The University Senate of Michigan Technological University

PROPOSAL 32-95

PH.D. PROGRAM IN MATHEMATICAL SCIENCES

The requirements to initiate the proposed Ph.D. program are described below.

The following sections are attached.

Section 3.1 Faculty Qualifications and Areas of Expertise
Section 3.2 Faculty Research Publications: June 1991 to June 1994
Section 3.3 Sponsored Grants of the Faculty: June 1991 to June 1994
Section A Qualifying Exam Details
Section B New Courses
Section C Sample Curriculum

1 Rationale and Philosophy

1.1 An Overview

It is our conviction that the implementation of this Ph.D. program will lead to the emergence of a new breed of graduate student. We envision that our program will produce mathematical scientists who are sophisticated theoretically, who are familiar with the role played by their discipline in modern industry, and who, while specializing in one field, are knowledgeable about several areas of research. These scientists will be first-rate researchers who will be aware of the intricate connections among the mathematical sub-disciplines. They will be capable teachers who are qualified to teach courses in the traditional curriculum but who are comfortable experimenting with alternative teaching methods as well.

A program with such high goals must strive to meet several criteria, and the following narrative outlines the ways in which this proposal for a Doctoral Degree in the Mathematical Sciences will meet them. Much thought and careful planning has gone into the preparation of this proposal; this investment of time and attention has resulted in a plan for a Ph.D. program that will be novel, timely, and filled with the potential for success.

1.2 Special Features of the Program

1.2.1 Research Foci

We believe that the specific goals of our program are most likely to be met by restricting our degree offerings to three sharply focused areas of the Mathematical Sciences: Applied Mathematics, Discrete Mathematics, and Statistics and Probability. Each of these areas is important to the industrially aware doctoral student, and, more important, these areas reflect the main research interests of our faculty members. Our strengths within these areas are diverse. Our faculty members have done important work in Coding Theory; Combinatorial Design Theory; Combinatorial Number Theory; Cryptography; Differential Equations; Elasticity and the Mechanics of Solids; Extremal Graph Theory; Extremal Problems in Mathematical Statistics; Fluid Mechanics; Functional Equations; Matrix Theory; Numerical Analysis; Probabilistic Combinatorics; Probability Inequalities; Ramsey Theory; Sampling Theory; and Statistical Quality/Process Control. These and other (rapidly emerging) areas will form the research base of the program. However, faculty members whose primary research strengths lie in Group Theory or Topology, for example, will also contribute to the program, by teaching key courses, and providing research support for students obtaining a degree in one of the three areas of concentration mentioned above. We will endeavor to steer our students in new directions, while having them work on research problems that are challenging, contemporary, and fulfilling.

It simply makes no sense for us to offer a traditional doctoral degree in the Mathematical Sciences, and we do not envision enrolling students in our program who wish to specialize in, say, Topology or Ring Theory; there are many excellent programs, both inside and outside the state of Michigan, to which such students can be referred.

1.2.2 Broad Training

We would not like to fall into the trap of producing doctoral students who are one-dimensional--students who, having written a creditable thesis in one of the areas mentioned above, are quite unaware of the others, or who are naively ignorant of the rich mathematical background that lies beyond the boundaries of their work, or who, for that matter, are ignorant of the nonacademic aspects of the mathematics they have studied. We will ensure that each student is mathematically literate, in the best sense of that phrase, and, more important, that he or she is capable of adapting very naturally to the nonrarefied, nonacademic atmosphere of government or industry. In particular, each student will be required to take the following two-quarter sequences:

1. Statistical Methods;

2. Mathematical Modeling; and

3. Combinatorial Optimization.

The structure of these sequences will be unique: students will be exposed to key concepts and techniques, and the thrust of the instructional offerings will be toward broad understanding, rather than intricate detail. Such an approach will mean that all students, regardless of their field of specialty, will have a serious appreciation of each of the three areas encompassed by our doctoral program.

1.2.3 Internships and Industrial Training

The current employment situation in academe is bleak for new Ph.D.s in the Mathematical Sciences. Mary Crystal Cage writes[(1)]:

Most freshly minted Ph.D.'s in science and engineering are best suited to be university researchers. Unfortunately that's not where the jobs are.

