Part III

Examples

Chapter 8
University of Michigan[1]

The task force chose to visit the University of Michigan as a result of presentations at various focus groups by current chair Al Taylor and former chair Don Lewis. From these discussions it had become apparent that something important was happening at Michigan: the department's leadership had succeeded in making a number of significant changes in freshman instruction while at the same time enhancing and strengthening scholarly activities and graduate education.

	1995–1997 Average /yr
Students	
Full-Time Undergraduates	22,019
Junior/Senior Majors	146
Master's Degrees Awarded	17
Ph.D. Degrees Awarded	16
Full-Time Graduate Students	117
First-Year Graduate Students	22
Fall Term Course Enrollments	
Below Calculus	719 (11%)
First-Year Calculus	3,025 (47%)
Other Undergraduate	2,475 (38%)
All Undergraduate Courses	6,219 (96%)
All Graduate Courses	252 (4%)
Teaching Faculty	
Full-Time Tenured or T-track	57
Full-Time Non-tenure-track	32
Part-Time	1

We were not disappointed by our visit. It was evident that the department culture had, for the most part, changed and that administrators had provided significant additional resources to support the department's scholarly and instructional activities. In addition, there was real evidence of systemic change in the department's culture. To cite just two favorable portents: the department awarded an endowed chair to the leader of the calculus reform initiative and tenured the director of its Mathematics Learning Laboratory.

The site-visit took place on September 19 and 20, 1996. Members of the team were Carl Cowen, Ray Johnson, Barbara Keyfitz, Mort Lowengrub, and

[1] Number of full-time undergraduates in the table is taken from the National Center for Education Statistics, U.S. Department of Education, Fall Enrollment, 1996. The remaining data is from the AMS-IMS-MAA Annual Survey, 1995, 1996, and 1997. The table reports the average of all available data provided by the department during the three-year period.

Raquel Storti from the AMS staff. The department had recently moved into newly renovated quarters, which certainly gave the site-visitors an immediate positive view of the administration's attitude toward the department. This impression was borne out by conversations with administrators over the next two days.

Overall we found a culture in the mathematics department that encourages and rewards innovation, one that is well rounded, that strikes a balance between teaching and research, and that supports the work of students and colleagues at all levels. This department is deeply committed to all aspects of its mission: teaching, learning, training, and research. The most respected faculty members strongly support this holistic philosophy, and their support has made a significant difference in the attitudes of both students and faculty toward the department's responsibilities. Everyone we spoke with was committed to providing a first-rate educational experience for students at all levels. In addition, the department has established a very productive environment for its postdocs.

The largest share of credit for the changes we noted was given to Don Lewis, who served as chair for ten years. Lewis had a true vision for the department and understood how to harmonize this vision with the goals of the dean of the College of Literature, Science, and the Arts and with the mission of the university. Lewis had the twin goals of returning the department to a place among the top five research departments in the United States, a place it held from the 1930s through the 1950s, and of having the faculty take as much pride and care in their teaching as they did in their research and direction of doctoral theses. The goal to be among the top five was very attractive to faculty, and Lewis was able to channel their energy and enthusiasm toward improving teaching as well, since it was on the basis of teaching that the department would get the dean's support for its other goals. Thanks to Don's advocacy, the dean and other administrators came to think of the department as both a research institute and a teaching faculty, and they came to understand that to achieve its goals the department would need funding and support for both functions. This view was borne out in our meeting with the dean of the College, Edie Goldenberg, who took great pride in the mathematics department's achievements.

The remainder of this report is divided into several sections: the Freshman Program the Mathematics Laboratory, the Postdoc Program, the View from the Dean, and, an addendum written by Al Taylor, the present chair of the Michigan department, which provides an accounting of the incremental cost of change. It should be noted that we do not attempt to highlight all aspects of the undergraduate program. We have singled out those elements that are unusual and have helped maintain and enhance overall excellence.

The Freshman Program

At Michigan the freshman program consists of a precalculus class titled Data Functions and Graphs; the reformed calculus program; a calculus with Maple class; honors courses for science and engineering students; a course titled Calculus and Combinations, with a second semester entitled Calculus and Dynamical Systems; and a theoretically based honors course for mathematics majors.

Reformed calculus was not the only experimental program developed by the faculty. Don Lewis, as chair, was always willing to let senior faculty conduct experimental courses as long as they committed themselves to three-year involvement and were prepared to do assessments of their efforts. The faculty who developed these courses (we spoke with most of them) expressed real pride in the success of their students. Indeed, it was clear to us that faculty interest in these courses has led to a much better overall freshman program. Phil Hanlon's course titled Calculus and Combinations, followed by Calculus and Dynamical Systems, is an example of such experimentation; Lewis has referred to this class as

Math Department Lounge

"mathematics as an experimental science." Other courses for freshmen developed by faculty included Hanlon's Geometry and the Imagination; Montgomery's Problems in Number Theory; Wasserman's Maple-based calculus class; Krasny and colleagues' honors class for engineers; and the largest experiment, Mort Brown's Calculus based on the Harvard Consortium material. The College administration, impressed with these efforts, provided supplemental summer funding for course development. The chair's philosophy of giving faculty freedom and encouragement to experiment contributed substantially to the positive change in the department's attitude toward undergraduate, particularly freshman, instruction.

Most of the teaching in both freshman and sophomore calculus is done by Graduate Student Instructors (GSIs) and postdoc term assistant professors (TAPs); out of a total of 260 freshmen and sophomores, 40 are taught by tenured/tenure-track faculty. It was clear to the Site-visit Committee, however, that no matter who is doing the actual teaching in a given semester, the level of commitment by the faculty as a whole is very high. In addition, evidence of involvement and success in such teaching is taken into account in promotion and tenure decisions. The department successfully nominated Mort Brown for an endowed chair based on his remarkable achievements in reforming the calculus program.

GSIs and TAPs alike regard their experience with the teaching atmosphere at Michigan as an advantage in the tight job market, and knowledge of the Michigan Calculus is felt to be exportable. Two third-year TAPs whom we interviewed clearly were very happy with their teaching loads and with the research mentoring they had received; they felt that the three-year initial appointments were very comfortable and did not consider the term assistant professorships to be exploitative. We concluded that Michigan's method of delivering calculus instruction is ideal for a system with a large number of junior and term personnel— these young people are too mature to be satisfied with roles as "teaching assistants" in traditional calculus recitations but not ready to be instructors of record in traditional large sections of calculus or precalculus.

The special training received by all participants in the Michigan Calculus is another distinguishing feature of the program. Beverly Black, who holds a joint appointment in the university's Center for Teaching and Learning, was brought into the department to help lead this effort. In practice, all incoming graduate students, postdocs, and assistant professors participate in a week-long session before the start of the fall term. This session is well structured and is described in detail in a manual written by Beverly Black, Pat Shure, and Doug Shaw titled *The Michigan Calculus Program, Instructor Training Materials for Cooperative Learning, Homework Teams, Interactive Lecturing, Teaching Writing.* This material also provides the basis for a continual assessment program that is led by the manual's authors. See the addendum to this chapter by Al Taylor, which describes the remarkable change in professional development and assessment.

The essential idea underlying the freshman program at Michigan is to focus on learning rather than on teaching. In particular, the Michigan approach downgrades lecturing in favor of a more interactive student learning environment. Expecting that most newcomers will have received their own graduate and possibly undergraduate training in more traditional modes, the program focuses on the mechanics of delivery: organizing the classroom, identifying material suitable for lectures and for student-based discovery, and initiating student interactions with one another. This learning-centered approach may be a new one for young teachers and even for some experienced college-level mathematics teachers, but it is demonstrably one that works.

The Mathematics Laboratory

The Michigan Math Laboratory has been an important component in the department's successful approach to undergraduate learning. Its primary mission is to provide assistance to a large number of students in lower-division courses. But it also appears to have a positive effect on the math program in general, giving math majors a place to meet each other, giving them a chance to improve their skills, and perhaps making the major seem more attractive. Bob Megginson, a tenured associate professor of mathematics, has the oversight of the lab as half of his duties. (The other half of his duties includes 1 + 1 teaching and committee work.)

The lab places an emphasis on providing both high-quality tutoring and an atmosphere of efficient service. When a student seeking assistance signs in and

The Michigan Math Lab

indicates the course for which help is needed, the lab manager, who acts as a traffic controller, directs the student to a table at which a tutor handling that course has space at the moment. The tutor's job is to diagnose a student's problem, lead the student to an answer to the immediate question, and provide a new task similar to the one just conquered in order to solidify the concepts.

The tutors are undergraduates; about half are math majors. Also, each TA in a course whose students use the lab is required to spend at least one of his/her three office hours in the lab (some choose to spend all three there). Tutors are chosen on the basis of performance in math courses (up through at least linear algebra) and a short interview to determine communication skills and attitudes. Tutors are paid $8 per hour and are expected to work between 4 and 12 hours per week.

Tutors go through a four-hour training session before classes begin. The training utilizes video tapes to show good and bad examples of tutoring, and the trainees role play, with experienced tutors acting as "students". The goal of the training is to make sure the tutors get students actively engaged in solving their own problems. Tutors are expected to ask leading questions so that students work out problems for themselves rather than having the tutor dictate answers.

The lab also gives more than 10,000 "gateway exams" each year. These are basic tests of skill used to assure that students have mastered material needed for their current classes. Students can take an exam as many times as needed to pass. Students are encouraged to seek tutoring if they are having difficulty passing the exams. These exams attract students to the laboratory; once there, students realize how helpful tutors can be, and the return rate is very high.

In addition to the tutors, the math lab staff includes six student managers who work 8 to 12 hours per week and lab director Bob Megginson. The lab is open 39 hours per week. The lab enjoys adequate space, occupying a large room (approximately 3,200 sq. ft.) with tables for tutoring, individual study, and taking exams. Its funding of about $25,000 for tutors and managers comes from the mathematics department's budget.

The Postdoc Program

The mathematics department was able to convince the Michigan administration that limiting freshman calculus classes to fewer than 32 students would provide a much better educational experience. The department agreed that approximately one-third of the calculus teaching would be staffed by tenured faculty, one-third by graduate students, and one-third by postdocs (also called term assistant professors). The presence of these postdocs has been a real plus for the department's intellectual life. They contribute to "cross-pollination," and in turn they feel well integrated into all aspects of departmental activity.

The two postdocs we interviewed were in the third year of their programs, and we found them extremely positive about their experiences. The department had provided extensive training for their teaching assignments, as well as mentors for their research efforts. The goal was to help these new faculty (all holding their Ph.D.'s less than three years) adjust to a balance between their instructional and research activities.

The postdocs we interviewed saw the Michigan department as a very professional one and one that takes teaching responsibilities most seriously. The postdocs felt free to discuss pedagogical issues along with their research accomplishments; they regarded the treatment and respect they get to be no different than that accorded regular continuing faculty members.

The View from the Dean

Perhaps one of the most enlightening discussions we had during our visit was with the then dean of the College of Literature, Science, and the Arts, Edie Goldenberg. She was clearly very proud and supportive of the mathematics department's efforts and achievements. She views the mathematics faculty as one deeply committed to their scholarly endeavors but at the same time equally committed to their instructional responsibilities.

From Dean Goldenberg's perspective, leadership in the department was key to its success. Don Lewis was chair when she began as dean, and he persuaded her that Michigan could build a renowned mathematics department while making significant moves toward improvement of education, including K–12. He even brought in teams from the department to give demonstrations of instruction based on the calculus reform movement. Dean Goldenberg saw firsthand what changes were possible, and she made a commitment to helping make these changes a reality.

The changes in the mathematics department contributed to Dean Goldenberg's goals of significantly improving undergraduate education throughout the College. Her first investments were in mathematics and writing. She was delighted with the change in attitude of students and other units in the university toward learning in mathematics. The department clearly delivered on its promises, and she was more than willing to become a partner in helping the department obtain additional resources. The provost at Michigan provided several million dollars for LAS undergraduate initiatives, and the mathematics department received a substantial portion of those funds. Dean Goldenberg reiterated several times that had the mathematics department not taken its commitments and responsibilities seriously, she would not have invested in its work.

Another initiative of the dean was to link mathematics more effectively with other parts of the campus. The College and department agreed on an arrangement for joint appointments in applied mathematics with engineering and other areas; this initiative led to another expansion of the department in a direction meeting needs of many units on the campus. The changes that have occurred in the mathematics department have, according to the dean, been applauded by the School of Engineering. As a result, the engineering school has made no attempt to take over any of the mathematics courses for engineers.

The dean praised the department's undergraduate research program. Both parents and faculty colleagues around the campus have been excited about undergraduate participation in research. This program is another example of how the department has contributed positively to the College's image and reputation.

Dean Goldenberg also cited the mathematics department's leadership in assessment of teaching, thanks to a partnership with the Center for Research on Learning and Teaching. The dean has used the department's work as a model for other College units.

The Michigan mathematics department leadership has done a marvelous job of educating their dean on the role mathematics can play in teaching, research, and outreach. The time both Don Lewis and Al Taylor have taken to work with Dean Goldenberg has paid handsome dividends.

Freshman-Sophomore Mathematics—University of Michigan: An Accounting of the Incremental Cost of Change

B.A. Taylor, Chair
August, 1997

Introduction

Freshman-sophomore mathematics instruction at the University of Michigan has seen many changes in teaching and administration over the past decade. Hopefully, these changes have resulted in a significant improvement in mathematics instruction for our students. The bottom line on evaluation is, Is it better than what we were doing before? I think there is no doubt the answer is a resounding yes.

The cost of these changes was and continues to be substantial. As at any department whose faculty is concerned with quality education, change continues as we strive to improve all aspects of our educational program. Fortunately, this decade has been one in which improving the experience of freshmen students was, and continues to be, a very high priority of our administration. We have received financial support as well as encouragement in working toward our goals. The aim of this report is to record, from an administrative point of view, the nature and incremental cost of our changes to date. My best estimate of the direct costs involved is about $700,000, or approximately 15 percent of the budget expended in teaching these courses.

The largest and most expensive changes were made to the first-year mainstream calculus courses, Math 115 and 116, which have enrollments of approximately 4,300 students in an academic year. The academic and pedagogical changes for this project, which was funded in part by a grant from the National Science Foundation, have been described in a report by Morton Brown.[2]

Materials prepared for the mainstream sophomore year courses, Math 215 and 216, which enroll approximately 3,000 students each year, are also available there. A formal report on the academic and pedagogical changes implemented there has not yet been prepared.

Summary of Incremental Costs

The following table summarizes the costs of our revised instructional program. Each item is explained in more detail in the following paragraph with the

[2] Brown, Morton, "Planning and Change: The Michigan Calculus Project", in *Calculus: The Dynamics of Change*, Mathematical Association of America Notes, no. 39, A. Wayne Roberts, ed., 1996.

corresponding label. All salary costs are in terms of dollars in the 1996–97 academic year.

1. Direct incremental annual costs

A. New junior faculty positions (9 FTE @$53,000)	$ 477,000
B. Computer labs (5@$24,000 plus systems support)	$ 180,000
C. Instructor training support	$ 30,000
D. Mathematics Tutoring Center	$ 15,000
Total	***$ 702,000***

2. Indirect costs

A. Space charges for additional faculty
B. Systems support for computer labs
C. Increased workload on departmental staff and administration
Unable to accurately estimate these costs.

3. Startup and other one-time costs, supported by NSF grants over a six-year period

A. Faculty release time for planning and curriculum development.
B. Development of instructor training program.
C. Release time for curriculum development.
Total (grant support and matching University funds) ***$1,083,000***

To put these costs in context, I estimate that the total departmental budget attributable to the freshman-sophomore instructional program, neglecting such overhead costs as space and utilities, is about $4,849,000. Thus, the incremental costs are about 14% of the total. The estimated total costs are broken down as follows.

4. Costs of freshman-sophomore instruction, exclusive of space and other infrastructure costs absorbed by the College

A. Salary cost of tenured/tenure-track faculty involvement	$ 1,632,000
B. Salary cost of other post-doctoral faculty	$ 1,477,000
C. Salary/tuition cost of graduate student instructors	$ 1,280,000
D. Mathematics tutoring center personnel	$ 88,000
E. Office/systems staff time attributed to freshman-sophomore program	$ 342,000
F. Staff support from the Center for Research in Learning and Teaching	$ 30,000
Total	***$ 4,849,000***

Explanations of the Incremental Costs by Item

1.A. New junior faculty positions (9 FTE @$53,000) $ 477,000

The major part of the ongoing costs are due to increased faculty needed to reduce class size and to increase support for instructors of freshman courses. In the early 1980s, class size in freshman calculus at Michigan was about 35 students, with some sections taught by faculty ranging up to 50 students. After having experimented with teaching in large lectures, medium lectures, etc., we became convinced that the best educational method for teaching freshman mathematics is the small-class format with a single instructor in charge—the smaller the better, although the size of the classes must be large enough to make the cost affordable. Over the course of the decade, our average class size has come down until it is now about 29, with no freshman class allowed to have more than 32 students. We also ran some pilot projects with class size as small as 24. The class size reduction has required us to teach about 24 extra sections each year, or 6 FTE's (full time equivalents). The remaining 3 FTE's have gone into educational administration of the courses, primarily increased support and training for classroom instructors. The additional faculty we have hired are primarily new Ph.D.'s with three-year appointments as assistant professors who teach two courses each term and are also expected to carry on an active research program. Their salaries in the 1996–97 academic year were \$38,000, \$39,000, or \$40,000 depending on whether they had held a Ph.D. for one, two, or three or more years. Only mathematicians who have held the Ph.D. for less than three years are eligible for these non-tenurable appointments. (Only tenure/tenure-track appointments are made to those who have held the Ph.D. for three or more years, except for short term visitors.)

