Graduate Programs in the Department of Mathematical Sciences

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1 The Academic Program

1.1 Introduction

The Department of Mathematical Sciences offers programs of study leading to M.S. and Ph.D. degrees in Applied Mathematics and Mathematics. Requirements for the degrees in the various programs are spelled out in detail in the Program Descriptions chapter of this document. Our program is sufficiently small that we will be able to give individualized attention to your graduate studies.

The authority for administering the program rests with the Committee on Graduate Studies. The Director of Graduate Studies will serve as adviser to all students until such time as a supervisor for the thesis or dissertation is appointed. Director of Graduate Studies will help you formulate your plan of study through formal meetings with individual graduate students. These meetings occur twice yearly before the beginning of the preregistration period.

New students, as part of the usual orientation program, will meet with the Departmental Director of Graduate Studies to plan their first year of study in the program. It is recommended that incoming students with an MS take the Preliminary Exam prior to beginning courses. Success in this exam will allow students to place out of some introductory courses. Well prepared students with a BS may also take Preliminary Exam prior to beginning course work (sample exams will be mailed on request). Exams are usually given the week before classes begin. Check the website for details.

During advisement, help will be given concerning course selection based on student's interests, student's undergraduate background, and the results of the preliminary exam if you choose to take it. Each student will have a progress sheet on which the courses taken, grades, and progress toward the degree is noted. Before each semester, students must obtain their advisor's permission to register. Continuing students are required to enroll for courses during the preregistration period, and are required to meet with the Director of Graduate Studies. You should feel free to discuss with a faculty member any difficulties you are having. It is important that you get sound advice and correct information.

1.2 General Plan of Study

In making your plan of study, you should pay particular attention to the timing of course offerings, and your background and interests. It is not unusual that you may want to, or need to, change your plan as your

experience in the Department grows. Nevertheless, such tentative plans will serve to insure progress toward your degree.

Here are some things to keep in mind in drawing your plan.

- Students holding Graduate Assistantships **GA**, Research Assistantships **RA**, or Graduate Teaching Assistantships **TA** must register for 9 hours of course work.
- It is expected that the requirements for a Master's degree be completed by the end of the fourth semester.
- A student must pass the Preliminary Exam by the beginning of the fourth semester in order to continue his/her studies beyond the Master's degree (see chapter on Preliminary Examinations).

For a student to remain in the Graduate Program a minimum cumulative GPA of 3.0 (B) is required. Students who do not perform to this standard are subject to review and/or dismissed as determined by the Graduate Student Probation Policy.

Permission to continue study toward a Ph.D. degree is given on the basis of a complete review of your academic performance. The Graduate Committee permits students to enter the Ph.D. program on the basis of (1) Prelim Exam score, (2) course grades, (3) instructor assessments.

By the time you are admitted to the Ph.D. program, it is desirable to have identified a general area in which you wish to work. The Department will waive course requirements and certify that hour requirements have been met after a review of your record.

Waiver of course requirements are made if either (i) you pass a Prelim Exam based on material covered by the course (ii) you earn at least a grade of "B" in a higher level course in the subject or (iii) you discuss your course work with a designated staff member who will certify that you have mastered the course material. The Committee on Graduate Studies will give final approval to course waivers.

Waiver of hour requirements will be made on the basis of transcripts and information supplied by you. You should make an appointment with a member of the Graduate Committee as early as possible to insure that all the information the Committee will need is available. It is important that your course waivers be approved as early as possible so that you know what requirements you will have to satisfy for your degree.

1.3 Financial Aid

Financial aid for study at Delaware takes several forms including Research Assistantships, or Departmental Fellowships, Teaching Assistantships and Tuition Scholarships. These forms of financial aid are awarded by the Department on a year–by–year basis. There is also a University Fellowship which is awarded by the University on a competitive basis. Continuation of support is dependent upon your academic progress and your performance of any duties assigned to you. All students receiving support of any kind are expected to discharge assigned tasks including certain jobs such as proctoring of departmental examinations and assisting with undergraduate registration ("drop–add").