According to a report from the National Academies of Science and Engineering and the Institute of Medicine, only about a third of new doctoral recipients will end up working for the academy. The rest will find employment in industry, schools and two-year colleges, government agencies, and other non-research institutions.

The academies and the institute say universities must correct this mismatch of academic training and job availability. ...

It is not uncommon for doctoral students in excellent programs to postpone graduation by up to two years, while they "retrain" themselves by learning Statistics, acquiring programming skills, etc. There is an obvious reason for this, as well as a solution: The academic background of a typical graduate student in the Mathematical Sciences consists solely of theoretical mathematics. By the time the student has obtained a Ph.D., he/she would find it hard to function in a nonacademic environment. The students we graduate from our degree program will be different. We will require that each student spend between one and two quarters as an "Industrial Intern" at a government agency or private company. The students' internships will form an integral part of the doctoral program, and we expect that, as the program gets better established, more and more support will be forthcoming from the student's employing firm or agency and from other external sources.

In order to provide our students with such internships, we will take the following steps: We are in contact with several government agencies, including the National Security Agency (NSA), the National Aeronautical and Space Administration (NASA), the Department of Energy (DOE), the National Institutes of Health (NIH), and the National Labs to secure internships for our future students. At the industrial level, we are in touch with several of the members of our Advisory Board. Through our contacts at General Motors, we will work to secure industrial internships in the automobile industry. Through our contacts at Chesapeake Decision Sciences, we will work to develop internships in the Oil Industry. Our contacts in the Pharmaceutical Industry will also be exploited, and we hope to place students there as well.

In addition, NSF has established a new program entitled "University - Industry Cooperative Research Programs in the Mathematical Sciences." This program supports industry-based graduate research assistantships and cooperative fellowships in the Mathematical Sciences, with stipends of up to $20,000 per year (these stipends involve industry cost-sharing). The department will attempt to find industrial partners, and we will apply for this grant during the coming year.

Although the internship program will be labor-intensive, the outcome for our students will be enviable: Because of this industrial experience, our typical doctoral student will be a person who is capable of doing serious mathematics motivated by real-life applications; he or she will be a mathematician who can both give to and take from industry and academe.

1.2.4 Mathematical-Technological Skills

In today's tight job market, it is obvious that a student with a broad spectrum of technical and mathematical abilities is in higher demand than another student who has "merely" written a solid dissertation. We propose, therefore, to broaden each student's prospects by insisting that he/she

1. be experienced in the art of technical writing, having produced and submitted for publication one or more papers, using TEX or one of its variants, before graduation;

2. have had at least one year of experience as an assistant or teacher in one of our Calculus with *Mathematica* sections;

3. have taken the unique course currently titled *Advanced Mathematics with Mathematica* (and taught currently by S. W. Graham), early in his/her career; and

4. be familiar with modern operating systems such as UNIX and Windows, be able to work easily with spreadsheets etc., be able to use a powerful statistical package such as SAS, and be able to program effectively in a high-level language such as C++. These last requirements might most easily be met by incorporating the use of the corresponding skills in core coursework.

1.2.5 Teaching Skills

In recent years, the mathematical community has taken a step in the right direction by paying an increasing amount of attention to pedagogical issues and teaching skills. We will reinforce this trend by ensuring that each of our Ph.D. students leaves the program as a capable and well-rounded teacher. To accomplish this goal, we will ask each student to participate in a series of teaching workshops and seminars, and be subject to numerous student, peer, and faculty evaluations. These steps will enable us to state unequivocally to prospective employers that our students are good teachers. No student will be allowed to graduate without fulfilling this requirement or without having taught, unassisted, courses at the elementary level. Students will also be required to make presentations at research-level seminars. There have been many cases of individuals who, although they were tops in mathematical research, were denied good academic positions because they had no teaching experience. Indeed holders of prestigious NSF Doctoral Fellowships are now required to spend at least one term as a teaching assistant.