Problems associated with teaching many small sections are well known. First, it is expensive. The costs of having all such courses taught by tenured faculty are prohibitive. However, it is essential that senior faculty be intimately involved with and have control of all aspects of the course. Maintaining uniformity in material covered and quality of instruction is difficult and must be constantly monitored by senior faculty. With so many young instructors, many of them initially inexperienced, an extensive training and support program must be maintained. In some years we have had as many as 45 new faculty and graduate student instructors in our start-of-the-year professional development program. Providing this experience and training in teaching is an important part of our department's educational mission in supporting mathematics and its teaching throughout the country. Over the past five years 150 Ph.D.'s in mathematics, both postdocs and our own Ph.D. alumni, have been through our program. On several occasions I have received laudatory comments from department chairs at smaller institutions on the experience and attitude toward teaching of our alumni.

The costs of setting up and maintaining this instructor-development program are significant and, in my view, essential. It amounts to about 3 FTE's of increased faculty effort over our old program. To explain where the increased effort has gone, let me compare the work done now on our mainstream freshman calculus courses with that done previously. Before, each of the first- and second-term courses, Math 115 and 116, had a faculty member and a graduate student assistant overseeing the course in each term. This amounted to 2 FTE's of effort in each academic year. Their responsibilities consisted of a formidable list of tasks:

(i) Preparing syllabi and texts, preparing and oversight of the administration of uniform exams, other day-to-day administration of the course

(ii) Advising instructors on best practices in teaching, holding meetings for instructors to coordinate sections

(iii) Monitoring the quality of classroom instruction, working with individual instructors on methods of improving instruction

(iv) Monitoring the effectiveness of the course for students

(v) Working with client departments to make sure the syllabus is appropriate for their students. Consulting with them on curricular issues and changes

(vi) Monitoring national curriculum development to bring improvements to the Michigan program, e.g., in integrating technology into the curriculum

(vii) Dealing with student complaint and disciplinary actions

(viii) Coordination with leaders of other freshman-sophomore courses to make sure the courses mesh properly over the two-year program

It is pretty tough to see how two faculty members, each assisted by a graduate student, can operate the mechanics of teaching over 140 sections of courses with 120 different instructors and 4,300 students, and still find time to carry out all these other tasks. Further, each faculty member was also expected to teach a course each term, keep working with graduate and other advanced students, and maintain his program of scholarly research and publication. Indeed, only a superhero could keep up with the expectations of such a job.

Recognizing this, we now have about two additional FTE's of effort that go into supporting Math 115/116, with the third incremental FTE of effort being put into the second-year program. One of these is split among experienced faculty, postdocs, and graduate students who visit classes and generally assist in instructor training on an ongoing basis. Another is split between two faculty members who have time to consult with colleagues in other departments and think about the long-term development and evaluation of our efforts. The FTE on the second-year courses goes into writing and coordinating the computer labs and oversight of the graduate student instructors who assist in the labs. In addition to this, we also have the half-time assistance of a staff member from the University's Center for Research on Learning and Teaching, who assists in instructor training, works with instructors in the classroom, and assists in evaluating the effectiveness of the program. While in the early stages of a curriculum development effort one can count on extraordinary efforts of talented individuals to make good things happen, to maintain educational improvements, one has to have a structure in place where jobs can be done and rewarded on a basis commensurate with other departmental work. Further, it has to be realized that a "half-time" assignment to such a position should not be a 20-hour-per-week job unless the faculty member is also released from the normal expectations of maintaining research and other scholarly activities. Sufficient support of the most important person in teaching, the classroom instructor, is essential if quality is to be maintained.

While the costs of our program are substantial, there are also significant benefits that accrue to the individual instructors, to the department, and to students. When I came to Michigan as a new faculty member—and, indeed, when I first taught as a graduate student in the 1960s—the support given new instructors was almost nonexistent: “Here’s the book, the syllabus, and there’s the classroom. Bring us your first exam so we can check it over for you. Come to see me if you have any problems.” The difference today for faculty and graduate student instructors is remarkable. Before classes start there is a week-long professional development program where they are given extensive training on the goals of the course, the goals of the student population in the course, and suggested teaching methods for helping the students reach their goals. All faculty, even senior faculty, who have not taught the course recently go through this program. Throughout the term there are classroom visits and regular meetings with other instructors to discuss problems and ideas as well as coordination with other sections. Materials describing our instructor program, developed primarily by Pat Shure and Beverly Black, have been published by Wiley.[3] New teachers very rapidly come to appreciate the role of mathematics instruction and its importance in a university setting.

For the department, the incremental positions have brought us the benefit of more bright young faculty full of ideas and enthusiasm. They enrich the scholarly life of every mathematician (and colleagues from other departments with whom they interact) at Michigan. Part of our professional development program for young faculty focuses on the necessity of maintaining a balance of work in teaching and in scholarly research, both of which are essential to a successful academic career.

For the students in elementary mathematics courses, they have the advantage of supportive and enthusiastic instructors who are experts in the discipline and who have an appreciation of mathematics and its wide range of applications. The small class size allows them to get to know and work individually with their instructor. For more advanced students of mathematics, there are more experienced faculty available to talk about and work on individual questions and research problems.

1.B. Computer laboratories

We have five computer laboratories, each consisting of fifteen UNIX workstations that are used in the sophomore-year courses and for several other courses (e.g., honors and upper division). We estimate the labs have a three-year lifespan and the equipment and ancillary charges of replacement are about $60,000. There are additional costs for having student monitors in the labs, approximately $4,000 per lab per year, and we estimate the labs require at least 40 percent of the effort of our two departmental computer systems staff, or about $50,000 per year. We were fortunate to have received the machines in three of our labs as a gift from the Hewlett Packard Corporation in support of our work to integrate technology (MAPLE) as a key part of our multivariable calculus course.

1.C Instructor training support

This item is mostly the half-time effort of a staff member from the Center for Research on Learning and Teaching. There has also been some summer sup-

[3] Black, Beverly, Shure, Patricia, and Shaw, Douglas, *The Michigan Calculus Program Instructor Training Manual*, John Wiley and Sons, 1997.

port for those preparing the professional development program for new faculty and graduate students.

1.D. Mathematics tutoring center

For many years the department has had a tutoring center, called the Math Lab, for students enrolled in freshman-sophomore courses. Since the move to our new facility in East Hall and in support of our increased use of "gateway" or "mastery" exams, the number of student visits per academic year has increased to over 20,000. The increased cost of undergraduate student tutors in the lab is about $15,000 per year. We continue to operate the lab with the same amount of faculty and graduate student support.

2.A,B,C Indirect costs

Whenever the number of faculty in a department increases, there is a corresponding increase in all infrastructure costs: more offices, more secretarial support, more computers, bigger phone bills, more activity of all sorts. It is very difficult to quantify these costs, since they are not charged directly to the department. There is also a discernible increase in faculty workload. The postdocs we hire are not required to fulfill departmental service obligations. They are expected only to do excellent teaching and excellent research. So, the service obligations of a larger faculty (more than 90) are spread over the tenured/tenure track faculty (55). In addition, hiring several postdocs each year (around 12–14 in recent years) requires a large amount of faculty and administrative effort. Care is taken to see that there is a senior person working in the area of each postdoc who can serve as a mentor, so it requires senior faculty members to read applications and come forward with their recommendations.

3. Startup and other one-time costs

The courses that have been affected by the changes under discussion here involve about three-fourths of the student credit hours that we teach in each academic year. Thus, these changes have been extensive and required much work and preparation. Diagnosing and working to improve our courses was a constant goal of Morton Brown since he took on the role of associate chairman around 1980. He deserves great credit for recognizing the need for improvement and for attacking the problem long before resources were available to support changes. These resources arrived with an NSF grant along with matching funds from the College of Literature, Science, and the Arts, which allowed for faculty release time, some support for graduate students, the ability to hire consultants for evaluation and advice, and trying out smaller class sizes (such as 24 instead of 32). The College also has supported dedicated, specially furnished classrooms that support the active learning methods used in Math 115/116. Important planning and much detailed work was carried out by faculty members Morton Brown, Patricia Shure, and Robert Megginson, and by our CRLT consultant, Beverly Black. They were assisted along the way by the active cooperation of many senior faculty who devoted time to learning about the project and teaching in it. The support of the department chair, Donald J. Lewis, who pushed for the project and was persuasive in obtaining the support of the administration, was crucial.

Lewis's support was also instrumental in supporting several curriculum development projects in the department and, indeed, in creating an atmosphere within the department where such work is recognized as valuable, even essential, to meet our obligations as educators. One of these projects that had substantial startup costs in faculty release time led to the current form of our second-year courses. The idea of computer labs using MAPLE to assist in teaching multivariable calculus was started at Michigan in the late 1980s by John Harer (now at Duke University) and C.K. Cheung (now of Boston College), who have since written a book using their ideas. When they left Michigan, the program was taken over and modified by Estela Gavosto, now at the University of Kansas, and Alejandro Uribe. Our current program, which we believe is quite successful, has the form they created. Their materials will be disseminated soon, supported by an NSF grant. Some is currently available on our home page:

http://www.math.lsa.umich.edu.

Many of the startup costs and all of the large project startup costs have been supported by external grants. While departmental funds can begin pilot projects, the total costs of a full-blown effort involving evaluation and consultants needs significantly more external support than a department can supply with its own resources.

The amount estimated for this item, $1,083,000, is the total of the NSF ($500,000) and matching university funds ($583,000) that were put into the two projects: Math 115/116 (freshman-sophomore calculus), total of $963,000 and Math 215 (multivariable calculus), total of $120,000. While the department has spent more than this on curriculum development during the past decade, the remaining work has been supported by the departmental budget on an ongoing basis.

Chapter 9
Oklahoma State University[1]

We selected Oklahoma State University for a visit since it is a prototypical land-grant university, characterized by the changes and challenges of public institutions, with a reputation for a mathematics department that is highly regarded within the institution and active and visible within the research community. We wanted to understand the reasons for what, from a distance, seemed a very successful undertaking both locally, in undergraduate education, and nationally, at the research level.

	1995–1997 Average /yr)
Students	
Full-Time Undergraduates	12,985
Junior/Senior Majors	58
Master's Degrees Awarded	2
Ph.D. Degrees Awarded	3
Full-Time Graduate Students	36
First-Year Graduate Students	9
Fall Term Course Enrollments	
Below Calculus	1,638 (35%)
First-Year Calculus	964 (21%)
Other Undergraduate Courses	1,985 (43%)
All Undergraduate Courses	4,587 (99%)
All Graduate Courses	53 (1%)
Teaching Faculty	
Full-Time Tenured or T-track	32
Full-Time Non-tenure-track	7
Part-Time	5

The University and the Department

Oklahoma State University is a land-grant university, sharing and competing for the role as the major higher education institution of that state with the University of Oklahoma. Some statistics sketch a picture of this institution. For 1992–93 it reported a faculty complement of 1,114 faculty, of which 76 were part-time, and a student body of approximately 19,000; it awarded 2,710 bachelor's degrees, 713 master's, and 227 doctorates. As these figures indicate, its educational activities are broadly distributed from undergraduate to graduate in-

[1] Number of full-time undergraduates in table is taken from the National Center for Education Statistics, U.S. Department of Education, Fall Enrollment, 1996. The remaining data is from the AMS-IMS-MAA Annual Survey, 1995, 1996, and 1997. The table reports the average of all available data provided by the department during the three-year period.

struction. Typical of a land-grant university, a notable proportion of its activities are in “land-grant” areas of instruction, such as education and agriculture. The College of Arts and Sciences encompasses 37% of the faculty and 42% of the instructional load (a weighed combination of instruction at different levels) of the institution.

The Department of Mathematics, one of the units of the College of Arts and Sciences, had a faculty complement of 32 (of which 3 were part-time), approximately 45 graduate assistants funded by the state budget, and an additional group of approximately 60 undergraduate student employees. The total number of declared undergraduate majors was 78; it awarded 18 bachelor’s, 10 master’s, and 1 doctorate. Not unexpectedly it provided a high volume of undergraduate instruction, especially at the freshman and sophomore levels (a total of approximately 30,000 credit hours). These figures indicate a typical department within a public research land-grant university with a significant and rather high component of service teaching, a small complement of undergraduate majors, and an active graduate program. An analysis of the budget and activities of this department yielded that its instructional faculty represents approximately 3.4% of that of the University, its budget 4.6%, and its school credit production 6.5% (but when weighed by level of instruction, 4.4%). These figures suggest that the department has a relatively high teaching load but that the University administration has financially responded well to its instructional demands and to its scholarly and research activities. These tentative conclusions confirmed the reasons that motivated the site-visit: the department was successful in making an appropriate case for itself within the University. What were the reasons for this success?

At the conclusion of the visit, the visiting team felt that the department and its leadership had successfully managed, on the one hand, to respond to the mission and demands of the institution in undergraduate instruction and, on the other, to its ambitions in research. Further, it had, over an extended period of time and through stable leadership, ably communicated these successes within the administration of the University, where it was perceived as a highly collegiate unit, devoted to high scholarly and instructional standards yet entrepreneurial and aggressive in research and education. Central to this success, it appeared, were conscious efforts to leverage scholarly and educational activities on each other; to devise effective and efficient means of instruction at the undergraduate level that were highly regarded not only by students but especially by faculty in other colleges and departments; and through an explicit policy, to focus on a few areas of research.

Faculty and Research

The department sees itself as (and is) a research department. Research activities are mostly focused on a few areas in pure mathematics that are well supported by competitive grants. The graduate and postdoctoral programs are, as expected, similarly focused. The graduate program is relatively small; its further development is regarded by the faculty as one of their challenges. Its doctoral graduates predominantly enter the teaching profession at four-year institutions. As is the case in many research departments, the quality of the graduate students and their preparation is not commensurate with that of the research faculty. The graduate and research environment is enlivened by a postdoctoral program, with a cohort of four young mathematicians of excellent pedigree in the areas of departmental research focus. These postdocs are involved in the teaching functions of the department, developing their teaching skill, but having significant time for research and scholarship. The department is acknowledged to be an excellent environment for their further scholarly development.

The OSU Math Building

The departmental faculty is concentrated in two areas: mathematics education and some specific areas of pure mathematics research. The relatively small size of the faculty has prompted the department to follow a policy of concentrating its activities in a few areas rather than attempting to provide coverage of broad fields. It has also very successfully developed a very good atmosphere of mutual respect and support between those members of the faculty whose major interests are in educational activities and production of educational materials and those at the forefront of mathematics research. The end result is a high level of activity and of publication in both areas. In the education area the faculty has developed and published textbooks on the use of technology and mathematical software in conjunction with calculus instruction; they have been awarded numerous grants from the National Science Foundation for instructional activities at the calculus and precalculus levels and have engaged in consortia for major "reform" projects; they are actively involved in outreach activities to the K–12 system of the state. In this arena the faculty has leveraged its commitment to instructional activities within the University and outreach activities within the state with projects supported by peer-reviewed external grants that give it internal credibility and national visibility. At the research level the focus on scholarly activities is on a relatively narrow set of mathematical subfields in number theory, representation theory, algebraic topology, and analysis; this focus has resulted in the department developing a national (and international) reputation in these areas and considerable visibility.

At the cost of mathematical breadth, given its size, the department has developed concentrations of activity of a critical mass that have enabled it to secure significant resources from external grants in a highly competitive environment. The externally funded research and educational activities of the department brought in, in 1994, approximately $900,000 per year, more than one-third of the funds provided from state budgets. This is a notable figure that speaks, on one hand, of payoff on focus, but also on determined efforts to aggressively pursue national funding and visibility in focus areas of education and research. The scholarly activities of the department are underscored by a small, equally focused postdoctoral program that attracts young mathematicians of excellent pedigree, enlivens the research environment, and gives further national visibility to the department. This visibility is very much prized by the University administration, which is well informed about it and very supportive, as testified by the award to a member of the department of one of the few chaired professorships available to the University administration.