The Department encourages students to compete in nationally advertised graduate fellowships. Information on what are currently available can be obtained from the graduate studies secretary.

The Department has a limit on its support of graduate students. The total number of semesters a student can be funded under a TA , GA, or Fellowship/RA is 10 semesters; 8 semesters for a student entering with a Master's degree. The department, however, will make every attempt to provide some form of funding for qualified students during their tenure.

The stipend for Teaching and Research Assistants for the 2006-2007 academic year is determined by the following schedule. Check the Departmental websites for updates.

1. Initial appointments of first year graduate students, $ 13,000.
2. TA qualified second year graduate students or initial appointment of TA qualified graduate students who have passed the Preliminary Exam, $13,250.
3. Graduate students who have passed their Candidacy Exam, and a language exam $13,500.

Students will remain at level 2 until the requirements for level 3 are met.

As most students are supported as Teaching Assistants, at least for some period of their studies, it is expected that all graduate students prepare themselves for classroom teaching. All new students are required to participate in the Department's orientation and TA training program which takes place in the days before the beginning of classes. The program includes both departmental and University presentations. In addition, new teaching assistants are required to attend teaching workshops scheduled by the department.

For foreign students, preparation for classroom duties includes work with the English Language Institute (ELI) both in the month preceding the Fall or Spring term as appropriate. Students also must attend departmental training sessions. ELI must certify that a foreign student has a sufficient command of English before the Department can make a classroom assignment. It is Departmental policy that no foreign student be supported more than two semesters without being certified for classroom assignments by ELI. Foreign students are expected to meet the following schedule with respect to test scores reported by ELI:

(1) achieve a score of at least 600 on the TOEFL examination (or an equivalent score on another examination approved by ELI) before the beginning of the first semester of study;

(2) attend the workshop for foreign Teaching Assistants given by ELI and CTE before the *beginning of the Fall or Spring term* of residence;

(3) must meet the minimum requirements set forth by the University's policy for SPEAK and UDIA scores for ITA instructional assignments (level II).

1.3.1 Support for Student Travel

The department would like to encourage graduate students to attend national meetings to present papers and to help in job searches. Therefore the department will support student travel as follows:

1. Supported graduate students who pass both the preliminary and candidacy exams will be awarded an amount of travel money (at the current rate determined by the department) for use during the remainder of their studies at Delaware. This money can be spent on a combination of approved travel at the choice of the student.

2. The student can apply to use this money to pay the costs of attending scientific meetings or other educational/academic events. To make an application for travel funds the student must fill out a travel approval form available from the Graduate Administrative Assistant. The form must be completed and approved before travel commences (it needs to be signed by the students adviser, and if grant funds are to be used, the PI of the grant also needs to approve the use of the grant funds). In no cases will students be reimbursed for travel without prior approval of this form.

3. Except as noted below, in no case will any funds beyond the amount approved for the student at the time of passing the candidacy exams. We recommend that students reserve some travel money to attend a national meeting for recruitment purposes late in your time at Delaware. Exceptions to the funding cap are as follows:

   (a) Students who wish to return to their undergraduate school to help recruit new graduate students may petition the department for extra support.

   (b) Students may also petition the Graduate Committee to receive partial funding to attend special training programs/workshops or clinics. Such requests must be clearly documented.

1.3.2 Support during the Summer

Graduate student contracts are usually for nine months. Opportunities for further employment during the summer months include Research Assistantships and Teaching positions. In addition the department offers summer support as follows:

- Continuing students, with financial support, who are in their first summer at Delaware are eligible for summer support at the rate specified in their offer letter.

  - Students are expected to be at Delaware during this time and available for classes and workshops as determined by the Graduate Committee.

  - At the request of the student this support may be carried over to the second summer.

- Students who have passed the candidacy exam and language exams are eligible for a further one summer of support at the current rate for summer support determined by the department.

