult, almost impossible, to convince donors that their contributions should go toward subsidizing faculty to do research during the summer. About the only form of research support that will attract private contributions is a conference or an annual lecture with a well-defined purpose, such as the annual undergraduate or graduate honors lecture. Donors are far more likely to contribute to scholarships.

More mathematics departments will be involved with mathematics education and teacher training. There is a problem with education, though I don't think it is as big as some are trying to convince us it is, and the public believes that those who are capable should try to fix it. This is one of the reasons they support us. I think this is a good development. The more involved the best mathematical minds become with education, the more the profession will profit.

Is the future bright or dreary? Neither. It is uncertain. That is the way the future always is. What happens is a dynamic process. We will have the opportunity to make substantial input, but we cannot determine the outcome. The only certainty is that the profession has the ability to influence the future—as much as any force that is driving change.

William Rundell

"The future ain't what it used to be," may be the most pragmatic prediction, given the historical

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failures of our prophets, mathematical ones included. Yet the political winds of recent years have left little untouched, and it is impossible not to look ahead. Few can doubt that academic science, including mathematics, is going through a period of rapid change, and it is all too tempting to dwell on the negative side effects: diminished government support and greater accountability to a public that is almost completely ignorant of science, never mind scientific research.

The current trend is to predict the future of mathematics departments on the basis of resolving current difficulties. This negative approach is destined to lead to poor predictions, for our task is less to foresee than to enable; society invariably rewards those who have the ability and willingness to address current needs, and fiscal reductions are unlikely to be uniform. We should expect to see an increased emphasis on, and respect for, those areas that directly impact "public interest"—for example, the biological, medical, social, and information sciences. No discipline that wishes to prosper can fail to address the fundamental problems of the age. The intellectual problems of the future, as in the past, will involve deep mathematical questions. In this regard our discipline and mathematicians who treat these rapidly changing times as opportunities will be well placed to make fundamental contributions.

We cannot argue solely on the grounds that mathematics is critical to society and therefore academic mathematics departments should be supported at some predetermined level. The pragmatists will counter that if we are so important and all-embracing, then why do we seem to attract so few students at both the undergraduate and graduate level (compared to, say, chemistry and computer science)? Even these small numbers face uncertain employment prospects. This is despite the fact that our talent pool, as measured by factors such as standard test scores, is always amongst the highest in the university. The pragmatists may be perplexed by the dichotomies of the situation but not persuaded to invest resources. One has to look no further than our colleagues in departments of English to see that society's perception of a discipline's importance does not translate into funds for its practitioners.

How do these generalities translate into actual changes within mathematics departments?

To be viewed as a key player in a research university, mathematics departments simply must have visible accomplishments. Although the prognosis is that mathematics departments cannot expect to have high levels of external funding and graduate enrollments, this is exactly what we need if we are to be taken seriously. Along with expansion must come significant diversification. The focus of many, if not most, of the Ph.D. granting departments must be redirected away from producing professors at similar institutions. This shift will require an acceleration of the already evident trend to reclaim the boundaries of the discipline. It must not be viewed as merely an attempt to produce more "sophisticated engineers", but rather a way to produce deeply trained mathematicians with significant knowledge of an application area. This could mean a number theorist moving into computer security, a differential geometer into crystallography, or a probabilist going into business analysis. The real change here, already started, is the realization by existing research faculty that the burden of these changes rests with them.

To be competitive we are going to have to offer students stipends comparable to salaries in the disciplines in which they will eventually work, which means the stipends will almost certainly have to be higher than they are now. We also must shorten the time to Ph.D. if we are to present an attractive alternative. How can we reconcile the clarion calls for more breadth, a significant outside area, and retention of research depth with probably the same amount of teaching requirements and a shorter time frame? Breadth must be interpreted as "not single focus". The traditional requirement of considerable knowledge of analysis, algebra, and geometry will no longer be relevant for all but a small proportion of graduates. Let me stress this is not a call for relinquishing the core of the discipline, but simply a return to the style of Newton, Gauss, and von Neumann.

Many smaller programs will be able to flourish by concentrating on excellence in a single topic. Some of the present larger programs will be forced to shrink dramatically. The public who pay for the system and are our real clients and the employers who hire our students will ultimately determine which departments will prosper. A formal accreditation system, especially one that ignores market forces, is almost certainly doomed to failure.

At most large research universities undergraduate mathematics majors represent about one percent of the degrees awarded (the percentage is higher at private and liberal arts institutions). A department that teaches less than ten percent of its credit hours to its own majors is also going to be vulnerable to competitive pressure. As engineering enrollments decline, are we surprised that engineering departments, with a surplus of faculty, are trying to ensure that their majors take as few courses outside their department as possible? Engineering today, the College of Business tomorrow?

This one issue—the small number of undergraduate mathematics majors—has received relatively scant attention. It should be a priority within the mathematics community to considerably expand the number of students specializing in the discipline—again by offering more broadly based programs in addition to the traditional core. The advantages are numerous. First some obvious ones; an expanded base for graduate programs and the political reality that in a formula-funded institution majors translate into resources. Second, it is a known fact that alumni tend to favor the institution and department where they received their undergraduate education, and this is true whether it is with private funds or those of their employers that they influence—funds we will need to replace those we are currently losing. Third, and most critical, mathematical training **is** important to society's needs, and we should be more evangelical about this fact.

Our influence with the high schools is, despite the recent rhetoric, always going to be remote. Change at the graduate level will be limited by the quality of the undergraduate pool. Therefore, it makes a great deal of sense to concentrate on the undergraduate program, where we have a large captive audience. The quality undergraduate institutions have known all this for years, yet it seems to be neglected at the large research universities. The cost of an expanded undergraduate major is far cheaper than a comparable expansion at the graduate level and would require very few additional resources.