Instructional Programs

The research success of the department could not be sustained within an institution like Oklahoma State University without a successful program of undergraduate instruction, for the "service" component of the department provides the base on which its other activities are built. Three components of undergraduate instruction were noted by the site-visit team for particular attention: the quality of service and general education courses, the significant involvement of departmental faculty in programs of teacher education, and the role of the Mathematics Resources Learning Center.

Typical of departments of mathematics, less than one percent of the instruction in the freshman and sophomore years is devoted to its own majors, and instruction at this level represents approximately 80 percent of all registrations in mathematics courses. The department at Oklahoma State University, through the component of its faculty, where interests center on education and educational research, has developed a very good set of innovative course offerings that are well regarded by students and by the "customer" departments. Notable to the site-visit team was the fact that, in discussions with senior administrators of the University, the instructional program of the department was praised; this is seldom the case. The department has aggressively developed a set of elementary mathematics courses for general education purposes, transforming the standard remedial college algebra courses into innovative precalculus courses; it has produced textbooks and manuals, and exploited the use of calculators. Notable is the wide appeal to students of a general education course entitled Applications of Modern Mathematics, based on COMAP's textbook *For All Practical Purposes*. The significant effort the department has put into its general education courses has attracted significant external funding and simultaneously has responded positively to the needs of a large student population whose interests and abilities in mathematics are limited. This effort is particularly prized by the senior administration of the University, highly concerned with the retention of beginning students. Equally entrepreneurial and innovative have been the efforts, again led by those faculty members interested in education and educational research, with innovative and well-executed developments in the calculus and subsequent courses in differential equations. The organization of these courses is thoughtfully planned, there is a thorough program for graduate students to prepare them to teach such courses, and a significant infusion of technology is evident. Mathematica, Matlab, and Derive are integrated into these courses. The department has astutely involved the customer departments and their faculties (in engineering, the sciences, and business) in the development of these courses, resulting in a sense of ownership and satisfaction on their part. The attention and effort that the department has devoted to lower-division instruction has resulted in a very good program, external funding, and high regard within the University; it has also resulted in a level of financial support from internal budgets that would be most unlikely otherwise. That a component of the departmental faculty is strongly devoted to educational research efforts was most important to such success.

A second notable aspect of undergraduate instruction is the significant involvement of departmental faculty in instructional programs, centered in the College of Education, in the preparation of elementary and high school teachers. Many of the faculty within the department whose interest centers on mathematics education also hold appointments in the College of Education. What was striking

The Mathematics Lab

to the site-visit team, however, was that undergraduates majoring in mathematics education looked to the Department of Mathematics as their home, not the College of Education; they constituted a significant component of the departmental undergraduate student body and looked to the faculty of the department as their mentors and advisors. Note that at many public universities, secondary mathematics education majors are counted as a component of the mathematics department's majors.

A critical part of the successful undergraduate program of instruction is the Mathematics Resources Learning Center (MRLC). This Center is dedicated to the support of undergraduate and outreach educational programs. It is a large complex, capable of easily accommodating up to sixty students; it is equipped with approximately forty networked computer terminals with appropriate software, and it is staffed mostly by undergraduate upper-division students, managed by the senior staff officer of the department and recent graduates. The Center serves a number of interrelated purposes. It is a tutorial center where lower-division students receive help from more advanced students; it is a place for access to software, technology, and tapes and visuals associated with courses; it is a place for students to do homework and engage in collaborative learning; and it is an inviting place to study mathematics, with help accessible as needed. It is also the centerpiece of outreach activities to the local K–12 mathematics education community. By all measures, the Center is very successful in its tutorial and technological tasks; it clearly provides, through well-trained and managed undergraduate tutors, effective and efficient instructional support. Three aspects of the Center struck the site-visit team. The first was that many of the student tutors were students in the College of Education, not mathematics majors, yet they exuded a sense of pride and of closeness to the Department of Mathematics, clearly motivated through their involvement in the Center and in its teaching functions. One of the staff members of the Center, a recent graduate of the College of Education who planned a career in teaching high school mathematics, stated that he regarded the Center as his future point of contact with the University, and of referral for his high school students. Through the Center the department has ably appropriated as quasi-majors a number of students in the College of Education—a number larger than the number of its own majors. Secondly, the Center has leveraged this attraction of education students into an effective outreach program to high schools and into close contact with high school teachers. As a result, the department is viewed very positively in the high school community, and the Center hosts a number of high school mathematics competitions and teacher-training programs. Finally, the Center has become the center for the interactions of undergraduates registered in mathematics courses: it is the visible and accessible face of the department, and it is a welcoming, helpful, and friendly face. There is a palpable good feeling on the part of students for the Center, and great pride and loyalty on the part of the student tutors. Senior administrators of the University are fully aware of the Center and prize its contributions. The Center is, in the view of the site-visit team, an activity most worthy of emulation because of its effectiveness and efficiency in instruction, as a test bed for technological innovation and outreach activities, and as demonstrable evidence of the central role and importance of mathematics in undergraduate instruction. It is also an effective and economical means to demonstrate the commitment of the department to undergraduate students.

The mathematics major in the department is not significantly different from the standard one, but the role of the department in the preparation of K–12 teachers, as noted above, is very significant. The department has a long tradition, dating from the '60s, of strong involvement in mathematics education and of outreach activities directed to the K–12 system of the state. This tradition has been sustained through the evolution, dating from the early '80s, of the department from a mostly teaching unit into a research department. This evolution was managed adroitly, resulting in retaining a commitment to undergraduates—be they majors, students in the teacher-training programs, or majors in the sciences, engineering, and business—as the department attracted new faculty with strong interests and commitments to research and graduate education. The success of this evolution is palpable in the sense of mutual respect and support between members of the faculty who see themselves as educators and those committed to being at the forefront of research. This respect and mutual support underpin the quality and commitment to undergraduate programs.

The Mathematics Resources Learning Center is the focus of interactions in undergraduate education; the teas and coffees held in the commons of the department, especially in conjunction with seminars and colloquia, provide interactions for graduate students, postdoctorals, and faculty. The environment of these is highly collegial. The leadership of the department has successfully nurtured the growth of an atmosphere that is supportive but intellectually demanding, and a sense of community with high respect for a diversity of talents. The site-visit team could not but be impressed with the level of morale in the department.

Relationships within the University

The site-visit team early perceived that the department and its leadership had been very successful in communicating and establishing good relationships with other units of the University and with its senior administrators. This success was clearly based on real results: its commitment to undergraduate education and its visibility in research. But beyond this reality, the site-visit team noted that the department consciously and ably communicated these, placed considerable energy in preventing isolation from other units, and consistently involved faculty in other departments.

A key factor explaining the high regard of the department, in the view of the site-visitors, was the long-term leadership of two chairs who have astutely devoted considerable energy to interactions outside the department and have consciously treated other departments and senior administrators as their "customers".

Notable, for example, is the colloquium in the department in which faculty from other units are invited to speak about problems of a mathematical nature in their research. Chemists, physicists, and engineers have through this means been brought in contact with departmental faculty who, given the nature of their research in pure mathematics, are unlikely to engage in interdisciplinary research projects. The result has been, besides a few cross-departmental research activities, a very good level of interactions, a broad understanding of the department by other units, and a sincere appreciation of its contributions. This interaction has been furthered by the conscious involvement of the customer departments and their faculty in the design and evaluation of undergraduate courses. This investment by the department, and especially by its leadership, has had a significant payoff: faculty in other units speak knowledgeably about the department and of its contributions to their students and to the mission of the University.

Equally impressive was the rather detailed knowledge by senior administrators at the University of the contributions, successes, opportunities, and problems within the department. The leadership of the department had clearly done considerable work to communicate these in a realistic manner. The result was that senior administrators viewed themselves as allies of the department and were personally proud of its successes and concerned with its problems. “They are batting 1.000,” a dean stated to us, then elaborated on the excellent morale and collegiality of the department and on his efforts on behalf of its graduate program, under attack by state officials concerned with its small size.

Central to the high regard of the department is that it has astutely aligned its activities to the mission of the university and of the perceived needs of other units in the institution. The ambitions of Oklahoma State University are centered on the quality of the undergraduate education it provides the citizens of the state and on its reputation and contributions as a national research university. The department has ably addressed both of these ambitions with limited resources. It has also seen to it, through astute communications and interactions, that its successes in a subject that is central to both education and research are seen as integral to those of the university.

Concluding Remarks

Oklahoma State University is not a particularly well-funded institution, especially among research universities. Yet, within limited resources, the Department of Mathematics has succeeded in developing a highly regarded undergraduate program and vital and nationally visible research activities. Long-term leadership and commitment to long-term strategies based on alignment with the local educational mission and national visibility in research played a key role in this success. Important also is the entrepreneurial and innovative nature of undergraduate educational activities that can be stimulated within a research department conscious of the importance of its educational mission as a necessary base for its scholarly ambitions. Lastly, significant efforts devoted to communication with other departments and units and with senior administrators has undoubtedly been an important element in the success of the department.

Chapter 10
University of Chicago[1]

The Task Force chose to visit the University of Chicago because several Task Force members had favorable information about the culture and esprit de corps of the mathematics graduate program that prepared future faculty to be both good researchers and good teachers. The mathematics department was known to have a very successful undergraduate program, a number of outreach programs to Chicago schools, and a new entrepreneurial Master's Program in Financial Mathematics.

	1995–1997 Average /yr
Students	
Full-Time Undergraduates	3,515
Junior/Senior Majors	58
Master's Degrees Awarded	24
Ph.D. Degrees Awarded	13
Full-Time Graduate Students	91
First-Year Graduate Students	14
Fall Term Course Enrollments	
Below Calculus	43 (3%)
First-Year Calculus	895 (58%)
Other Undergraduate Courses	458 (30%)
All Undergraduate Courses	1,395 (91%)
All Graduate Courses	139 (9%)
Teaching Faculty	
Full-Time Tenured or T-track	33
Full-Time Non-tenure-track	15
Part-Time	1

The site-visit took place on October 21 and 22, 1996. Members of the team were Carl Cowen, Mort Lowengrub, Alan Newell, David Vogan, and Raquel Storti from the AMS staff. Our mission was to explore those activities which stood out from the norm, programs we might all learn from and in some cases emulate. The reader should understand that we were not there as general critics. Like all departments, the University of Chicago has its weaknesses and idiosyncrasies.

[1]Number of full-time undergraduates in table is taken from the National Center for Education Statistics, U.S. Department of Education, Fall Enrollment, 1996. The remaining data is from the AMS-IMS-MAA Annual Survey, 1995, 1996, 1997. The table reports the average of all available data provided by the department during the three-year period.

The Department and the University

The department, consistently ranked among the top five in the nation, has a distinctive structure. There are presently twenty-eight senior faculty members, almost all of whom occupy professorial rank with one associate professor. They have eight assistant professors, one research associate, thirteen Dickson Instructors, and one senior lecturer. The prestige of the department has positive consequences for junior faculty, who tend to be highly sought after for permanent positions elsewhere. The many long-term visitors enrich the environment in visibly concrete ways. Although the department has an applied component (it offers, through the computational and applied mathematics program (CAMP), interdisciplinary tracks leading to the M.Sc. and Ph.D. degrees), its culture is strongly oriented towards what would traditionally be called pure mathematics.

From its inception in 1893, the University has been at the forefront of graduate education in the United States. The current total enrollment reflects the commitment to graduate education. Almost half of the approximately 12,000 degree students are enrolled at the graduate level. This includes the professional schools. The College of Arts and Science, which reflects that balance, is now continuing to increase its undergraduate enrollment, presently 3,500. This means an increased obligation for the Department of Mathematics, which is the single largest provider of instruction. The instruction is carried out by both faculty members and graduate students. Graduate students who teach are given lecturer rank. Perhaps uniquely among U.S. universities, only 60 percent of faculty teaching time is devoted to the undergraduate level. Undergraduate mathematics at Chicago at all levels intentionally retains a graduate student emphasis. The department determines the quality of a graduating class of undergraduate majors by their later performances at Group I graduate schools and in their academic careers. Of Chicago's graduates in mathematics, about 50 percent go on to Ph.D. programs in mathematics, and about 25 percent to Ph.D.'s in other disciplines. Much of the success of the undergraduate program is attributed to small class sizes and a well-trained cohort of graduate student teachers. Indeed, this culture was developed as far back as the early seventies when Felix Browder, the chair at that time, negotiated with the University a plan for more graduate positions in return for a cast-iron agreement concerning the training and mentoring of graduate students, about which we will talk more later. The success of the small-class format, along with the careful training of graduate lecturers/assistants, is consistent with the reasons for success we found elsewhere.

Mathematics at Chicago is taught the old-fashioned way. For the most part, there are no concessions to the movement towards the introduction of computation into the curriculum, although some compromises to this policy have been made for science courses given to physics and chemistry majors. Moreover, there is also recognition that a majority of those mathematics graduates who decide not to go on to graduate school will end up in the worlds of accounting, finance, and business, and because of this they are about to introduce an option in mathematical economics.

Candidates for the graduate program are chosen carefully and then supported generously and enthusiastically. The aim is to bring in about fifteen per year.

First-year students concentrate entirely on their studies. Second-year students begin to become involved in teaching and by the third year are fully involved in teaching about three courses per year, one course per quarter. The average student takes five years to complete the Ph.D. program. The dean strongly supports the graduate program, and there are no plans to discourage graduate enrollment unless it is demonstrated that Chicago graduates are having troubles in the job market.

The Graduate Program

The program enjoys an esprit de corps way beyond that at most universities. How is this achieved? The first answer is that the students are carefully chosen in the initial instance and then are made to feel extraordinarily special and welcome. They come with the attitude that they must work and work very hard, and the expectation is that in return the department will nurture their development as

Tea in the Math Department

mathematicians. The second answer is that all students bond with each other and with the department during a first year baptism of fire consisting of three year-long course sequences in Algebra, Analysis, and Topology and Geometry. The courses involve an enormous amount of material and homework and are fairly rigidly structured. They are usually given by nine different professors. They also encourage a spirit of genuine cooperation among students, a spirit which is initially based perhaps less on altruism and more on sheer survival instinct. During this period the students have no obligations other than to attend to their own learning. The spirit of collegial cooperation engendered in this first year seems to stay with students throughout their graduate studies and manifests itself in continued interest in each other’s progress and in many student-sponsored activities such as weekly “pizza seminars”. The third answer is that everybody is involved in teaching and is carefully nursed into the teaching process throughout a well-organized second year, and monitored continuously thereafter. They begin their second year by sitting in on the classes they will eventually teach, then by handling tutorial sessions and lectures on an occasional basis, and finally by taking full responsibility for their own class. Undergraduate classes are small, about 30–35 students, and are regularly visited by faculty mentors. Examinations that are set by novice lecturers must pass the eagle-eyed scrutiny of the uncompromising Paul Sally.

There are no qualifying examinations as such. Students are introduced to the research culture by taking on two separate projects during their second and third years and making oral presentations. These serve as "qualifiers" for the Ph.D. Once students pass this stage, they begin dissertation work. Students chosen for the program are expected to succeed, and through hands-on mentoring and nurturing are given every opportunity to do so. Financial support is guaranteed. The Task Force recognizes that the University of Chicago is singularly blessed by having access to the best young minds and having more-than-average financial resources for its graduate programs. Nevertheless, these ingredients alone do not guarantee success. It is the clear statement and consistent application of its own distinctive policies; a fairly rigid core structure; a nurturing, collegial and caring environment; attention to training in teaching as well as research; and the installation of a feeling of confidence in, and the expectation of, good things from every student admitted that makes a good program work. We saw a good example of such a program at the University of Chicago.

Educational and Outreach Activities

The University of Chicago Mathematics Department has a very clear commitment to excellence in undergraduate education at a level that is rare for a department rated so highly for the quality of its research faculty. Both in the teaching of undergraduate classes and in the careful mentoring of graduate students as classroom instructors, the faculty is very much involved. The program of study is unusually rigorous, and it is a point of great pride in the department that its best undergraduates are given a diet of courses that is intellectually rich well beyond what might be expected, even in an outstanding department. The department is also aware of the fact that it is the unit in the University that teaches the most, and it is dedicated to providing a high-quality education for those many students who require mathematics in their course work but are not mathematics or even physical science majors. Among the faculty, five have won the University's Quantrell Award for excellence in undergraduate teaching, the oldest prize in the nation for college teaching.