1.3 Local, Regional, and National Need for the Program; Relationship to Other Programs

Michigan Technological University is ready to play a more significant role in science and technology education. Doctoral programs have been instituted in virtually every area of the sciences and engineering, and we feel that both the time and the climate are ripe for the development of our program. In addition to fulfilling the broader goals of the university, the adoption of this proposal will also recognize the zeal and readiness of our faculty to guide students into successful research/industrial careers.

Over the last ten years, our teaching loads have seen a steady decline; at the same time, both the quality and the quantity of our research output has skyrocketed. Our external funding has increased dramatically during the same period. These changes have helped us to prepare to meet the challenges that the implementation of a Ph.D. program will create.

Although the traditional job market is presently bleak, we believe that the Ph.D. program in Mathematical Sciences outlined in this proposal will actually enhance prospects for graduate student employment. Our students will have skills that employers need. Our typical Ph.D. recipient will be a good communicator and teacher. Additionally, he or she will have a solid dissertation and, in some cases, will have submitted two (or more) papers for publication. He or she will be adept at the use of TEX, *Mathematica*, SAS and C++. Our graduates will have participated in the innovative use of technology in the classroom; they will have a broad grasp of the discipline; they will have spent quality professional time outside the academic environment; and they will have both the training and the flexibility to succeed in either industry or academe.

There are no Ph.D. programs in the discipline in the Upper Peninsula, and the programs at the University of Minnesota and the University of Wisconsin are broad-based and large. Michigan Technological University is the only one of the four designated research universities in the state of Michigan that does *not* have a Ph.D. program in the Mathematical Sciences. The programs at the University of Michigan (UM) and Michigan State University (MSU) are, once again, traditional ones that train students for academic careers. The programs at Western Michigan University, Central Michigan University, and Wayne State University are smaller operations with restricted foci, but with the same essential underlying philosophy as the ones at MSU and UM. The same is true of many doctoral programs nationwide. MTU has an important role to play in the training of future mathematical scientists, and we will offer a distinct alternative to traditional programs. Some of the successful programs we seek to emulate, in terms of alternative curricula and rapid growth (if not in precise substance) are the ones at Georgia Tech and the University of Waterloo.

1.4 Source of Students

We expect that the number of students seeking admission to our innovative and non-traditional program will increase dramatically after the first few years of its existence. Each year, about ten of our own mathematical sciences majors go on to graduate school, and we believe that an important component of our applicant base will consist of these students. The Upper and Lower Peninsulas of Michigan, as well as the states of Wisconsin and Minnesota, are likely to generate several more applications due to geographical proximity and the fact that our program will offer prospective students an exciting alternative to the better-established, but undeniably traditional, programs in the states of Michigan, Wisconsin, and Minnesota. As word of our program spreads, we envision a time in the not-too-distant future when our recruitment base spreads to the other states in the midwest, and even to those beyond.

An important source of applicants to any doctoral degree program consists of foreign students. Trends in our Masters programs indicate that over 50% of our applicants will be from foreign candidates. These foreign candidates will be well-screened for their suitability for our program not only in terms of the usual barometers (GRE and TOEFL scores, letters of recommendation, and so forth), but also for their compatibility with, and understanding of, our underlying philosophy. We also expect to use our growing contacts with government and industry as a vehicle to recruit students for our program who wish to "go back to school" after a few (or many) years away from an academic environment.

1.5 Program Evaluation and Goals

Our goal is to produce at least 2 Ph.D. students each year. We will evaluate the program at the end of the first 5 years with respect to this goal. If our goal appears to be unattainable or if the students fail to be able to find employment the existence of the program will be reconsidered. An external review of the program will also be conducted.

2 Coursework and Degree Requirements

2.1 General Requirements

General coursework (and other) requirements for students entering this Ph.D. program with a bachelor's degree in mathematics, science or engineering are:

1. Background courses if necessary;

2. Graduate linear algebra course (3 credits);

3. Advanced Mathematics with *Mathematica* (3 credits);

4. Interdisciplinary courses (18 credits);

5. Advanced courses and dissertation research (57 credits);

6. Internship

7. Qualifying examination

8. Comprehensive examination

9. Doctoral dissertation and defense

Students entering with a master's degree in mathematics must also complete these requirements with the exception that in item 5 only 21 credits are required.