- The duration of support is for the first summer session.

- By university policy, all students supported during the summer must register as full-time students (minimum 3 credit hours) for M868,or M964, or M969.

- Students who are being supported may not teach, or receive other University of Delaware support in the first summer session.

2 Miscellaneous Information

Change of Address or Telephone Number Please notify the Math Office (301 Ewing) of your current address and telephone number and notify us immediately of any changes.

Class Enrollment Limits Limits for all classes are established by the Department.

Class Supplies TA classroom supplies (as opposed to personal supplies) may be secured from the workroom supply cabinet (obtain key from 501 Ewing). Available supplies: grade books, chalk, pencils, pens, writing pads. *These supplies are for the classes you are teaching, not the classes you are taking.*

Computer Accounts As students you are automatically given accounts for e-mail on the university's Unix machines. Please go to Smith Hall, Room 2A, to obtain your user number and password. For your mathematical sciences workstation account all students need to fill out a "System Security and Access" form available from the staff office in Ewing. This form must be completed and handed in to the Graduate Assistant. For additional computing resources, please see the Assistant to the Chair.

Typing of Tests The policy is that the office staff does not type tests for graduate student TAs. The two exceptions to the rule are:

1. If you are the instructor in charge of a course during the *regular semester,* the office staff will do your hourlies and final the same way they do a regular faculty member's work. You are expected to adhere to the same policy for turning these exams as the faculty members do; i.e., at least 3 days before the hourly is due and at the time given you by the staff for finals. Also, you are expected to turn in the exams in good order – the office staff does not have time to redo exams several times because of their inability to decipher your notes.
2. During special sessions the office staff does not normally type exams but exceptions may be made for single exams given to several different sections of a course. The same policy holds for turning them in in a timely manner – at least 3 days before.
   As a courtesy to the typist, you are expected to be available to proofread all exams when they are typed so that corrections and duplication can be done in good time.
   All requests for typing services must be made to Mrs. Burns and she will assign the work to the staff.

Keys Ewing Offices and outside Ewing entrance keys. (The office key opens Ewing public areas: work room, computer terminal room, and the conference room).

Proctoring of Exams As part of their obligation to the department, all students are required to assist in the proctoring of the hour exams and finals in courses with common exams (e.g. M010, M115, M221, etc.). Failure to do your share will affect your winter/summer teaching assignments and may jeopardize future support from the Department.

Pay Checks You are paid twice monthly, on the 15th and the last day of the month. In order to receive your first check, you will need to fill out a W–4 form and an I–9 for tax purposes. All graduate students must use direct deposit.

Foreign students who receive temporary Social Security Numbers will need to fill out a second W–4 form when they receive their permanent Social Security Numbers, or their paychecks will be halted. These students must also change their UD ID cards.

Checks are automatically deposited after a form (obtained in 501 Ewing) is sent to Payroll. Your check stub can be seen on line. Your stipend continues straight through all nine months of the academic year and, therefore, you can expect your paycheck as usual between semesters.

Winter session is a separate contract, and this stipend is added into your paycheck over the Winter session period. Your stipend does not include summer session, but there is a possibility of teaching. For winter and summer sessions, if you don't have 10 people in your class after the first day of class, contact someone in the Math Office, 501 Ewing Hall. Your pay could be substantially reduced if this happens.

Telephone Any call beyond the Newark local calling area is to be paid by the student making the call.

Textbooks Desk copies may be obtained in 501 Ewing by TA's for courses in which they are assisting.

Copying Free copying for the course in which you are assisting. Ten (10) cents per copy for personal use. Please note the key count number and the number of copies made. The photocopy machine is not to be used for multiple copies for class use (see office staff for >100 copies). Any exceptions must be approved by the office staff.