The director of undergraduate studies is Paul Sally, a University of Chicago phenomenon and a man of formidable presence and commitment. Bob Fefferman, the department chairman, introduced him to us as a kind of local miracle who combines a deep respect for the role and purpose of research with an equally strong commitment to undergraduate education and all the care and attention that the molding of a quality learning environment entails. The associate director of undergraduate studies is Diane Herrmann, who holds the (nontenured) position of senior lecturer and who plays an absolutely crucial role in the day-to-day functioning of the College program. Whether in visiting the classes of new junior faculty or in the training of graduate students in the teaching of mathematics, Paul and Diane carefully oversee a large, high-quality operation carried on by the entire senior faculty. Thus, at Chicago the faculty is determined, in the context of a high-powered research environment, to take time and energy to fashion and nurture a first-rate college mathematics program. A consequence of these efforts is that Chicago graduates the highest percentage of mathematics majors, over 5 percent, of any highly selective U.S. university.

In addition to the high priority that the department places on excellence in undergraduate education, there is also a commitment (again rare among the highest-level research mathematics departments) to a precollegiate education. The department has been involved with precollege education for a decade and a half, starting well before such activities became politically popular and correct on the national level. This commitment is deeply engrained in, and a real point of pride for, the department as a whole. The motivation for the involvement was pure and professional. If the professional mathematicians at the top of the field do not take the initiative in improving the mathematical literacy of the high school population and the nurturing of creative minds and fertile imaginations, then who will?

Classroom at Chicago

The University of Chicago School Mathematics Project has begun to affect the shape of precollege mathematics education across the country. While Chicago School Mathematics efforts started many decades ago, the current project grew out of the work of Professors Paul Sally, Zalman Usiskin, Max Bell, and Izaak Wirszup. Beginning in 1983 with funding from the Amoco Foundation, UCSMP has developed a series of mathematics textbooks for K–12 and sponsors conferences and teacher development programs. There are now about three million students using UCSMP curricula. A central goal of the project is to “upgrade the mathematics experience of the average student.” This goal is approached in a variety of ways: by examining mathematics curricula from the rest of the world, by looking closely at the mathematical skills that students actually bring to the classroom, and by removing the two-year pause that often separated sixth grade arithmetic from ninth-grade algebra.

The Young Scholars Program was begun in 1988 by Paul Sally and Diane Herrmann. It is aimed at students in the Chicago public schools, specifically, at the best one or two students in each school. A hundred students about to enter grades 7 through 12 come to the University every day for four weeks. Mornings are devoted to classes taught by mathematicians (in topics like geometry, number theory, coding theory, and computers and chaos). During the afternoons, counselors who are undergraduate students from Chicago and other universities lead small group activities, including problem-solving seminars and computer-based research. Every aspect of the program emphasizes a variety of career paths related to mathematics. There are weekly discussions with people from inside and outside the University whose work involves mathematics: astronomers, actuaries, engineers, physicists, computer scientists, and mathematics teachers, among others. For the older students, an admissions officer from Chicago makes a presentation about how to find an appropriate college or university. The program has helped to make the University of Chicago visible and accessible to many students who might otherwise never have considered it. More than ten alumni have become mathematics majors at Chicago, and eight or nine alumni enter the university each year. The program costs about $100,000 for one hundred students, all of whom commute from home. Support comes from the National Science Foundation, the Office of Gifted Programs of the Chicago Public Schools, and from the University of Chicago Mathematics Department. Paul Sally believes that a similar program could be run for as few as fifteen students. A ratio of four students to one counselor is good, but six to one is possible.

In 1991 Paul Sally organized Seminars for Elementary Specialists and Mathematics Education, or SESAME. Classes for fourth- through eighth-grade teachers are taught by faculty from the University of Chicago, Northwestern, the University of Illinois at Chicago, and other universities. The goal is “to develop a deep understanding of the conceptual foundations of mathematics, to generate activities that students can use to explore abstract ideas, and to convey a sense of mathematics that evolves from the ideas that are presented in an elementary school classroom.” Classes meet for three hours on ten Wednesday afternoons from January to June and for six hours a day during a two-week summer program. Participating teachers receive academic credit toward state endorsement as mathematics specialists; this follows three years of participation, or 270 contact hours. During this time they may take eight or nine courses on topics such as “Geometry with applications to the elementary school classroom”, “Probability and statistics with applications to the elementary school classroom”, and so on. Lectures are extremely interactive. The Chicago program reaches more than a hundred teachers a year, at a cost of $2,000 per teacher. Sally believes similar programs ought to be widespread. A reasonable scale to begin with is ten or twelve schools and two or three teachers from each school.

Robert Fefferman has continued a program begun by Israel Herstein for Chicago high school mathematics teachers and students. There are sixty-five high schools in Chicago, of which about ten offer a calculus course. The program involves twenty high school teachers, each of whom brings a student, and they take an analysis course together. This program has received much praise and has attracted an exceptionally strong endorsement from the University president, who sees this as yet another example of the positive leadership role played by the University in the city community.

There is significant interaction among the department’s outreach activities. The SESAME program is based on curricular ideas developed by UCSMP. Counselors for the Young Scholars Program are often drawn from a Summer Research Opportunities Program, which brings undergraduate mathematics majors from historically black colleges to Chicago. While many of these programs began with funding from government sources, they are also the kind of programs that should attract financial resources and partnerships from industry and the private sector.

Financial Mathematics M.Sc. Degree Program

Designed to take advantage of the increasing use of mathematics in the field of finance, this program has just been introduced by the Department of Mathematics at the University of Chicago. The goal is to produce graduates who understand the theoretical backgrounds underpinning various models used in the financial markets for pricing, hedging, assessment of risk, etc. The course consists of a combination of basic mathematics (thirty weeks with three lectures per week on numerical methods, differential equations, neural nets), probability theory (twenty weeks with three lectures per week on stochastic calculus), and economics (ten weeks with three lectures per week on the economics of uncertainty and capital and pricing), with lectures from experts in practical applications (thirty weeks with four lectures per week on simple option models, portfolio theory, fixed-income derivatives, foreign exchange, advanced option pricing, and risk management). The first three sections are taught by faculty from the mathematics, statistics, and economics departments respectively. The later sections and the applications are taught by experts drawn from a cross-section of the Chicago financial world.

The program seeks students who have a strong mathematics and/or science background who are interested in financial applications and in making a career in this area. It is a program grounded in mathematics and mathematical thinking rather than a program designed to teach a few mathematical tools to people with a background in economics and finance. It is expected that graduates will have a sufficiently strong background to adapt their models to changing market circumstances. Although it is too early to declare success, the program has started well, with 28 full-time equivalent students, of which 23 are taking the program full-time. It was begun with a loan given to the Department of Mathematics by the University. It was initiated by the department, who saw opportunities to fill a real need and to become involved in a revenue-producing operation. The department receives a certain fraction of the $27,000 tuition for each student and funds to cover the regular departmental responsibilities of the two and a half faculty members who run and teach in the program.

Although the program relies on the strong reputation in mathematics and economics enjoyed by the University of Chicago and, as currently organized, takes advantage of a local pool of talented colleagues in the financial world who can teach applications, it should serve as both a model and a stimulus for other mathematics departments to consider ways in which they may generate revenue and develop interfaces with important areas of application. It is also worth stating again that this is a program that is led by mathematicians, emphasizes mathematics and mathematical thinking, and takes advantage of the increasing reputation of mathematics in the economics and finance worlds.

It was certainly a grand and novel experience to see mathematicians leading ventures rather than simply providing peripheral support. In the past year several other universities have followed Chicago's lead into the interface of mathematics and finance.

Chapter 11
University of Arizona[1]

The Task Force team of Mort Lowengrub, Carl Cowen, John Garnett, Jim Lewis, and Raquel Storti visited the University of Arizona Mathematics Department February 27 and 28, 1997.

Arizona was selected for a site-visit for two reasons. First, the Department has a heavy service teaching responsibility. Finding out how it met that responsibility was interesting. Second, the Department has deliberately focused on certain areas of endeavor, notably mathematics education and applied mathematics. (It should be noted that the former chair of this department, Alan Newell, is a member of our Task Force.)

	1995–1997 Average /yr
Students	
Full-Time Undergraduates	21,511
Junior/Senior Majors	230
Master's Degrees Awarded	8
Ph.D. Degrees Awarded	3
Full-Time Graduate Students	58
First-Year Graduate Students	21
Fall Term Course Enrollments	
Below Calculus	2,872 (44%)
First-Year Calculus	1,975 (30%)
Other Undergraduate Courses	1,382 (21%)
All Undergraduate Courses	6,229 (95%)
All Graduate Courses	314 (5%)
Teaching Faculty	
Full-Time Tenured or T-track	59
Full-Time Non-tenure-track	32
Part-Time	3

The visitors received an enthusiastic and gracious reception from the Arizona faculty, staff, and administration. Arizona is an excellent example of a mathematics department that understands its role within its university and performs this role with distinction. University administrators laud the department's concern for students, particularly for students from other majors; its interest in teaching innovation and in quality teaching in general; and its atmosphere of cooperation between mathematicians and mathematics educators.

[1] Number of full-time undergraduates in table is taken from the National Center for Education Statistics, U.S. Department of Education, Fall Enrollment, 1996. Other data is from the AMS-IMS-MAA Annual Survey, 1995, 1996, and 1997. Course enrollment figures are from fall 1998.

Faculty from other departments praise the Arizona mathematicians for their pleasant accessibility and eager collaborations.

The department consciously tries to do some things very well and to expend minimal effort on activities it does not think it can do well. Besides mathematical education and applied mathematics, things the department does well includes innovative teaching of small classes and interaction with the Arizona high schools.

This report touches on seven aspects of the Arizona department:

Entry Level Courses

The Teaching Environment

Temporary Faculty

Mathematics Education

The Mathematics Center

The University-School Cooperative Teaching Program

Applied Mathematics

Entry-Level Courses

The Arizona department has a large service course load. In the fall semester 1998 there were over 3,100 enrollments in 93 sections of four different below calculus-level courses and finite mathematics, and nearly 2,800 enrollments in 81 sections of five different calculus courses. The large variance in the mathematical preparation of Arizona freshmen makes the department's service course job more challenging.

For many years the University of Arizona had inadequately supported pre-calculus teaching, until by 1984 resources had fallen to the point that College Algebra was offered in classes of over 100 students and in a self-study program of 5,000 students, while Finite Mathematics and Business Calculus were taught in classes of 300 to 600 students. Fewer than 55 percent of the students enrolled would complete these courses with a passing grade. In response to external and internal reviews, the department presented the University administration with a "Decision Package" in 1984. The package proposed a required mathematics placement test for all freshmen and class sizes of at most 35 in all courses except Business Calculus. In exchange the department promised to provide University of Arizona students "first-class mathematical instruction," to solve the problem of high attrition and failure in entry-level mathematics courses, and to upgrade the mathematics backgrounds of secondary school teachers.

The proposed package received administrative support in the concrete form of 10 new permanent faculty positions and an eventual annual budget supplement of $800,000 for visiting faculty. The plan to reduce class sizes was carried out on schedule, and by fall 1998 Arizona course listings included 50 sections of College Algebra, 12 sections of Trigonometry, 16 sections of Finite Mathematics, and 60 sections of Calculus I, II, and III. Most happily, the shift to small classes coincided with a dramatic and demonstrable improvement in student performance: between 1985 and 1990, the passing rate in undergraduate mathematics courses jumped from 55% to 77%, while enrollments in mathematics classes increased by nearly 30%.

The Teaching Environment

However, even small classes must be taught well, and at Arizona they are taught well. The department has a long-fostered environment in which teaching and research are of equal importance. A solid TA training program has been in place since 1985. The department offers regular seminars and workshops in which ladder faculty, lecturers, and teaching assistants learn innovative teaching methods. The research faculty treats the teaching faculty and the teaching assistants as equal colleagues and encourages them to develop new course materials. By departmental policy, every faculty member routinely teaches incoming freshmen. On several occasions, faculty promotions and salary increases have been justified completely on pedagogical contributions.

Temporary Faculty

Teaching 93 sections of precalculus and finite mathematics costs money, and the University of Arizona is not rich. Some of the courses are taught by regular faculty and some by teaching assistants, but most are in the hands of instructors

The Arizona Math Building

or lecturers. In 1998–99 the department employed 20 FTE's as instructors or lecturers on contracts ranging from one to three years, of whom nine were full-time lecturers on multiyear contracts. (By University policy, individuals who have a half-time appointment or higher for an academic year have the same benefits available to regular faculty, including health and retirement. Their offices are equipped with one or more computers, which are connected to the departmental network and the Internet.) The typical teaching load of a full-time instructor/lecturer is three courses per semester. The current starting salary of an instructor/lecturer is $25,000, and individuals on multiyear contracts earn between

$30,000 and $40,000. In addition to the instructors and lecturers, the department has visiting faculty from the high schools and the local community college. In 1998–99 there were four postdoctoral faculty and six visiting faculty. While it is undesirable to assign so many University courses to temporary faculty, the department has no other way to teach its beginning courses in small classes. They cannot afford the 40 new ladder faculty needed to teach 160 classes, and they cannot accommodate the 80 additional graduate students needed to cover 160 TA sections. The department recently established a three-year mathematics teaching postdoctoral position for recent Ph.D.'s in mathematics or mathematics education. The starting salary for teaching postdocs is currently $35,000 per year for a teaching load of two or three courses per semester, including upper-division courses. They are also provided with a small professional travel allowance. The department strongly encourages teaching postdocs to develop both their research program and activities in pedagogy and curriculum reform under the mentoring of a faculty member. The intention is that three years in the Arizona teaching environment will prepare them for future academic employment at four-year or master's institutions.

Mathematics Education

The department has instituted a Ph.D. program in mathematics education that requires 36 units of graduate mathematics courses, including algebra, real analysis, geometry and topology, and the same qualifying examination schedule as mathematics Ph.D. students. Students are also required to have at least two years of precollege teaching experience. Mathematics education Ph.D. theses entail research in mathematics education or the history of mathematics. Mathematics education grants account for 40% of the department's external funding. In the department there is a genuine spirit of cooperation between faculty in mathematics education and mathematics itself.

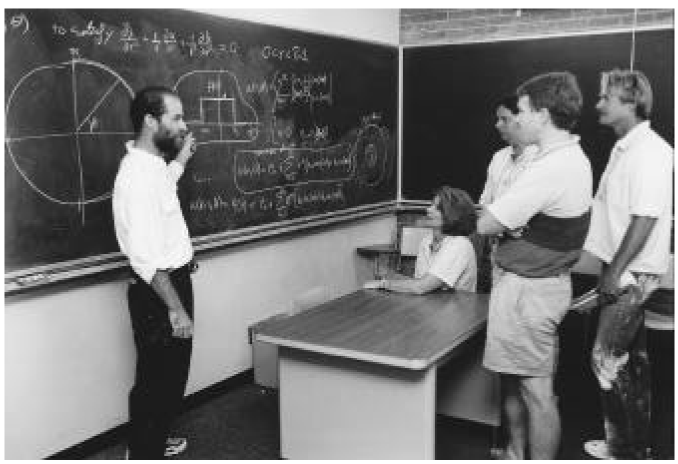
The department's three highest nonadministrative faculty salaries belong to professors in mathematics education. To encourage the equality between basic research, teaching, and educational research, the Faculty of Science (since renamed the College of Science) in 1992 established the Science Education Promotion and Tenure Committee, which provides a separate advancement track for faculty interested in precollege mathematics or science education.

The Mathematics Center

The Mathematics Center is a drop-in advising center for undergraduates considering a mathematics major. It provides students with quick answers to technical advising questions, and refers students with more academic questions to one of the faculty advisors. The Center has an undergraduate lounge and a small undergraduate library. It has instituted a series of undergraduate mathematics colloquia, it publishes a newsletter, and it sponsors career days and "math movies". The Center has instituted drop-in tutoring for upper-division mathematics courses, and it has been instrumental in the creation of the annual $1,000 Outstanding Mathematics Advisor Award.

The University-School Cooperative Teaching Program

In 1998–99 the Cooperative Teaching Program brought six teachers from local high schools or community colleges to the department, while the department sent their institutions six replacement teachers, some of whom were recent graduates in mathematics education. The University pays the replacement teachers $25,000 per year, and the school or college continues to cover its own teacher's salary and benefits. Visiting teachers teach four or five semester courses, take four advanced courses, participate in the Mathematics Instruction Colloquium and do a research project that will help the teacher's school district. The resulting communication between University of Arizona and the schools is beneficial for the University, for the schools, and for their students. Professor Elias Toubassi must be credited for this excellent ongoing program.



Classroom at Arizona

The Program in Applied Mathematics

Since its inception in 1978 the interdisciplinary program in applied mathematics has been oriented towards nonlinear analysis and computer simulations. Research topics have included shock waves, laser optics, pattern formation, turbulence, soil mechanics, kinetic theory, the earth's core, integrable systems, and population dynamics. After a fairly standard set of first-year courses (all taught by mathematics faculty), each student has an individual program that may involve problems from biology and image reconstruction to numerical PDE. One unique feature is Director Michael Tabor's Applied Mathematics Laboratory, where, in a one-year course, students make actual experimental observations in order to see firsthand how a modeling problem comes about. About 50 percent of the applied mathematics Ph.D. theses have been directed by mathematics faculty. (Note: The Arizona applied mathematics program is also discussed in the "Interdisciplinary Section" of Chapter 13.)