In addition to these requirements:

All students will be required to exhibit competency in the use of one or more modern computer operating systems, and they must be versatile users of a high-level programming language.

Under the supervision of the Director of the First-Year Program, all doctoral candidates must participate in a series of Teaching Effectiveness Workshops. They must have taught elementary courses unassisted, and they must have made presentations in a research seminar in their field of expertise.

We will recommend (but not require) that each student have prepared and submitted one or more research papers for publication *prior* to graduation. We realize that it is extremely difficult, in some areas of the Mathematical Sciences, to produce publishable results midstream, but we are also of the opinion that writing and typesetting mathematics should be an integral part of a doctoral program.

2.1.1 Interdisciplinary Courses

Each student in the program will be required to take the following two-quarter interdisciplinary sequences:

Mathematical Modeling I and II;

Statistical Methods I and II; and

Combinatorial Optimization I and II.

Details of the exact nature of these unique courses may be found in Appendices B.2, B.3, and B.4 respectively. We anticipate that these sequences will be offered in tandem, with a typical student taking Modeling I, Modeling II, Statistics I, Statistics II, Optimization I, and Optimization II during the first six quarters of their stay at Michigan Tech. One or two survey courses will be offered each summer.

2.1.2 Internship

Each student must spend between one and two terms as an Industrial or Government Intern or be actively involved in an industrially sponsored research project.

2.1.3 Qualifying Exam

Each student must take a qualifying exam for admission to candidacy for the doctoral degree. The contents of these exams are detailed in Appendix A; in each case, the qualifying exam will be written by an examination committee of graduate faculty consisting of at least two specialists in the appropriate field, at least one Applied Mathematician, at least one Discrete Mathematician, and at least one Statistician. Qualifying examinations will be given each winter, with a typical doctoral student taking the exam during his or her second year. Students will be allowed two attempts at passing the qualifying examination. If they fail to pass the qualifying exam, students will be permitted to complete the requirements for a master's degree.

2.1.4 Advisory Committee

Upon passing the qualifying examination, an advisory committee consisting of at least four members of the graduate faculty, will be selected in consultation with the student and the Mathematical Sciences Director of Graduate Studies, with the approval of the Dean of the Graduate School. At least one of these members will be from a cognate department or program.

2.1.5 Comprehensive Exam

Each doctoral candidate must pass a comprehensive exam covering more advanced material in his or her area(s) of specialty. The exact content of the comprehensive exam will be determined by the student's advisory committee, and the actual writing of the exam will be overseen by the above-mentioned examination committee.

2.1.6 Doctoral Dissertation

Each student must write and defend a doctoral dissertation.

3 Departmental Self-Study

3.4 Staff, Equipment, and Library

1. Staff Qualifications and Areas of Expertise

At the present time, the department employs one Administrative Aide, one Technical Communications Specialist (half-time), one Computer Support Specialist, one Secretary, and one Office Assistant. All of these support positions will play a role in the establishment of the Ph.D. program; for example, the Computer Support Specialist will continue to oversee the day-to-day running of our computer laboratories, which will be vital to the training of our new Ph.D. students.

2. Computer Equipment and Support for Research and Instruction

(a) Computer Equipment for Faculty Research.

At the present time, nine faculty members have NeXT machines installed in their offices, eight faculty members have Macintosh computers, twelve faculty members have Sun workstations installed in their offices, and two faculty members have PCs. Faculty can also make use of any of the department's computer laboratories.

(b) Computer Laboratories for Instruction.

The Department of Mathematical Sciences supports three computer laboratories. The Cleaves Byers Center for Computational Mathematics consists of sixteen networked NeXT workstations, which are primarily used for teaching our Calculus with *Mathematica* courses, and by graduate students and undergraduate majors for research. This lab is also used by the faculty and various staff members. We also have a new Sun laboratory, which began operation in the Fall term of 1994. This lab is heavily used for instruction in our new Technology Calculus courses. In addition, we have a new Mac lab that consist of twelve Macintosh computers, and it will be used primarily to educate our secondary education majors to use technology in their classrooms.