3 Regulations Relative to the Master's and Ph.D. Programs

1. In order to be graduated with a Master's Degree in Mathematics, a student must satisfy the general academic requirements of the Office of Graduate Studies and must have a "B" or better average in all courses.
2. Under normal circumstances a student with a "C" or lower grade in 3 courses will be advised to leave the graduate program.
3. A student who has not passed the Candidacy Exam for the Ph.D. degree is not allowed to register for Ph.D. dissertation or noncontractual research.
4. Two semesters experience in the teaching of undergraduates is required of all candidates for a Master's Degree and four semesters of undergraduate teaching experience is required for Ph.D. candidates. This is a Departmental requirement, exceptions are rarely permitted.
5. The Graduate Office requires that those graduate students holding Graduate Assistantships, Research Assistantships and Graduate Teaching Assistantships register for a *minimum* of 6 hours. It is the policy of the Department that all students register for 9 hours each semester. Under special circumstances, and when approved by the Graduate Committee, 3 hours may be taken as a listener. The Graduate Committee *strongly* discourages students in their first three years of study from registering as a listener. Students may carry more than the 9 credits which are covered by the tuition. A student wishing to carry 13 credits or more must first get permission from the Department Director of Graduate Studies and the Office of Graduate Studies.
6. Students who expect to continue beyond the Master's level toward a Ph.D. degree must file the request for permission to continue studies toward the Ph.D. no later than the second year of admission (Change of Classification Form).

4 Guidelines for the Teaching Assistant

1. Teaching Assistants are expected to attend lectures in the course in which they are assisting if so asked by the instructor. They are expected to know the content of the course, methods of teaching used by the professor, and the relative importance of the subject matter.
2. Teaching Assistants are responsible for assisting the professor in charge

of the course in the formulation, administration and grading of quizzes and examinations given in the course. Specific responsibilities will be discussed with the professor in charge.

3. Quiz sections should be conducted along guidelines specified by the professor in charge of the course. The quiz sections are an integral part of each course and are expected to meet for the full 50 minutes in the assigned classroom. Teaching Assistants may not dismiss class early unless directed to do so by the professor in charge of the course.

4. The Teaching Assistant will be informed what part he or she will play in the final exam process regarding grading and averaging and recording grades. The assignment of final course grades is the responsibility of the professor in charge of the course. No Teaching Assistant may leave campus until final exam grades for their course have been turned in to registration.

5. At the beginning of the semester, professors and Teaching Assistants together should plan office hours and then announce office hours to their classes.

6. Teaching Assistants are expected to spend an average of 20 hours per week working in the course in which they are assisting. This average includes time in class, in preparation for class, and in grading of quizzes and exams.

7. The TA cannot give out information on student performance (including grades) over the telephone. The TA cannot give out final exams. If students wish to see them, the TA will need to make an appointment to meet them after classes have ended, or leave the exams with a secretary in 501 Ewing and have students check with the secretaries. Final exams must remain in the department for one year after students take them.

8. Renewal of assistantships is not automatic. Continued support is contingent upon appropriate progress toward a degree and satisfactory performance of assigned duties as a graduate assistant.

9. Teaching Assistants may not be absent during any semester without permission of the Associate Chair.

5 Program Descriptions

5.1 Introduction

The Department of Mathematical Sciences offers programs of study leading to the degrees of Master of Science and Doctor of Philosophy in Applied

Mathematics and Mathematics.

Many of the major areas of mathematics are included among the research interests of the faculty of the department but the areas most heavily represented are applied mathematics, inverse problems, partial differential equations, integral equations, numerical analysis, complex function theory, discrete mathematics, and topology.

Each of the graduate programs in the department is relatively small allowing for close contact between graduate students and faculty. Individual attention is common. There are several active seminars on

Recent recipients of advanced degrees from the department are research topics and there is steady additional stimulus from professional visits by scientists from the U.S. and abroad. successfully employed in academic, government and industrial positions.