The following document explains the department's promotion and tenure criteria. Because it plays a large role in much of what is discussed above, we have included this document to illustrate how one department handles such matters.

An Overview of Performance Criteria for Promotion and Tenure in Mathematics

The purpose of this document is to give a larger perspective of the criteria the Promotion and Tenure Committee employs in arriving at its recommendations. These criteria are consistent with the stated guidelines of both the Department of Mathematics and the Faculty of Science, as well as the standards used by the mathematics community in general, and by some of the "top ten" departments in particular. In doing this, we wish to highlight some of the peculiarities of the mathematics community that set it apart from other academic disciplines.

In accordance with the land-grant charter of this University, we consider the contributions of each of our colleagues to the creative, the instructional, and the service missions of the University. We insist that quality be achieved in all these areas and that this work must be at a level consistent with our departmental goal of being one of the top ten departments in the country, i.e., the candidate must compare favorably with peers at that level.

A. Judging Stature and Excellence in Creative Activity

For most faculty members of the Department of Mathematics, creative activity constitutes research in mathematics. However, there is a significant fraction for whom creative activity constitutes research in mathematics education. The procedure for an individual to identify with one group or the other is clearly spelled out in the promotion and tenure guidelines of the department, and the Committee treats each case accordingly, as prescribed in the Faculty of Science guidelines. In both cases all the criteria used to judge creative activity are based on peer review, either direct or indirect, thereby indicating the regard and respect in which the candidate is held in his or her field.

It is absolutely essential that the Committee be able to ascertain that the candidate's work is of real significance, of high-quality, and sustainable. As a matter of practice, this judgement is invariably influenced by informal interaction, seminar presentations and the like, but as a matter of principle the judgement should ultimately be based on a real understanding of the candidate's work. Specifically, this understanding is built upon consideration of solicited letters from referees, the publication record, grants and awards received, as well as other indications of professional distinction.

A.1) Letters from Referees:

This is the crucial measure. The letters must indicate that the candidate's accomplishments are well known and highly regarded by the acknowledged experts in the candidate's field or fields. In both mathematics and mathematics education, most research is conducted individually or in small groups (as opposed to teams). One consequence of our standard, and of the individual nature of this research, is that the candidate must be consistently judged by the referees to have done significant independent and original work, demonstrating an ability to pick and solve problems of interest. It is not sufficient to have shown great zeal at extending the ideas of others. The referees often give insights into the publication record of the candidate, including his or her relative contribution to collaborative work.

A.2) The Publication Record:

It is impossible to describe in a uniform way how we actually identify work of high-quality. However, it is easy to identify an important caveat, for in mathematics quality is not always correlated with quantity. For instance, two of the premiere number theorists of this century, Artin and Hecke, each published fewer than fifty papers throughout their long careers. This value of quality is reflected in the fact that the Mathematics Division of the NSF limits publication lists to ten and that many mathematics departments, such as Harvard's, base tenure decisions on a candidate's five best papers. It is also important to emphasize that standards within mathematics are neither homogeneous nor static. Applied mathematics is closely akin to scientific disciplines, often even having an experimental component. As in most sciences, the formulation of a problem in applied mathematics can sometimes undergo a long and tortured evolution, involving many false or incomplete steps, and it is important for a researcher to leave his or her imprint along the way (pointing in the right direction, of course). In contrast, pure mathematics is not a scientific discipline at all. Results in pure mathematics consist of mathematically rigorous solutions of precisely stated problems. Such results are stated as "theorems", the demonstrations (proofs) of which are either correct or not and, once established, are not subject to change upon reexamination (although it is highly regarded to discover a major simplification in a long proof).

In many areas of both pure and applied mathematics, there is a strong consensus that emphasis should be placed on publishing rigorous and complete papers. A short "four-page" announcement of results with a loose outline of the arguments is rarely considered as a significant work, even if it appears in a refereed journal. This is because there is an enormous difference between seeing a reasonable strategy for a proof and actually carrying out a proof. The resulting emphasis on completeness sometimes dramatically slows the publication process and is reflected by two phenomena: (1) mathematicians often circulate their papers as preprints for extended periods prior to submission for publication, (2) the delay in publication for prestigious mathematics journals is frequently at least two years. For these reasons referees will often be familiar with and comment on works that have not yet appeared in journals (although these works have usually been submitted). Mathematics is slow and difficult, and there are sound reasons for emphasizing reliability over quantity. We should also note that in mathematics the order of authors' names on an article is usually alphabetical, with no regard to seniority or percentage of contribution. One seldom sees more than three authors on a mathematical paper, especially in pure mathematics, and usually all authors make essential contributions to the work. As a result, if asked to do so, candidates will often simply divide the percentage of contribution evenly among the authors. These circumstances sometimes muddle the issue of which author or authors are responsible for the key ideas; however, this matter is occasionally addressed by the referees, and we often have some knowledge of our own. We try to make this explicit in the individual reports.

A.3) Grants and Awards:

Opportunities for funding within mathematics vary greatly from field to field. Government agencies such as the Air Force, Army, Navy, Department of Energy, and National Institutes of Health usually make a small part of their overall research budgets available to applied mathematicians. However, pure mathematicians have far fewer sources of funds from which to draw. Even when funding is available in mathematics, the award sizes are much smaller than those in other scientific fields. For instance, the median annual award sizes for NSF grants from the Mathematics and Physical Sciences directorate (MPS) in disciplines other than math (astronomy, chemistry, materials research, and physics) are two and a half to almost four times as large as those in mathematics. The median annual size of NSF grants in mathematics was $22,862 in 1996 and $28,000 in 1997. In light of this situation, it is to be expected that candidates in mathematics will have funding levels substantially below candidates from other disciplines. However, when compared to other mathematics departments, the mathematics department at the University of Arizona does well. In 1997 it ranked twentieth among universities in terms of funding received from the NSF in mathematics.

Members of the Committee regard awards, such as Sloan Fellowships, as absolutely reliable indicators of the quality of the candidate's work, and outside support as a valuable indicator of its impact and potential. However, in mathematics neither is regarded as essential. There are three reasons for this. First, the great bulk of outside support comes from a single source, the NSF. Second, NSF funding for mathematical research has been and continues to be very tight. Third, in most areas of mathematics, a lack of outside support is not a real hindrance to continued productivity in research. The situation in mathematics is not comparable to that in other sciences where support for a research lab and assistants is essential. We are not aware of any mathematics department in the country that insists on outside support.

A.4) Postdoctoral Positions:

At variance with most scientific disciplines, in mathematics a postdoctoral position is often considered to be a prestigious award for a pretenured faculty member. This is the case for positions that allow researchers to conduct their own research, often with a reduced teaching load. These may come under the guise of "named instructorships", such as the Moore Instructorships at MIT, the Miller Fellowships at Berkeley, or our own Pierce and Rund Instructorships. They may also be postdoctoral fellowships awarded by a major research institute like the Mathematical Sciences Research Institute (MSRI) in Berkeley, the Institute for Mathematics and its Applications (IMA) in Minneapolis, or the Institute for Advanced Study (IAS) in Princeton. They may also be postdoctoral fellowships awarded by a government or private funding agency. In any guise, there are very few of these positions.

The Mathematical Sciences Postdoctoral Research Fellowships awarded by the NSF each year provide a notable case in point. Despite the name, these fellowships are quite different from traditional postdoctoral positions in the sciences. First, the research plan for each fellowship is prepared by the applicant, not by a mathematician at the host institution. Second, each of these fellowships is awarded directly to the applicant by an NSF panel of mathematical scientists, not by a senior researcher at the host institution. Third, only 25–30 of these fellowships are awarded each year. Recipients of these fellowships often have concurrent tenure-track appointments. They also typically teach. For these reasons, the Committee members regard these awards as quite prestigious and regard the years of fellowship as time spent at the assistant professor level.

A.5) Other Measures:

There are other measures used by the Committee, such as invitations to speak at conferences, contributions to conference proceedings, and seminar participation. While we consider such indicators positively, less weight is attached to a lack in the first two measures than in other disciplines because in many areas of mathematics there are not as many conferences as in, for example, areas of Physics. This reflects the general funding situation of mathematics. For similar reasons, memberships on professional committees, while a solid indicator that the candidate is regarded highly within the mathematics community, are not considered to be essential (being fewer per capita than in other disciplines).

B. Judging Excellence in Teaching

The criteria used by the Committee are essentially those spelled out in Section II of the Faculty of Science Statement on Guidelines.

In evaluating teaching we try to take a balanced approach in weighing student evaluation forms, student comments, peer review, and follow-up interviews with students. The Committee expects faculty to set high standards in all courses, but pays particular attention to teaching performance in lower-division undergraduate courses. We also value contributions to all instructional programs through resource development (like new courses, textbooks, and software), especially if it is nationally recognized through grants or awards. Involvement in undergraduate advising, the Honors Program, minority mentoring, graduate admissions and advising, the preparation and grading of qualifying and preliminary written exams, and oral exam committees are also contributions that weigh in favor of a candidate. In addition, the Committee fully recognizes similar contributions by faculty to interdisciplinary programs.

It is expected that faculty attaining the rank of full professor will have played a significant role in developing the quality of our graduate program. Perhaps the most direct way of contributing to this is to guide the research of a student in the Ph.D. or master's programs. However, this is not the only way. Organizing and participating in working groups or seminars which introduce students to current trends or research problems is a valued activity in a department as diverse and interactive as ours. Of equal importance is participation in the design and teaching of the core graduate curriculum as well as the more specialized year courses designed to lead students into active research.

In mathematics it is rare that a pretenured faculty member takes on a Ph.D. student. What we look for in such faculty members are the qualities that make for an effective adviser, such as the ability to interact one-on-one with students. The input on such judgements is generated by comments and letters from graduate students and our own observations.

C. Judging Excellence in Academic and Cultural Service

There is an important point to be made here. The Mathematics Department does a great deal more teaching than the other departments in the Faculty of Science. For this reason it is quite natural that our academic service contributions tend to be internal to the department and University and are often teaching oriented. Academic service external to the University includes: refereeing for, sitting on editorial boards of, and serving as editor of professional journals; serving on national organizing or governing committees of, or holding office in professional societies; serving on peer review panels; organizing programs at or serving on the governing boards of research institutes.

Because of the centrality of mathematics to primary and secondary education, a large component of our cultural service is comprised of programs with local school systems, designed to enrich their students and faculty. Several such programs specifically target local minority populations. The quality of such programs is often reflected by their recognition through grants and awards.

In mathematics we do not expect extensive service contributions from pretenured faculty, although we do look for journal refereeing activity. We expect pretenured faculty to concentrate principally on teaching and research. However, for promotion to full professor we expect an extensive and productive service record, both external and internal to the University.

Chapter 12
University of Texas at Austin[1]

The Task Force visited the University of Texas at Austin on December 4–5, 1996. Representing the Task Force were Carl Cowen, Douglas Lind, Mort Lowengrub, Don McClure, and Raquel Storti. This report focuses on the Emerging Scholars Program at the UT Mathematics Department, which has been successfully copied at scores of institutions. The report also discusses the department's Actuarial Studies Program, Introduction to Research Lectures for graduate students, and Saturday Morning Math Group for local high school students.

	1995–1997 Average /yr
Students	
Full-Time Undergraduates	31,121
Junior/Senior Majors	335
Master's Degrees Awarded	26
Ph.D. Degrees Awarded	12
Full-Time Graduate Students	104
First-Year Graduate Students	19
Fall Term Course Enrollments	
Below Calculus	2,397 (23%)
First-Year Calculus	4,835 (46%)
Other Undergraduate Courses	3,082 (29%)
All Undergraduate Courses	10,314 (98%)
All Graduate Courses	263 (2%)
Teaching Faculty	
Full-Time Tenured or T-track	65
Full-Time Non-tenure-track	13
Part-Time	10

Emerging Scholars Program

The Emerging Scholars Program (ESP) is a joint project of the Department of Mathematics, the Charles A. Dana Center, and the College of Natural Sciences. It aims to stimulate and assure the success of highly qualified but "at risk" students in freshman calculus. The program's immediate goal is to increase the numbers of women, underrepresented minorities, and rural white males who

[1] Number of full-time undergraduates in table is taken from the National Center for Education Statistics, U.S. Department of Education, Fall Enrollment, 1996. The remaining data is from the AMS-IMS-MAA Annual Survey, 1995, 1996, and 1997. The table reports the average of all available data provided by the department during the three-year period.

excel in calculus. A longer-term goal is to develop minority and women mathematicians and scientists. A distinguishing feature is providing ESP students with a mathematically rich and challenging environment combined with a community life focused on shared intellectual interests and professional goals.

The heart of the ESP lies in the intensive discussion sections attached to a standard calculus course. These sections, limited to 24 students each, meet three times a week for two hours (while students in standard discussion sections of 40 students meet twice a week for one hour). For this extra work an ESP student earns two pass/fail credit hours in addition to the four credit hours all regular calculus students receive. Each ESP section is led by an advanced graduate student together with one or two undergraduates who are ESP alumni. Students work individually or in groups on carefully crafted problems ranging from average difficulty to those designed to stimulate independent thought and group discussion. The Task Force representatives observed one ESP section and participated in the discussions with students. The environment was very lively, and the group interactions were highly effective. For one Task Force member this experience was the most striking and memorable of the entire work of the Task Force.

Students must meet academic standards to be eligible for the ESP. The standards include aptitude gauged by SAT scores and achievement gauged by class rank in high school and performance in previous math courses. Students understand that they will be asked to work more and that they will develop ability to work independently on problems that go beyond routine ones. Students become a part of a peer group of highly motivated and equally capable students. In the friendly, supportive environment of the ESP section, they work together to share insights, learn from each other, and experience using the course material for meaningful problems.

While a small segment of the discussion section may involve presentation of material or concepts related to the regular calculus lectures, the focus of the sections is on group problem solving. Students work in small groups of 4 to 6 solving problems posed by the advanced graduate student associate instructor (AI) on a section "worksheet". The section staff are available for support, and they help guide group discussions, but the students learn to be self-reliant in solving the problems. One of the principal creative tasks of the AI is the careful design of the worksheet to include suitably difficult and interesting problems. The prior training of the AI stresses the importance of this role.

The ESP program began in the fall of 1988, under the leadership of Efraim Armendariz, with one section of 21 students. By the time of the site-visit there were seven sections with a total of about 120 students. The ESP was adapted from the Professional Development Program Mathematics Workshop developed by Uri Treisman at UC Berkeley. In 1991 Treisman was hired by UT Austin, and he brought with him the Charles A. Dana Center. Treisman was named a MacArthur Fellow in 1992 in recognition of his creativity in education.

The ESP has a marginal cost per year of about $120,000 or marginal cost per student of about $1,000. This includes stipends of about $12,000 each for six graduate student teaching assistants, program "overhead" of $30,000 for a coordinator responsible for administration and recruitment, and $20,000 for other costs such as staff training.

The program has compiled detailed and compelling data about its successes in better performance and higher retention rates. For example, since the start of the program ESP students have typically earned grades one-half to one full grade point higher than the class average. These data have convinced the UT administration that the program works and is well worth the costs. We found uniform and enthusiastic support for ESP from the administrators with whom we met.

The Texas Math Building

One of Triesman's key observations was that a primary cause of students' poor performance was academic isolation. The group work in ESP discussion sections counteracts this isolation and helps form social bonds that typically last far beyond the end of the course. Our observation of an ESP section showed that group conversation mixed serious work on the problems at hand with what's happening next weekend, with comparing notes about a physics course, and so on—weaving academic accomplishment into each student's life.

Although ESP students work longer and harder than other calculus students, they respond very well because they feel part of a cooperative effort. Here are some sample comments from students:

"By brainstorming and working together, we figure out what's going on and are able to handle problems from the homework on our own."

"From this program some of us have realized our potential and know that as a whole, we can boost each other's potential."

"I was in Emerging Scholars the first semester, but I decided to leave the second semester because my course was too heavy. After two weeks in the second semester of calculus, I decided to return to the program. I just did not realize what an asset the program was. The extra hours of work allow us to better comprehend the topics introduced in class."

It should be noted that the ESP program's creation of small learning communities helps significantly with problems of transition when moving from high school to a large state university.

A vigorous recruitment effort is run by the ESP coordinator. In the spring prior to matriculation, newly admitted students are screened on the basis of SAT scores, class rank, and previous math achievement. The eligible students are "nominated" for the program and offered an opportunity to participate. The invitation letter stresses the "honors" aspect, the extra work involved, and the higher expectations for level of attainment in the calculus course. The screening effort especially seeks minority students and students from small towns; it also tries to attain some gender balance. Singling out students with letters of invitation works very well: students say they enroll in ESP "because they were asked."