It almost goes without saying that we need to pay careful attention to undergraduate instruction. Not only must we have, but we must be seen to have, an intellectually solid curriculum that is meaningful to the future careers of the students we teach. We also need to ensure that it is presented with enthusiasm. There has been considerable and much needed reform in calculus designed for science and engineers, but a lot less in calculus for liberal arts and business students, though change is equally necessary here.

However, there are pitfalls. Small projects combining enthusiastic instructors giving dedicated attention to hand-picked, talented students almost never scale up and have little relevance at large institutions. Introduction of computing technology is essential, but it is easy to allow form to replace substance. These issues must be tackled by mainstream faculty and with average students in mind. This is critically important to our future, and we need to be playing our first team lest the spin doctors, who will always be with us, get to substitute simple illusions for complicated truths.

These things mean new demands on faculty, who will not only have to take an expanded interest in research and curriculum matters but have to deal with a more diverse public. Mathematics departments have long been a refuge for the highly focused and socially noninteractive individual. They always will be, but there will be fewer such havens.

B. A. Taylor

The basic role of the university in our society—creating, disseminating, and preserving knowledge—will not change significantly in the foreseeable future, and the mathematics departments of large universities will not change dramatically either. In my optimistic scenario, good mathematics programs will bring success.

The balance between teaching, research, and service roles of faculty is evolving and will continue to do so. Faculty will become more involved with teaching, curriculum development, and administrative tasks. The importance of research and scholarship will remain very strong, but, except in very rare cases, it will not be sufficient in itself to justify promotion or other rewards for merit. Our mission will remain the same—to do high-quality research and effective teaching within a sound curricular framework, but we will be held more accountable, both individually and as departments, for the learning of our students.

There is an increasing need for mathematically educated citizens. Besides being a beautiful field, mathematics is a gateway discipline for science, engineering, and almost any technical field. This is true at all levels, from K–12 through graduate, and it is a tremendous advantage. We can keep jobs within mathematics departments if we are successful at providing appropriate curricula and effective teaching and at paying attention to the career paths of our students. As technology increases in importance throughout our economy, the significance of our contributions can increase correspondingly if we give students the knowledge and learning skills they need to succeed in technology-based careers. It needs to be widely understood and accepted that mathematics is important to the success of students with a variety of career interests.

The recent National Science Foundation report *Shaping the Future* points out (p. 6) that our educational system has produced a large supply of world-class scientists and at the same time done a poor job in science and mathematics education for most of the public. Thus I think we are doing

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many educational tasks quite well, and we must be careful to maintain these strengths, such as our graduate and honors programs. In addition, I do not think mathematicians have focused entirely on the top students. During the thirty years I have worked as a mathematics faculty member, it seems to me that mathematics faculty have always been changing the curriculum, trying to do a better job for more students. At the undergraduate level we have an ongoing commitment to curriculum and pedagogy reform. For example, the learning of mathematics needs to be integrated with the use of computers and calculators to do mathematics. We are already making progress on this important task.

In the face of declining research support, one defense of small and expensive graduate and honors programs lies in meeting our responsibilities to students at all levels. The bulk of our teaching will remain at the freshman-sophomore level (over 80 percent of the enrollment in my department), where the majority of the students are from other disciplines. We must collaborate with client disciplines to produce appropriate curricula for this level, with the interests of their students as the primary objective. In a time of competition for scarce resources, isolation from other departments would be disastrous.

At the junior-senior level, we would better fill our role in the university and society by increasing the number of mathematics majors. To do this will require efforts in two directions. First, in freshman-sophomore courses, we need to do a better job of explaining what mathematics majors do. Do most students understand that there are career paths for mathematics majors other than teaching? Through the efforts of the professional societies, there is now a lot of career information available. But do faculty have the information, and do they pass it on in their classes? Second, we need to know how our majors fare in the job market and the kinds of careers they take up. In my department, about 10 percent of undergraduate majors go on to graduate programs in mathematics, 30 percent go to graduate programs in other fields, and 60 percent get jobs in industry. Thus, very few of our students end up with jobs labeled "mathematician". Nevertheless, feedback from alumni and employers who recruit mathematics majors shows that they value the hallmarks of a mathematics major—problem-solving skills, clear thinking, and the ability to deal with abstract concepts. We have found that alumni are cooperative, even enthusiastic, about advising current students and giving feedback on what courses were important for them. Alumni support is an underutilized resource that departments should tap.

There is an increased competition within my university for scarce resources. Michigan is adopting the Value-Centered/Resource-Centered management accounting system, and such systems are increasingly popular nationwide. At its worst, this is a system where senior administrators let the accounting drive the decision making. It leads to individual units wanting to teach their own mathematics courses, their own computing courses, their own English courses, etc. In this environment, we will have a tough time regardless of the quality of our work. We need to work with administrators to ensure that decisions are driven by academic values, although restrained by the realities of limited resources.

I think the single word that best describes the pressures departments and faculty will feel in future years is *accountability*. Government funding agencies at all levels will demand that our teaching and research fill a societal role. Evaluation of departments by legislators, funding agencies, prospective students with tuition dollars, and consequently university administrators will be done through evaluations of the success of our students and our research. Advances in information technology are making it much easier for administrators to pull out quantitative measures of workload and efficiency and to ask prickly questions: How much tuition revenue is generated by this department? How many students does this faculty member teach? What are the rankings on student course evaluations? The best way to prepare for this environment is for faculty and administration to agree upon clearly defined goals and priorities and procedures for measuring success.

If we do not step up to define these, they are likely to be imposed externally. But if we do so and if we show people the value of mathematics in education, we will be able to count on the support of people inside and outside of our universities.