5.2 Admission Requirements

Admission to the graduate programs in Applied Mathematics and Mathematics is open to students who have completed the equivalent of a baccalaureate degree in mathematics or related fields, and have a sound preparation in linear algebra and advanced calculus. On a 4.0 system, applicants should have a GPA of at least 2.5 and an average of at least 3.0 in mathematics and related areas. Applicants who have completed an advanced degree must have done so with a GPA of at least 3.0. In addition, applicants must take the GRE Aptitude Test. The advanced test in mathematics is highly recommended. For foreign students the TOEFL exam is also required with a grade of 600 for the written exam or 250 for the electronic exam. Admission to the graduate program is selective and competitive based on the number of well-qualified applicants and the limits of available faculty and facilities. Those who meet stated minimum academic requirements are not guaranteed admission, nor are those who fail to meet those requirements necessarily precluded from admission if they offer other appropriate strengths.

5.3 Master's Degree Requirements for Mathematics and Applied Mathematics

To be eligible for the degree an MSc candidate must complete 30 hours of course work beyond the Bachelor's degree. This is a non-thesis degree. Students must maintain a GPA of 3.0 or better.

- Students must pass M600, M602, and M611, M616, M672 with a C.

Students may test out of M600, M602, and M672 by taking the Preliminary Exam and replace these courses with electives.

- Complete one of the following: M617 or M650.

- Complete an additional 12 hours of course work at or above the 600 level. At most 3 credit hours may be taken outside the department with approval of the graduate committee.

- Pass M667 (1 credit) (graduate student seminar, 1st and 2nd Years). The seminar is in addition to the 30 hours of course work.

- Of the 30 credit hours required for an MS, at most 3 credits can be from a reading course unless an exception is granted by the graduate committee.

- Choose a course adviser before the end of the second semester.

Summary

The 30-hour course and 4 hour seminar requirement is summarized below.

Core requirements	18	credit hours
Additional MS requirements	12	credit hours
Seminars-colloquia	4	credit hours

5.4 Ph.D. Requirements

Students with no prior graduate course work must complete 48 credit hours of courses and 4 credit hours of seminar requirement. In addition, a student must complete 9 credit hours of MATH 969 (Doctoral Dissertation). A maximum of 6 credit hours of research (MATH 868) is allowed to count towards the 48 credit hour requirement. A GPA of 3.0 or better must be maintained. Of the 48 hours, a maximum of 27 credit hours of 600-level courses in the mathematics department is allowed. After completing their course requirements, students are expected to enroll for at least one course each semester which may be as a listener) in addition to MATH 964 or MATH 969. Students entering with a Bachelor's degree must pass the Preliminary Exam in order to continue beyond their second year (beyond the first year for those entering with a Master's degree). A second written exam, the An oral Candidacy Exam, must be passed in order for a student to be admitted to the Ph.D. candidacy. The department requires the Ph.D. candidate to have reading knowledge of one of four languages: French, German, Italian or Russian. Substitution may be allowed upon petition.

Summary

The 61 credit Ph.D. requirement is summarized below.

	APPLIED	MATH
Core requirements same as the MS degree	18 credit hours	18 credit hours
Additional PhD requirements	12 credit hours	12 credit hours
Electives	18 credit hours	18 credit hours
Seminars-Colloquia	4 credit hours	4 credit hours
Doctoral dissertation	9 credit hours	9 credit hours

Requirements for PhD

- Complete the requirements for MS and pass the Preliminary Exam based on M600, M602 and M672 or M611.

- Complete 48 credit hours of scheduled courses at the 6xx or higher level, of which a maximum of 27 hours can be 6xx level courses in the Math Department. More than 6 credit hours outside the department requires graduate committee approval.

- Pass the oral candidacy examination by a committee of at least 3 faculty members. The syllabus will be designed by the student in collaboration with his/her committee and subject to approval by the Graduate Committee. The exam should contain material from at least one 8xx level course.

- Dissertation

5.5 Course Offerings

The following schedule of classes is to help plan a student's program of study.

Schedule of Courses

We can only offer 3 M8xx level courses per semester. Because of the areas of interest of the faculty members, the following schedule of courses is proposed.