During freshman orientation, all students intending to take calculus are informed about the ESP and the entrance requirements. At this point every eligible student has an opportunity to express his or her interest.

The ESP is selective but not exclusionary. While the program strongly encourages participation of women and underrepresented minority groups, it is open to all students who meet the academic selection criteria. All students who meet the selection criteria and choose to participate are accommodated. At the time of our visit to UT, the program was serving about 120 calculus students out of an estimated 1,500 students in the regular calculus sequence. About two-thirds of the students are African American, Hispanic, or Native American. The rest are white non-Hispanic or of Asian ancestry. About half of the participants are women.

The ESP model is highly adaptable and has been successfully used around the country. See Chapter 13 for a description of full and partial adaptations of ESP at other doctoral institutions. Texas runs training sessions for implementers elsewhere.

ESP is designed not to intrude on the normal calculus instruction, but to be an added enrichment program, so disruption to a department is minimal. However, in the UT mathematics department ESP ideas have spread to many faculty's approach to teaching. In all likelihood, the combined efforts of ESP and the Actuarial Studies Program have led to a large increase in the number of mathematics majors from underrepresented groups. In 1997, for example, the department had 404 majors, of whom 185 (45.7%) were women and 103 (25.4%) were African American or Hispanic (46 in the intersection). Within the University as a whole in 1997, the undergraduate enrollment was 33,800, of whom 16,805 (49.7%) were women and 5,316 (15.7%) were African American or Hispanic.

Actuarial Studies Program

A very small actuarial program was started at the University of Texas in 1913 in the Mathematics Department and moved in 1958 to the Finance Department in the Business School. In 1988 when the Finance Department canceled the actuarial program to focus its resources on mainstream finance, the Texas actuarial community approached the Mathematics Department to take back the program. The department agreed in principle to take on the program, providing one faculty member and one TA to teach full time in the program, while the actuarial community agreed to raise several thousand dollars a year for operating expenses. The first challenge was finding a faculty member to teach actuarial science and run the program.

James Daniel, the chair of the Undergraduate Curriculum Committee at the time and former department chair, was ready for a new challenge and eagerly accepted the responsibility to run the program.

Daniel teaches five or six actuarial science courses, four each year. The rest of the actuarial studies program consists of existing mathematics courses in calculus, probability and statistics, etc., plus selected courses in business, accounting, and finance. Instead of learning just the material needed to teach core courses, Daniel wanted to become deeply knowledgeable about actuarial science. He spent one year of intense study and managed to pass all the actuarial exams required for associate membership in the Society of Actuaries.

The Texas Math Computer Lab

Under his guidance the Texas actuarial program has flourished. It graduates close to 20 students a year, and most quickly have multiple job offers. Daniel is in his office ten hours a day recruiting students, advising them and later helping place them, championing his program among the Texas actuarial community (for good will, internships, and fund raising), working with alums, and more. The Texas actuarial community now contributes over $40,000 in expendable annual gift funds for a mixture of scholarships and operating expenses (e.g., printing and mailing résumé booklets and an alumni newsletter). During 1994–96 the insurance industry raised $300,000 to triple a modest endowment of an actuarial science professorship that Daniel holds; and the university added more than $150,000 in matching funds. Daniel has organized a national caucus of mathematics faculty interested in actuarial science who meet regularly at annual AMS/MAA national meetings.

Introduction to Research

The department sponsors a special series of outside speakers each year, primarily intended to introduce graduate students in their first two years to different areas of research. At the time of the site-visit, this program, called “Introduction to Research”. had been running for three years. The focused speaker program was started by Dan Freed and John Luecke and was funded initially through matching funds associated with NSF PYI awards.

Approximately six scientists participate each year. A committee of postdoctoral fellows, in consultation with graduate students, carefully picks the speakers based on their ability to inspire and motivate. The introductory intention of this program is made clear to invitees, as well as the expectation that they interact in a number of informal ways with graduate students during their stay. This organizational activity is regarded as part of the professional training of the postdocs. The postdocs we spoke with had a valuable sense of ownership of this program and clearly worked hard to make it a success.

Speakers have responded to the goal of the special speaker program, and attendance at the talks is high, usually more than a hundred people. The department has made a six-year commitment to support this program, at a level of about $6,000 per year from departmental discretionary funds.

Saturday Morning Math Group

At least once a month, Austin-area high school students are invited to the UT campus for a half-day program of talks and math activities guided by faculty and graduate students. The program is an outgrowth of an NSF-funded Regional Geometry Institute. Initially organized and funded by Dan Freed and Karen Uhlenbeck, the program is now supported by the Department of Mathematics. The graduate-student coordinator is responsible for identifying a topic and principal speaker, usually a local faculty member, and for developing activities and materials which engage the high school students in exploration and discovery. Attendance at sessions has grown steadily and now averages well above 100 students per session. In addition to providing inspiration and support to some of the brightest high school students in the area, the Saturday morning programs also serve to promote contacts with local high school teachers, even to the point of pulling them in to working in the teacher preparation summer programs.

Chapter 13
Examples of Successful Practices

Service Courses in the First Two Years

These courses, among which we include calculus, generate over 80 percent of the enrollments at most research mathematics departments. As discussed extensively in Part I of this book, high-quality, innovative instruction in these courses is a critical part to any plan to seek increased resources for mathematics.

The Task Force has learned about a variety of new approaches to teaching calculus. The calculus reform movement has, in combination with other factors such as cheaper, more powerful technology, had a major influence on virtually all calculus texts. A 1995 NSF-sponsored survey found that three-quarters of all doctoral mathematics departments were engaged in modest or major calculus reform. The survey documented that most “reform” calculus courses at universities were using traditional texts supplemented in recitations and labs by reform activities, such as cooperative learning and computer-based experiments. There are a dozen volumes in the MAA Notes series devoted to new technology, pedagogy, and instruction associated with calculus, e.g., MAA Notes #30, *Problems for Student Investigation.* Dozens more are available from commercial publishers. The use of technology, especially graphing calculators, in calculus instruction is now widespread; graphing calculators have been required for several years in one part of the AP Calculus exam (another part of the exam forbids them). There is now a fairly continuous range (not partially ordered) of approaches to teaching calculus.

The new approaches generally require more faculty time, but as Tennessee mathematics chair John Conway put it: Not to pay enough attention to the way calculus is taught is probably asking for trouble. The MAA Notes #39, *Calculus: The Dynamics of Change*, has a careful analysis of the additional faculty effort, resources, and other costs associated with new approaches to calculus instruction.

Nearly everyone believes that small classes are better suited than large lectures to such active learning, but to get the resources for small classes requires creative approaches by mathematics departments. The site-visit report on Michigan describes how that department turned an innovative, small-class approach to calculus instruction, which Michigan called New Wave calculus, into a vehicle for obtaining a large number of new junior faculty positions. The site-visit to Arizona documented a very different approach to keeping the size of introductory mathematics courses manageable—the use of large numbers of highly effective (non-Ph.D.) adjunct faculty. Coupled with leadership in calculus reform, the smaller class sizes have earned a very good reputation for mathematics instruction and for the mathematics department at the University of Arizona. Another good example is found at nearby Arizona State University.

Arizona State University

In the early 1990s the ASU administration identified college algebra, along with a few other courses, as a major source of discontent for students enrolled in freshman courses. After constructive discussions involving virtually all interested parties, the University and the department decided to commit substantial new resources for the establishment of a "First Year Mathematics" program within the Department of Mathematics. All courses within this program are taught in small sections using a very interactive format. Curricula were revised to reflect modern realities, and technology was integrated into almost all courses. Marilyn Carlson, a mathematics education Ph.D. from Kansas, was hired as the director of this program, and nearly thirty new lecturer positions were created. These faculty members, who typically hold three-year renewable contracts, "run" the entire FYM program in a closely coordinated manner despite huge numbers of sections in some courses—in some over 60 sections. The changes have led to dramatic improvements in grades and passing rates, including those in subsequent courses, as well as improved freshmen retention and improved general satisfaction with ASU's instructional programs in the entire community. In 1998 the FYM faculty won the coveted Governor's Award for Excellence.

It is important to note that at the same time the FYM program was being developed, the ASU mathematics department was also getting new tenure-track faculty to help advance the University's research agenda of becoming a Carnegie Research I institution, a goal achieved in 1994. The department and university leadership recognized the need to balance scholarship and instruction, and they allocated adequate resources for both.

The success of these innovations relied on proper recognition in terms of tenure and promotion, and also in salary increases. According to the department chair Rosemary Renaut, it was absolutely critical that faculty involved in instructional innovations knew that their involvement would be recognized and rewarded. The benefit to the department of its attention to its service role has been the creation of a significantly improved climate in which to request and receive new resources, whether in the form of new faculty positions or equipment for the research programs.

One method to enrich calculus instruction is with technology. Many mathematics departments have experimented with Maple or Mathematica-based calculus reform courses as an alternative to the mainstream calculus courses. The Mathematical Sciences Department at RPI (Rensselaer Polytechnic Institute) obtained a very large institutional investment in technology for its calculus course. However, there were questions about how to use this technology effectively. The concept of a studio classroom brought pedagogical changes to match the new technology in calculus. Subsequent to mathematics' use of this approach, the studio classroom became a rallying point for educational innovation across the RPI campus. Lecture, recitation, and laboratory are integrated into a single-classroom teaching style. The course TA is in the class helping the professor work with groups of students. The laboratory component involves sophisticated interactive, multimedia simulations of various physical phenomena. Students have their own laptops to enable them to take the simulations and computer algebra systems back to the dorms with them.

Precalculus reform efforts are starting to yield texts that face the difficult task of being interesting while developing skills in algebra, trigonometry, and analytic geometry needed in calculus. The title "precalculus" is a bit of a misnomer, for studies show that about one student in seven who enrolls in precalculus will successfully complete a semester of calculus. Almost twenty years ago Dartmouth started a widely copied trend of incorporating precalculus material into the first semester of calculus. The resulting precalculus/calculus course is typically two semesters long. With publishers now able to produce customized texts with chapters from precalculus and calculus texts, such combined courses are becoming easier to design.

Several innovative textbooks developed over the past dozen years have given new life to general education courses in mathematics. A number of mathematics departments have successful general education courses, in the eyes of faculty and students, using the CoMAP text *For All Practical Purposes* (also a PBS telecourse).

One of the frequent complaints by faculty is that students are inadequately prepared for freshman-level mathematics. The University of Arizona uses a novel approach to supplement placement exams. Fifteen percent of the grade in some UA freshman mathematics courses is based on a test at the end of the first week of the course that covers the prerequisites for the course. Students who do poorly have time to transfer to a lower-level mathematics course. To prepare students for these tests, admitted students are sent computer disks over the summer with samples of the placement and first-week tests along with a tutorial for learning this material.

Many mathematics departments have developed highly effective resource or learning centers to help students get more personal assistance to complement large lectures and formal problem-solving recitations. The Oklahoma State site-visit discusses their very successful resource center, which is supported by a fee paid by all students in lower-division courses. The Michigan site-visit discusses the critical role of the Michigan Math Laboratory for mathematics majors as well as students in lower-division mathematics classes. Following is a description of the mathematics learning center at Virginia Tech, which has substantially extended the services normally associated with such centers.

Virginia Tech

Recently, the provost at Virginia Tech has been touting to other provosts the exciting Mathematics Emporium that was created at his institution. That sort of publicity is rare for mathematics instruction. The Emporium, opened in fall 1997, is located in a formerly empty building near the Virginia Tech campus. It is open 24 hours a day, seven days a week. Faculty, assisted by a large number of graduate students and undergraduates, are present 14 hours a day for help. There are 500 computers grouped attractively in study pods of six. There is 24-hour technical help with the computers. At the pods and elsewhere in the Emporium much of the space is laid out to facilitate students working in groups. Other areas are designed for individual study.

The idea of teaching math in a computer-enhanced environment got its start in the spring of 1993 when the mathematics department began using Mathematica in two of its first-year calculus courses. With nearly 2,000 students taking the new classes each semester, convincing assessments were possible that showed that students in the new Information Technology (IT) initiative had final grades that were half a grade higher than those of students in traditional courses (both groups of students had a common final exam). Later assessments showed that IT students taking other mathematics or engineering courses were doing better than students who had been in traditional math classes.

"By the spring of 1995, other colleges were encouraging the department to bring all its lower-level courses into the stream of technological change," mathematics chair Robert Olin recalled. The faculty changed the precalculus course, with similar positive results. As the department continued to reform its lower-level courses technologically, the concept of the Mathematics Emporium was born.

The computers give students extensive diagnostic quizzes, electronic hyperlinked textbooks, and interactive, self-paced tutorials. All the software at the Mathematics Emporium can also be accessed over the Internet. The risk for alienation of students through computer-driven instruction is turned instead into an opportunity to spot and correct problems before they become critical. The instant feedback that computers can give maintains students' attention much better than do homework assignments that are returned days after they were done.

The Emporium environment for learning basic course skills enabled the department to redesign the traditional classroom component of some courses. In one mathematics course, classes are now grouped by major field, and more time is dedicated to showing examples connected to individual interests. Many introductory courses have course testing done in the Emporium, freeing up valuable class time. Moreover, the Emporium setup allows professors to give tests in multiple versions that students can take when they are ready. In some cases, tests can be taken more than once, in the spirit of the Keller plan (popular in the 1970s).

Interested readers can consult the Virginia Tech Mathematics Emporium's home page at http://www.emporium.vt.edu.

Successful Undergraduate Mathematics Majors

The major challenge for most mathematics departments is attracting significant numbers of students to major in mathematics. Unfortunately, the broad appeal of mathematics of the 1960s is gone, when 5 percent of entering freshmen wanted to be mathematics majors and the mathematics department could set high standards to wean the percentage down to about 2 percent. For almost three decades, less than 1 percent of entering freshmen have expressed an interest in majoring in mathematics. Several mathematics departments have successfully countered this trend by broadening the constituency for the mathematics major with alternatives to the standard mathematics major. However, a few schools, most notably the University of Chicago, have continued to be very successful with a major program geared towards preparing students for graduate study in mathematics. Among Group I mathematics departments, Chicago has the highest percentage of graduates majoring in mathematics. In addition, Chicago has the most students going on to doctoral study in mathematics—about 50 percent of their math majors. See Chapter 10 for further information.

Inclusive mathematics major programs tend to be among the most successful in getting more majors to go to graduate school in pure mathematics than programs focused on that outcome. The inclusive programs draw in more students, many of whom are not initially thinking about graduate study. This increased number of students allows for more elective courses and generates a critical mass of enthusiastic mathematics majors on campus who make math an “in” major.

Here are profiles of three successful mathematics majors that are highly inclusive.

UCLA

For many years, the UCLA mathematics department has graduated the most mathematics majors of any U.S. university. About 175 of UCLA’s 5,000 undergraduate degrees are awarded in mathematics. The department has an inclusive research tradition with very strong applied mathematics. The undergraduate program reflects that inclusive tradition with a variety of options. The graduate-study-oriented “pure mathematics” track attracts 10 percent of the majors and is like such mathematics majors at other institutions. About 25 percent of the majors are in tracks in mathematics of computation and in physical science-oriented applied mathematics, both of which are quite rigorous. The largest track, with 50 percent of the majors, is the applied science track, which has five options. It is geared to students seeking employment in business or industry after completing their undergraduate studies, although a number get an advanced degree sooner or later. Most students in the mathematics/applied science track select a decision science option: management, operations research, or actuarial science. Other tracks are preservice school mathematics teaching preparation and a joint mathematics/economics major.

The inclusiveness of the department is reflected with impressive demographics: 25 percent of the UCLA’s mathematics majors are non-Asian minority students.

The department has a tradition of being a friendly place where faculty and students socialize together. To make the department a friendly place for undergraduates, it employs two enthusiastic former UCLA mathematics majors whose job is to advise undergraduates (one spends half-time managing the UCLA Mathematics and Science Scholars Program). Faculty feel these advisors are critical to the department’s positive reputation among undergraduates and its large number of mathematics majors.

There are three active support groups for mathematics majors. The most important is the Undergraduate Mathematics Student Organization, which promotes:

- Academic awareness of the mathematics major
- Better student-faculty relations
- Information on career opportunities in mathematics
- A peer network for mathematics majors

Each year the UMSO runs résumé workshops, interviewing skills workshops, several career workshops and panel discussions, as well as a T-shirt contest and faculty dinners.

Bruins for Mathematics is a departmental alumni organization that provides alumni support and professional contacts for students. The UCLA Actuarial Club is for students who have an interest in the actuarial profession, and sponsors informational talks by local actuaries. The department provides review sessions to prepare undergraduate students for the first two actuarial examinations.