(c) Support Staff for Research and Instructional Computing Equipment.

The Center for Experimental Computation (CEC) facilitates the use of computers for research, instructional, and administrative activities in the departments of Computer Science, Mathematics, Physics, Biological Sciences, and Social Sciences. The staff of the CEC assists the various departments by planning, evaluating, purchasing, and installing hardware and software packages, providing user services such as backups and restores, and performing general computer maintenance for approximately 200 computer systems. The CEC supports approximately 1,300 user accounts per year. These systems range from PCs to workstations and hypercubes to mini-mainframes. The CEC has designed and constructed the current async and ethernet networks within Fisher Hall. The CEC maintains all mail service and domain name service for the departments of Computer Science, Mathematics, and Physics.

3. Library Holdings

The Michigan Tech Library contains 710,000 volumes and currently subscribes to 3,000 print serials and periodicals. These holdings include a number of the major journals within the areas of interest in this proposal. Among these are *Discrete Mathematics; Journal of Combinatorial Designs; Journal of Combinatorial Theory, Series A and B; Journal of the American Statistical Association; Biometrika; Annals of Statistics* and the complete set of SIAM journals. Students of applied mathematics will also have an extensive engineering literature to draw upon.

The library has open stacks, microfilm, graduate student and faculty carrels, inter-library loan privileges, photocopying facilities, and computerized bibliographic search services.

3.5 Programs, Resources, and Costs

1. Current Degree Programs and Enrollment

The Department of Mathematical Sciences services both its own majors as well as all other departments within the university. During the 1993-94 academic year, 6,023 students were enrolled in freshman and sophomore level mathematics courses, while 3,157 students were enrolled in junior and senior level mathematics courses. The undergraduate program in the Mathematical Sciences has approximately 120 majors, who graduate under one of four possible options, namely Applied Mathematics, Statistics, Computational Mathematics, and General Mathematics.

There are four areas of concentration within the Master's degree program in the Mathematical Sciences, namely Applied Mathematics, Discrete Mathematics, Pure Mathematics, and Statistics. There are generally six graduate courses offered per quarter. As new faculty members with different areas of expertise have joined the department, an increasing number of graduate-level Special Topics courses have been offered each quarter. Topics which have been represented in the past two years have included Categorical Data Analysis, Probabilistic Combinatorics, Reliability Theory, Resampling Theory, Wavelets, Chaos Theory, and Statistics: its Abuses and Uses. We also now offer, on a yearly basis, the graduate course Advanced Mathematics with *Mathematica*, which has been described in detail elsewhere in this proposal. The Department of Mathematical Sciences usually has about 17 graduate teaching assistants in the M.S. program, about half of whom graduate each year.

2. Impact on Current Resources and Programs

We expect that the addition of a Ph.D. program in the Mathematical Sciences will strengthen existing graduate programs in the Sciences and Engineering. The department has a large service commitment with one of the highest student to faculty ratios in the university. The additional staffing requested to support the new program will also allow us to better address our service commitment.

3. Needs and Costs

(a) Faculty Positions: Two senior level positions and one junior level position. The senior level faculty are needed in the areas of Applied Statistics and Applied Mathematics, while the junior level position is requested in the area of Combinatorial Optimization. We hope to obtain the two senior level faculty from several expected retirements over the next three years. The junior level position is a new position requested as part of the annual budget request.

(b) Six Additional TA Positions: This request is mainly to support our implementation of Calculus with *Mathematica*. This will entail smaller class sizes, as well as a need for more TAs in the laboratories.

(c) Library Upgrade: To support the proposed Ph.D. program, we request 8 additional journals in Statistics/Probability at an initial cost of approximately $3,200 each year; 3 additional journals in Combinatorics at an initial cost of approximately $1,200 per year; and 3 additional journals in Applied Mathematics at an initial cost of about $1,200 each year. The total cost of the library upgrade is $5,600 per year (initially).

1. [1]M.C. Cage, "Science and Engineering Doctoral Students Should Prepare for an Off-Campus Future, Report Advises", The Chronicle of Higher Education, Volume XLI, Number 33, April 28, 1995.

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