Fall	Spring
M600 (Analysis I)	M602 (Analysis II)
M611 (Numerical Analysis I)	M612 (Numerical Analysis II)
M616 (Applied Math I)	M617 (Applied Math II)
M672 (Linear Algebra)	M650 (Algebra)
M689 (Combinatorics II)	M688 (Combinatorics I)
M630 (Probability)	M631 (Stochastic)
M694 (Optimization)	
M810 (Asymptotics)	M835 (PDEs)
M850: Probability (Topics)	M806 (Functional) M807 (Complex)
M845 (Groups) M827 (Topology)	(Topics) M838 (Numerical PDE)

- The courses grouped together will be offered in alternate years.

- The graduate committee will invite proposals for these topics courses and will advise the chair which proposals to accept.

5.5.1 Typical Course Choices During the PhD

Here we outline a typical choice of courses for students in the applied mathematics or mathematics PhD programs. The tables assume that the student starts in the fall of academic year one with an undergraduate degree in mathematics.

The actual sequence of courses taken by any given student is likely to differ from this sequence based on individual needs, interests and when the student enters the program.

Sample Courses of Study for PhD

A student interested in Applied Mathematics may choose

Year	Fall	Spring
1	M600,M616, M611	M602, M612, M617
2	M672, M810, Topics	M835, M838,M806/M807
3	M630, Topics	Topics, M806/M807
4	M850, Topics/Research	Topics/Research

If M806 is offered in the second year for Applied Mathematics, a student may take Functional Analysis in the fourth year after they have had M672.

A student interested in Combinatorics may choose

Year	Fall	Spring
1	M600, M672, M616	M602, M650, M688
2	M689, M611, M845/M827	M850, M806/M807, Topics/Research
3	M845/827, M630/Topics	M631, M806/M807
4	M694 , Research	Topics/ Research

A student interested in Analysis may take

Year	Fall	Spring
1	M600, M672, M616	M602, M806/M807, M617
2	M630, M611,M810	M835,M806/M807,M612
3	M850/Topics, M694	M631, Topics/M838
4	Topics/ Research	Topics/Research

5.5.2 Summary

The 48 hour course requirement is be summarized below. A student must *in addition* complete 9 credit hours of MATH 969.

	APPLIED	PURE
Core requirements	18 credit hours	18 credit hours
Additional PhD requirements	12 credit hours	12 credit hours
Electives	18 credit hours	18 credit hours

Of the electives, a student may choose to complete 6 credit hours with MATH 868. In the Applied Mathematics option 6 of the 18 hours of electives must be in areas of application. All electives must be approved by the graduate committee.

5.6 Examinations

5.6.1 Preliminary Exam

Offered before the beginning of each semester, this one written examination covers material from MATH 600 and MATH 602 (Advanced calculus)

and another examination covers material from MATH 672 (Linear algebra). or from MATH 611 (Numerical Linear Algebra). Students entering with Bachelor's degrees are required to pass the Prelim by the beginning of their 4th semester (by the beginning of their 2nd semester for students entering with Master's degrees). Students who do not meet this requirement are recommended for dismissal.

5.6.2 Candidacy Exam

This oral examination can take place at any time mutually agreed by the Examining Committee and student. Students entering with a Bachelor's degree must pass the Candidacy Exam by the beginning of their 6th semester of study (by the beginning of the 4th semester of study for those entering with a Master's degree). A second and final attempt is permitted following a failed attempt. Dismissal will be recommended for a student who does not pass the Candidacy Exam on the second try.

The student should take the following steps to organize their oral examination and are advised to allow ample time for the process:

1. Contact four faculty to act as an Examining Committee. Since the student must be examined on two topics, normally two faculty will be expert in each area (one examiner should be the adviser if the student has already chosen an adviser).