Vanderbilt University

The Vanderbilt mathematics department has a major that attracts a broad clientele, including many preprofessional students (premed, prelaw, and pre-MBA). A sizable number of math majors pursue a second major as well; mathematics and economics is the most popular combination. After calculus, linear algebra, and differential equations, the major may be completed with five additional courses, giving the student a minimum total of 32 hours. No additional restrictions are put on the choice of courses. Students planning advanced study in mathematics typically take much more than 32 credits and usually take several graduate courses.

Mathematics is very popular as a second major among engineering students, who typically need just four additional courses beyond those required for their B.E. degree. Applied math and statistics are the subject areas that engineers usually pursue. Including double majors, Vanderbilt has the highest percentage of its bachelor's degrees awarded to mathematics majors of any U.S. doctoral university.

The Vanderbilt program attracts substantial numbers of students, engineers and nonengineers alike to take more mathematics than they normally would. One pedagogical consequence is that the teaching opportunities for the faculty are diversified, and there is not the heavy concentration of calculus and precalculus service teaching found in most mathematics programs. Students have obviously benefited by having a stronger background and better credentials for doing graduate work or attracting more lucrative job offers.

In short, this is a program very much in tune with the liberal arts philosophy espoused by many leading private universities. Its flexibility allows and encourages students to pursue mathematics at a level and depth consistent with their career objectives.

SUNY-Stony Brook

The Stony Brook applied mathematics department offers a popular major that has much in common with both the UCLA and Vanderbilt models. Its B.S. major requires 42 credits of mathematics (and 17 credits in related departments). The major is oriented towards the “decision science” side of applied mathematics and has little emphasis on proofs. Its electives are almost all in probability/statistics or operations research.

The special strength of the Stony Brook applied mathematics program is attracting students who were good in mathematics in high school but were advised by guidance counselors to major in engineering or computer science for career purposes. Many of these students grow disenchanted with these majors and eventually turn to applied mathematics or develop a double major with applied mathematics. While only a handful of entering students express an interest in applied mathematics, about 100 of Stony Brook’s 2,200 bachelor’s graduates are applied mathematics majors; about half are double majors. There are also about 40 Stony Brook (pure) mathematics majors graduated each year.

There are three components of Stony Brook’s success that may be applicable at other institutions. The first is curricular. The focus of the major is decision sciences oriented mathematics. Recall that the most popular option in the UCLA mathematics major is the decision science track. Many mathematics departments equate applied mathematics with topics like differential equations. Businesses today are making extensive use of statistics, operations research, and game theory to solve their problems, and generally they value people with training in these areas for positions in finance and management. Scores of Stony Brook economics majors add applied mathematics as a second major because of the strong reputation of this double major for getting into good MBA programs.

The second component of Stony Brook’s success is that the applied mathematics department has very good relations with other departments through joint research and educational collaborations. There are a number of cross-listed courses and faculty with adjunct appointments in applied mathematics. This has resulted in higher-than-average mathematics requirements for other majors. For example, a computer science major who wants to switch in the junior year to applied mathematics or add it as a second major needs only five additional courses, because the CS major already requires five mathematics courses and two mathematically oriented CS courses can also be counted towards the applied mathematics major.

Finally, the department identified its two beginning junior-level courses in discrete methods and probability/statistics as key courses. Majors in computer science and engineering are required or encouraged to take these courses, which each enroll over 300 students a year. The department staffs the two courses with its best teachers and shapes their syllabi to make further study in applied mathematics look as appealing as possible.

Many successful undergraduate programs at research universities have a key person or small group who has devoted a huge amount of effort for many years to make the program succeed. At Chicago, Paul Sally and Diane Hermann have played this role for the undergraduate program. For a special component of the undergraduate program, strong leadership is absolutely essential. The University of Texas’s actuarial program discussed in Chapter 12 provides a good example.

It should be noted that the attractive professional careers available to actuaries can provide an excellent basis for recruiting students into mathematics. The mathematics department at small Lebanon Valley College in eastern Pennsylvania regularly gets 10 percent of the freshman class planning on a major in actuarial science or mathematics (the national average is below 1 percent) by focusing on actuarial careers in school visits and publicity materials. While most students concerned about careers enter with actuarial plans, the majority later switch to a mathematics major.

Some of the common features of highly effective undergraduate mathematics programs that were studied in the MAA study “Models That Work: Case Studies in Effective Undergraduate Mathematics Programs” are:

- Faculty take a very personal approach to their classes, even in multisection courses
- Faculty set high expectations for students and then help them meet these expectations
- The faculty are not satisfied with the current program, no matter how successful it may be
- Placement exams are very important

St. Olaf College has an interesting way to promote the inclusive nature of its major. It has a “contract major”, in which the requirements of a student’s major program in mathematics are carefully thought out by a student with a faculty advisor. The negotiation of the “contract” might involve, for example, a student wanting to take an applied curriculum with virtually no proof-oriented courses beyond linear algebra, and the professor arguing for adding, say, analysis and abstract algebra; sometimes the roles are reversed, with the professor pressing for some breadth in the mathematical sciences. While individually negotiated, in reality almost all the contracts tend to follow one of three general curricula, emphasizing pure mathematics, computer science, or applied mathematics.

The approach Mt. Holyoke College has taken to inclusiveness is also worth noting. It has extended the Michigan strategy of freshman alternative entries to the standard calculus sequence. Students can start the mathematics major with one of two general education seminars—one in geometry and one in number theory (taking calculus in the junior year)—as well as a traditional or very reform version of calculus. Then all students are funneled into a sophomore Laboratory in Mathematics Experimentation, in which students explore six pure and applied open-ended problems and write 10-page papers about them. After the laboratory course, students branch out. There are some traditional courses in analysis, algebra, and geometry. Along with some traditional courses, the department also has developed topics courses with minimal prerequisites, for example, a course in knot theory and a course on Lie groups (the latter has Calculus I and linear algebra as its prerequisites).

Programs for Underrepresented Groups in Mathematics

There are two groups that historically have been underrepresented in undergraduate mathematics classes and in careers that require strong mathematical skills—women and non-Asian minorities. A number of years ago the phrase "math anxiety" was coined to refer to the learning problems, largely nonacademic, that women bring with them into mathematics classes. For a long time the problems that non-Asian minorities had with mathematics were thought to be mostly academic, that is, poor K–12 preparation to do college-level mathematics, and were addressed through special remedial programs. Then the thinking about minorities' problems started to consider other factors. This rethinking was accelerated by Uri Treisman's successful Professional Development Program (PDP) for minorities at UC-Berkeley, which achieved remarkable successes by setting high standards and emphasizing collaborative learning and group study habits.

Introductory Mathematics Courses

Numerous studies have shown that mathematics has proven to be a major barrier to increasing the number of (non-Asian) minorities and women in S.M.E. (science, mathematics, and engineering) majors. In this section we present information about some special programs, similar to Treisman's PDP program, that help women and minorities succeed in freshman mathematics courses. While there are more programs focused just on minorities, the University of Texas ESP program mentioned below and many other programs modeled on ESP target minorities and women as well as students from rural or inner-city schools.

Many of the new pedagogical approaches to teaching calculus and other introductory mathematics, such as cooperative learning, extensive writing, and open-ended projects, have been shown, in the words of Sheila Tobias, to "disproportionately benefit" groups underrepresented in mathematics. The study "Talk about Leaving", which is summarized in Chapter 22, states that "... switchers and non-switchers [out of S.M.E.] were almost unanimous in their view that no set of problems in S.M.E. majors was more in need of urgent, radical improvement than faculty pedagogy." In sum, efforts to help women and minorities succeed in mathematics are closely connected to efforts to provide high-quality mathematics instruction and to attract more students to enjoy and effectively learn mathematics.

The University of Texas Emerging Scholars Program

The following is a summary of the Texas Emerging Scholars Program (ESP). It is discussed in considerable detail in Chapter 12. The heart of ESP consists of intensive workshop sections that are supplementary to standard calculus courses. Each ESP section is led by an advanced graduate student with the assistance of two undergraduate ESP alumni. The main activity of a section is for students to work in small groups of 4 to 6 solving specially designed, challenging problems. These learning communities help ease the transition for the students from high school to a large university in all their studies. The section staff are available for support, and they help guide group discussions, but the students learn to be self-reliant in solving the problems.

The results have been impressive: ESP students have typically earned grades one half to one full grade point higher than the average of their mathematics class. Dropout rates for students in the ESP program are very low. ESP serves about 120 students at a cost of about $120,000 per year. While ESP strongly encourages participation of women and underrepresented minority groups, it is open to all students who meet the academic selection criteria and are willing to do the extra work.

The ESP program has been copied successfully at scores of institutions. Texas runs a training program on leading ESP workshops for faculty and graduate students from other institutions. For example, the University of Kentucky's MathExcel Program uses Texas's structure of three 2-hour workshops per week (instead of the regular two 1-hour recitations) and targets the same set of students. MathExcel continues into the second year with special sections of Calculus III and Calculus IV, but these do not entail extra class time. MathExcel workshop leaders are sent to the Texas training program. There are about 60 students in the Kentucky program, and the cost of the extra TAs and their training is about $33,000 a year, or about $500 per student per year. The results of Kentucky's MathExcel program have mirrored the successes at Texas in higher grades and improved retention. Since a number of other universities have also had very positive results with programs modeled on ESP, all mathematics departments should give serious consideration to starting similar programs.

The UCLA Mathematics and Science Scholars Program

The UCLA Mathematics and Science Scholars Program, abbreviated MS^2, was begun in 1992 by Professors Phil Curtis and Mark Green and Undergraduate Advisor Linda Johnson. It is a two-year intensive honors program that stresses academic excellence and professional development in mathematics, physics and chemistry. It was modeled on some other programs, especially the Uri Treisman program at Berkeley and the Texas ESP Program. The MS^2 program has three components:

PRISM (Pre-instruction in Science and Mathematics) is a two-week bridge program that takes place in the summer before the first quarter at UCLA. The students attend daily lectures in mathematics and chemistry and take field trips to nearby industrial sites to see how science is used in the "real world". PRISM students get free room and board on campus and an opportunity to meet other students with common intellectual interests before the school year begins.

EXCEL workshops (Excellence through Collaboration for Efficient Learners) are mathematics, physics, and chemistry workshops for freshmen and sophomores. Excel workshops are very similar to the ESP workshops, except that UCLA students receive no additional academic credit for the workshops and attend an ordinary one hour TA section or laboratory for each course as well as the four-hour-per-week workshop.

Mathematics 98 is a four-unit honors course taken during the first quarter at UCLA. Here students engage in research projects with a faculty sponsor and have weekly seminars by faculty explaining current research in science or by guest speakers who introduce students to the various careers available for mathematics and science majors. In addition, MS^2 students receive intensive academic counseling by the MS^2 director, priority enrollment in classes, individual tutoring, and a sense of community begun in the PRISM summer program and maintained throughout the year with several small social events.

Each year the program admits 50 freshmen (a total of 100 over two years) who are carefully selected by the director and a departmental committee for their ability, motivation and interest in mathematics and science. Through 1997 MS^2 admitted only minority or low-income students, but since 1998 the program has been open to all. MS^2 costs $1,000 per student, or $100,000 per year. It is funded by the chancellor, the dean of physical sciences, and the minority-oriented Academic Advancement Program of the Letters and Science College, and the Department of Mathematics ($30,000 of the total). The cost breakdown is PRISM $23,000, EXCEL $59,000, and Director $18,000. The director, a former UCLA mathematics major, devotes half her time to MS^2 and half her time as an undergraduate advisor in mathematics.

The MS^2 program is very successful in mathematics: MS^2 students who actively attend the Excel workshops get much higher grades, generally one half to one full grade point above the class. Curiously, the workshops have little effect on grades in chemistry or physics.

Mathematics Majors

Further along the pipeline, special attention is needed to increase the number of women and minorities majoring in S.M.E. disciplines and continuing on for graduate study. The successful mathematics majors, which are seen by students as welcoming and inclusive, have higher percentages of women and minorities than the typical mathematics major at a doctoral mathematics department (e.g., at Stony Brook, 18 percent are non-Asian minorities). UCLA's MS^2 program is not intended to recruit majors, just help students in lower-division mathematics and science courses, but over 60 percent of its students major in mathematics or science. The result of MS^2 combined with other strengths of UCLA is that 25 percent of UCLA mathematics majors are (non-Asian) minority students.

A successful program for minority mathematics majors at UC-Davis is described below. Many universities have some type of "Women in Science and Engineering" effort to attract more women into S.M.E. majors. We note that the University of Nebraska mathematics department's efforts to increase participation of women and minorities in mathematics were honored at the White House in fall 1998 with a Presidential Award for Excellence in Science, Mathematics, and Engineering Mentoring.

UC-Davis Minority Undergraduate Research Participation in the Physical and Mathematical Sciences (MURPPS).

MURPPS is a mentoring program designed to increase the number of women and minority students who obtain bachelor's degrees and pursue graduate work in the physical sciences and mathematics. It is sponsored jointly by the NSF, private foundations, and industry. It is directed by Emeritus Professor Henry Alder of the Davis mathematics department.

In MURPPS the emphasis is on individual research by a student paired one-on-one with an individual faculty mentor. Students receive a $600-per-quarter stipend, for which they are expected to spend ten hours a week working on a research project agreed upon by the student and the mentor and to participate in the Mathematical and Physical Sciences Seminar, which meets two hours a week for two quarters of the freshman year. In addition, MURPPS students may apply for a summer research internship, which pays $2,000 plus room and board. MURPPS participants present their research results every April at the UC-Davis Annual Undergraduate Research Conference.

MURPPS students are chosen from non-Asian minority and women students who are U.S. citizens or permanent residents. The students are expected to maintain a grade point average consistent with the admission requirements for graduate school and to have a satisfactory performance evaluation from their research mentor. In fall 1998 MURPPS had 29 students, including 10 freshmen.

Graduate Study in Mathematics

Finally, those minority and female students who enter graduate school in mathematics face major hurdles; too many leave without a Ph.D. There are often too few of them, there are few role models among the faculty to turn to for support, and, especially for minority students, their preparation is often below average. Along with having an overall friendly atmosphere in the mathematics department, most successful efforts for women and minorities at doctoral mathematics departments involve a committed faculty member, often a minority member. For example, Richard Tapia's great success in mentoring Mexican-American and Hispanic-American doctoral students at Rice has been recognized with a Presidential Award for Excellence in Science, Mathematics, and Engineering Mentoring (he was also featured in a PBS program two years ago). Nancy Kopell has been very successful in mentoring female graduate students at Boston University, 35 percent of whose graduate students are women. The success of such programs breeds future success, as prospective graduate students from underrepresented groups who visit the department see a welcoming environment with a critical mass of women or minority students.

University of Maryland

In trying to understand the causes for the high dropout rate among minority students at the University of Maryland, Raymond Johnson talked to faculty at Historically Black institutions. He identified another factor: that in graduate school the Black students missed the support network that other students had learned to build up as undergraduates. Johnson took it upon himself to sustain these students until they could build these networks, and organized small informal gatherings so that entering students could meet each other and more advanced students. (It should also be noted that the University of Maryland grants financial aid to students who display potential but who need to take some undergraduate courses in their first year.) The result has been striking. Of the twenty African-American graduate students with whom Johnson has worked, two have their Ph.D. degree, five have been admitted to candidacy, and five more are expected to pass their candidacy exams within one year. Another three or four have master's degrees, and some of these are pursuing doctoral degrees in other disciplines.

NSF's new Graduate Minority Education (GME) initiative for minority students in S.M.E. disciplines provides an opportunity for a doctoral mathematics department to collaborate with other S.M.E. departments at their institution for federal assistance in starting new programs to attract and retain more minority graduate students.

Broadening Graduate Education and Professional Development

One of the concerns voiced in several national studies of U.S. graduate education in the sciences and mathematics is that while doctoral students are excellently prepared to undertake research, they have minimal formal training in teaching. However, the vast majority of faculty positions are at colleges and comprehensive universities where quality instruction is the highest priority in the institution's mission. The Pew Foundation initiative, Preparing Future Faculty (PFF), has supported efforts to better prepare future professors for teaching and other aspects of their professional life in typical collegiate departments. To convey the importance and attraction of a rich professional life beyond the confines of the traditional research-intensive department, the University of Washington PFF program was linked with Seattle University, a medium-sized private institution, and Seattle Central Community College, nationally known for its innovative mathematics programs. As one of the PFF activities, selected UW graduate students are mentored for a quarter by individual faculty at a partner institution, typically meeting with mentors at least once a week on a project mutually agreed to. The Cornell PFF program is discussed in the following vignette.

Cornell University

The Preparing Future Faculty program in mathematics at Cornell has four general components. The first is an outreach effort to liberal art colleges. The primary vehicle is a program in which graduate students present lively mathematical talks to mathematics clubs and faculty at nearby colleges on, for example, topology and DNA. Graduate students also have informal discussions with students about what it is like to be a graduate student in mathematics. In return, during conversations with the faculty, say, over lunch, the graduate students learn about the life in a mathematics department in a liberal arts college. Another aspect of this outreach has graduate students going to regional meetings of the Mathematical Association of America to give talks to collegiate audiences, speak with undergraduates considering graduate study in mathematics, and interact with college mathematics faculty.

The second component brings college faculty to Cornell for job fairs. At the fairs, these faculty discuss the job market, requirements for tenure at their institutions, preparing CV's and cover letters, what they look for in letters of recommendation, teaching portfolios, and the like.

The third component involves instructional innovation. One year, faculty from Ithaca College presented talks about their NSF-funded calculus reform effort that involved student projects. The following year a group of Cornell graduate students took the initiative, with encouragement of Cornell faculty, to develop and teach their version of a reform calculus course with projects.

The fourth component involves a course in college teaching, which covers topics such as constructing course syllabi, cheating, handling obnoxious students, alternatives to lecturing, peer review, student mentoring, and the organizational structures of universities and colleges.

There has been growing interest in graduate training for something other than original research in mathematics. With the increasing use of quantitative methods on Wall Street, a few mathematics departments have started a financial mathematics master's program (a larger number of financial engineering M.S. programs have been started in engineering schools). Not surprisingly, NYU, two miles from Wall Street, recently started such a program. In this two-year M.S. program, students with a background in undergraduate mathematics take courses and seminars taught by Courant faculty and by investment bankers from the area. Those with a particular interest in computation may enter the scientific computing program, with a specialization in computational finance. The financial mathematics program at the University of Chicago is discussed in Chapter 10.

Industrial mathematics is another area of growing interest. The first and only Ph.D. program in this area is at the University of Minnesota. It was developed by Avner Friedman, director for the Institute for Mathematics and its Applications.

University of Minnesota

The Minnesota School of Mathematics offers M.S. and Ph.D. degrees in an industrial mathematics program. These are coordinated by the Minnesota Center for Industrial Mathematics, which is a center within the School of Mathematics. Ph.D. students in the program do a yearlong internship at an industrial research laboratory. M.S. students do a three-month summer internship. During the internship students develop a research topic leading to a Ph.D. or master's thesis. The MCIM's contacts with industry laboratories enables it to find suitable internship projects, chosen for their mathematical content. Participating companies include 3M, Bellcore, Honeywell, LORAM, Lucent, Ford, GM, Motorola, Deluxe Corporation, Lockheed-Martin, Computing Devices International, Medtronic, and Schlumberger. The students in the program have both a faculty advisor and an industry mentor. A university engineering laboratory can sometimes be substituted for an industry laboratory. Students' progress is closely monitored, and career development advice is provided. Graduates with master's degrees are often employed in industry, and Ph.D. graduates are well equipped for employment in both industry and academia. For more information go to

http://www.math.umn.edu/grad/.

Interdisciplinary Education and Research

The NSF initiative, Mathematical Sciences and Their Applications throughout the Curriculum, has given large grants to seven consortia to promote significant improvements in undergraduate education leading to increased student appreciation of and ability to use mathematics. NSF hopes that these projects will be models for better integrating mathematics into other disciplines, as well as for improving instruction in the mathematical sciences by incorporating other disciplinary perspectives. New courses, modules, software, and electronic materials are being developed by consortia centered at Dartmouth, Indiana, Nebraska/Oklahoma State, Pennsylvania, and West Point. The RPI consortium, Project Links, is developing a library of interactive multimedia learning modules integrating mathematical concepts with applications in science and engineering. The Stony Brook consortium is trying to achieve a broad, systemic change in quantitative instruction through diverse grassroots efforts by hundreds of faculty.

It is common in the sciences and engineering to see majors and graduate programs in new interdisciplinary fields develop, such as bioengineering and behavioral neurobiology. It is less common in the mathematical sciences. It is, however, common to see dual majors involving mathematics. Brown University makes a specialty of such majors, while the University of Washington provides an example of a truly interdisciplinary mathematical sciences major.

Brown University

Brown consciously promotes interdisciplinary education and research as mechanisms for effective utilization of small departments in a relatively small university. There are virtually no barriers to interdisciplinary and interdepartmental activities, and there is much encouragement.

At the undergraduate level, both the Department of Mathematics and the Division of Applied Mathematics offer a wide variety of interdepartmental concentrations (majors). Current standard concentrations include: mathematics-computer science, mathematics-economics, mathematics-physics, applied math-biology, applied math-computer science, applied math-economics (A.B. or Sc.B.), and applied math-psychology. The list of offerings has evolved over the last thirty years since Brown adopted its so-called “new curriculum”. Obsolete programs go away, and occasionally a new program is started. Usually the catalyst for proposing a new interdepartmental program is student interest voiced in the new program. Some of these programs are small and geared to preparation for advanced study. Others are large (mathematics-economics and applied math-economics) and have gained a reputation as excellent preparation for careers in business.

University of Washington

At the University of Washington, the Departments of Applied Mathematics, Mathematics, Statistics, and Computer Science recently worked together to create a new interdisciplinary undergraduate degree program. The result is called the Applied and Computational Mathematical Sciences (ACMS) degree program.

The aim of the ACMS program is to provide a solid foundation in both applied and computational mathematical science with areas of application. A core set of courses in the basic tools common to many disciplines is followed by a broad set of pathways to suit different interests, such as statistics or mathematical biology. Flexibility in the requirements allows students with specific interests in another area to pursue a double major, such as ACMS and economics. The program seeks to prepare its students to pursue a variety of positions in industry after graduation or to go on to graduate or professional school in many fields. The

ACMS program builds on the strengths of existing departments and programs while presenting new opportunities for students. The interdepartmental aspect of the ACMS program stresses the unity of the mathematical sciences and provides a balanced education with a firm foundation in all aspects of applied and computational mathematics while also encouraging an in-depth study in some particular direction.

This new interdisciplinary major replaces the most popular current major within the mathematics department. Although it should attract additional students, one consequence may well be a decline in nominal total count of majors within the department. But the department felt that the value of ACMS and the connections with other departments far outweighed concerns about this decline. This cooperative attitude has already borne fruit. The participating departments used the ACMS program as the foundation for a joint proposal to the NSF VIGRE program. The "horizontal" as well as "vertical" integration of undergraduate, graduate, and postdoctoral training using ACMS as a core organizing principle was one very attractive aspect of the proposal, and it was one of six funded in the first round.

It is common for applied mathematics groups, either within a mathematics department or as a separate department, to have some interdisciplinary collaborations. Along with traditional applications of mathematics in the physical sciences, many new opportunities are developing in the biomedical sciences. NYU's Courant Institute is a leader in this area. Although Charles Peskin's models of the heart have garnered much publicity (and a MacArthur Fellowship), there are many other Courant faculty with biomedical interests, including one professor with a joint appointment with biology. The University of Southern California has a major multidisciplinary Center for Computational and Structural Genetics led by mathematician Alan Waterman. At Brown a research/graduate training initiative in applied mathematics, computer science, cognitive sciences and neuroscience has been awarded significant funding for graduate student support through the IGERT program at NSF and through the Burroughs Wellcome Fund. The cooperation among Ph.D. programs in this area is truly interdisciplinary, providing students in biological neuroscience, for example, with much broader preparation in mathematics and providing students in applied mathematics with opportunities for research on problems of theoretical neuroscience or cognitive processes (e.g., vision and speech understanding). Another collaboration among mathematicians, physicists, and biological/medical scientists at the University of Arizona led to the Biology, Mathematics and Physics Initiative, an IGERT-funded graduate program providing training opportunities in areas such as biomedical engineering, ecology and evolutionary biology, molecular biology, radiology, and neuroscience (funding was also supplied by the Finn Foundation).

Large multidisciplinary centers are starting to involve mathematics. Perhaps the best example is the NSF Science and Technology Center at Rutgers, known as DIMACS, that specializes in discrete mathematics and computer algorithms. The University of Arizona's Program in Applied Mathematics, building on Arizona's strength in optical sciences, formed the Arizona Center for Mathematical

Sciences, funded by an AFOSR University Research Initiative grant and other agencies. The center provides a research and graduate training environment in nonlinear optics, laser physics, and other nonlinear phenomena.

Collaboration with industry is an area of growing interest. The two groups frequently cited as leaders in this effort are the University of Minnesota's Institute for Mathematical Sciences and Stony Brook's Department of Applied Mathematics and Statistics. Stony Brook has had about thirty industrial collaborations in the past few years, many with companies located at the other end of the country.

Putting It All Together

This section presents two vignettes of mathematics departments that have succeeded in bringing together a number of the different components described in this book; they are viewed as a model department by their university administrations and other departments. One, the Nebraska Department of Mathematics and Statistics, has had a reputation for being a successful department for several years. The other, the Rochester mathematics department, has gained this status at its institution quite recently. Happily, there are many mathematics departments that have been successful in achieving this goal. For example, most of the departments mentioned in this chapter and the departments that the Task Force visited are viewed as quite successful by their administrations.

In some cases this success is closely associated with a highly effective chair. However, the reality is that successful chairs cannot exist without the strong support of senior faculty and an activist climate collectively generated by all faculty. Conversely, while the chairs of many successful departments are not well known outside their campus, they have almost all become very effective in dealing with their administrations and other departments. They make sure that their departments respond constructively to the concerns of administrators and other departments at the same time that they communicate the achievements of their departments. These skills are difficult to master in a three-year term as chair.

University of Nebraska-Lincoln

In the late 1980s the Department of Mathematics and Statistics at the University of Nebraska-Lincoln developed a strategy of using success with undergraduate instruction and outreach activities as the means to secure resources from the University that might also benefit research and graduate education and move the department up to Group II status in the next NRC rankings. The department's stated goal was "to become a model department of mathematics in a research university where educational goals are integral to the departmental mission and are supported by broadly based participation in educational programs."

The most important change in the department has been a change in the culture. While the department chair (who is a member of this Task Force) enjoys a reputation as an effective chair, he is the first to give credit for the change to the faculty as a whole. Most faculty now have a strong commitment to being an excellent teacher in addition to a commitment to developing a high-quality research program. Moreover, many faculty are involved in at least one educational program that extends beyond a basic commitment to being a good teacher. Half the faculty have won a College or University Distinguished Teaching Award. In 1998 the department won the University of Nebraska's University-wide Department Teaching Award.

The department has rethought its instruction at all levels. Its below-calculus offerings have been restructured, with failure rates cut in half. The graduate program also benefited because the UNL administration provided $90,000 in additional TA support for this initiative. Mathematics faculty played an important role in advocating an increase in UNL's admission requirements, which substantially reduced the percentage of students placing below college algebra. In response to a campus-wide general education initiative, the department introduced a contemporary mathematics course (based on the text *For All Practical Purposes*) to meet the needs of students in the humanities, arts, and education. Because of the substantial demand for this course, the administration provided (over time) funds to support three new GTAs, one postdoctoral position, and one new tenure-track line.

The department reworked calculus with funding from the dean, provost and UN Foundation. The effort was led by a group of younger faculty, all with NSF research grants. As well as introducing a reform text and graphing calculators, they sought to create as active a learning environment as is possible with a large-lecture/recitation format. There are small-group work and extended writing projects which help calculus meet the expectations of the general education initiative. Another faculty member developed a Web-based system for giving "gateway exams" in calculus to test technical skills. Students are allowed to retake the exam many times until they meet the department's high standard. Ten other UNL departments are using the gateway software, and John Wiley is marketing the UNL calculus gateway exams nationally. On one recent day, the gateway server had 36,000 hits! An NSF grant supported the introduction of computer algebra software in differential equations and matrix theory courses. To help mathematics instruction connect better with other disciplines, the department secured a large grant, jointly with Oklahoma State, in the NSF Mathematics Across the Curriculum program to develop interdisciplinary courses.

An important component of the department's contribution to the University has been its impressive array of outreach activities. Most famous is the American Mathematics Competitions, which Walter Mientka ran at UNL for three decades. With special funding from the state legislature, the department initiated in 1989 a mathematics prognosis test for high school juniors, modeled after programs at Ohio State and LSU. Its UNL Math Day brings approximately 1,300 students to campus each year to compete in mathematics competitions. The program receives outstanding cooperation from the University because of its potential to help recruit outstanding students. Recently, UNL Math Day became sponsored by The Gallup Organization.

The most substantial recent outreach program was the Nebraska Math and Science Initiative. The department received $10,000,000 in NSF funding to establish a statewide systemic initiative involving school mathematics teachers across the state. Over time it grew to include a science component. One NMSI effort, a middle school videotape curriculum project called Math Vantage, won several national awards. The videotape is now producing royalties for an endowment to support math education activities in the department. After NMSI's NSF funding ended, the chancellor reallocated $150,000 (annually) to provide a permanent infrastructure for the NMSI Center, and the dean of Arts and Sciences designated math/science education an "Area of Strength", with an annual budget of $70,000 for the math and science chairs to support educational activities.

These and other educational activities have improved the instructional environment for faculty, helped attract better students, raised the level of external funding, and secured additional graduate TAships and faculty positions, while greatly enhancing the department's standing on campus. At the same time, the department recommitted itself to improving its graduate education and research productivity. Along with producing more Ph.D.'s, the department made a priority of recruiting and encouraging female graduate students. While in the 1980s the department produced only 23 Ph.D.'s, none of whom were women, it has produced 34 Ph.D.'s in just the past four years, 13 of whom were women, one of whom won an NSF postdoctoral fellowship. Currently half of the graduate students are women. In fall 1998, the department won an NSF Presidential Award for Excellence in Science, Mathematics, and Engineering Mentoring in recognition of its success with women.

In the past three years 75 percent of the faculty have had some type of external funding (including education grants). The department has taken the lead in a College-designated Area of Strength: discrete, experimental, and applied mathematics. Other faculty are actively involved in initiatives like the Gallup Research Center. The A&S College has been very supportive of the department's efforts to enhance its research standing—for example, by allowing it to make competitive offers with good start-up packages. The 1995 NRC ratings placed the department solidly in Group II.

University of Rochester

In 1998 the mathematics department at the University of Rochester won a recently established $30,000 University Award for Curricular Achievement. While it was under severe attack from its administration in 1995, it is now seen by them as a model department. The criticism of the department, which focused on calculus instruction and isolation from other departments, had the effect of uniting the mathematics faculty to undertake a multipronged effort to change its image on campus. Fortunately, several major initiatives, including WeBWorK (described below), were under development at the time and enhanced the impact of the department's renewed dedication to providing high-quality mathematics instruction.

At the time of the attack on the department, the University announced its Renaissance Plan to cut the incoming class size by 20 percent while simultaneously aiming to attract better students. The department aligned its instructional mission with this goal of educating stronger undergraduates. This plan has served it well, since mathematics enrollments have increased despite the smaller number of students. The department has become the most active participant in the University's new Quest program of lower-division courses that bring research into the classroom. The provost at Rochester now touts the fact that 10 percent of the current freshman class (triple the historical average) are in honors calculus classes that include special research-like workshops. In addition, the dropout rate in these courses has been cut in half.

The department took steps to address the perception as well as the substance of calculus instruction. Meetings were held with every department having a math requirement for its major. Two new courses arose from these discussions, along with a number of personal connections that have been maintained to coordinate mathematics instruction with courses in other subjects.

They also entered into a constructive dialog with a vocal critic of mathematics instruction who has a degree in applied mathematics and was teaching competing courses in the mechanical engineering department. This led to a joint appointment for him in mathematics, and mechanical engineering is now phasing out its mathematics offerings.

Among the many tangible results of the improved communication and documentation of department efforts are the curriculum award cited above and two $5,000 University teaching awards (five of which are given out each year) for mathematics professors in the past two years. The department was also successful in nominating one of its faculty for the MAA Seaway Section Award for Distinguished Teaching in 1997.

One of the criticisms of calculus instruction at Rochester was that homework was not being graded. The department has come up with a remarkable solution to this problem. Mike Gage, a faculty member who earlier in his career had worked as a systems programmer for Intel, led the development of a complex software package called WeBWorK that allows students to do their homework and have it graded through the Internet. Parameters can be randomized (within set limits) to give each student his or her own individual set of weekly homework problems. A student who enters a wrong answer can try again any number of times up to a deadline date. This immediate feedback has proved to be a strong motivational tool. Currently, 75 percent of all students in freshman calculus are working on their WeBWorK homework assignments until they get every problem right.

The Rochester Physics Department now uses WeBWorK, and several mathematics departments at other institutions have started using it. It has also sparked interest in some high schools. One high school teacher wrote, “The WeBWorK project is easily the most exciting and potentially beneficial use of web-based technology for education I have come across.” Interested readers are invited to contact Arnold Pizer (apizer@math.rochester.edu) or Mike Gage (gage@math.rochester.edu), or to browse

http://www.math.rochester.edu/WeBWorK/

using “practice1” as a login name and password.