2. After the faculty agree to serve as examiners the student should contact the Director of Graduate Studies at least six weeks in advance of the proposed examination date and supply the following information:

   (a) Date of the exam.
   (b) Names of the examiners making up the Examining Committee.
   (c) Choice of topics.

3. Final approval of the Examining Committee and topics rests with the Graduate Committee. Only after the Graduate Committee has approved the Examining Committee and topics may the exam take place.

The scheduling, topics and composition of the Examining Committee will be announced to the faculty.

It is the responsibility of the examining committee to decide the duration of the exam (typically 2-3 hours). They should report the results of the exam and a recommendation of Pass or Fail with written justification to the

Director of Graduate Studies within two days of the exam. A final decision on the outcome of the exam is the responsibility of the Graduate Committee.

In this examination a student must choose 2 topics from the following table:

Topic	Graduate Courses Pertaining to this Topic
Algebra	MATH 650 and MATH 845
Analysis	MATH 805 and MATH 807
Applied Mathematics	MATH 616, MATH 617 and MATH 810/M835
Discrete Mathematics	MATH 688 and MATH 689
Numerical and Functional Analysis	MATH 611, MATH 612 and MATH 806
Probability	MATH 630, MATH 631 and MATH 850

Another subject area may be substituted for one in the table above by petition to the graduate committee based on two graduate level courses and supported by a faculty member.

Should a candidate fail a part of the Candidacy Exam, the candidate need only retake the failed topic. In no case will a candidate be allowed to take the candidacy exam more than twice.

5.7 Seminar Attendance

Students are expected from the beginning of their studies to attend the graduate student seminars, departmental colloquia and some of the regularly scheduled research seminars.

5.8 Language Requirements

Students must demonstrate reading knowledge of 1 of 4 languages: French, German, Italian or Russian. Substitutions may be allowed upon petition.

5.9 Dissertation

A student must successfully defend his/her dissertation in front of a committee consisting of the thesis adviser and no less than 3 additional members, one of whom must be from outside the department. The dissertation must contain original publishable results.

5.10 Financial Aid

Students holding assistantships are expected to perform satisfactorily in their assigned duties and to make good progress in their academic work. Renewal of financial aid is not automatic. Due to the size of our program, we can only guarantee financial aid for 10 semesters for students entering with a Bachelor's degree; those entering with a Master's degree can expect to receive financial aid for 8 semesters. The department, however, will make every attempt to provide some form of funding for qualified students during their tenure.

For continued support beyond the 3rd year, a student entering with a Bachelor's degree must pass the Candidacy Exam by the beginning of his/her 6th semester. A student entering with a Master's degree must pass the Candidacy Exam by the beginning of his/her 4th semester in order to be guaranteed continued support beyond the 2nd year. For a student who does not pass the Candidacy Examination on the first try, there is no guarantee for support for the following academic year. However, a student may make a second and final attempt to pass the Candidacy Examination, and if the attempt is successful, the department will make every effort to secure funding for such a student.

5.11 Sustaining Status

Once a student has completed all the course requirements, passed the Preliminary and the Candidacy Examinations, met the language requirements, and registered for 9 credits of dissertation (MATH 969), the student is required to maintain his/her matriculation in the degree program by registering for Doctoral Sustaining (UNIV 999). A student must be registered in the semester in which the degree is awarded.

6 Preliminary Examinations

Those students who wish to continue work toward a Ph.D. degree must take a written examination called the Preliminary Examination. The Preliminary Examination contains two subject areas, Advanced Calculus and Linear Algebra or Numerical Linear Algebra. This Exam will be given twice each year, once before the start of the Fall Semester, and once before the start of the Spring Semester. For students entering with a Bachelor's degree, it is required that the Prelim Exam be passed by the beginning of the fourth semester of study. Providing it is before the beginning of the 4th semester, a student may take this exam several times. Only the part not passed needs to be repeated. Students who failed to pass both subject areas of the Preliminary Exam by the beginning of the fourth semester will be asked to leave the graduate program.

There are two examinations, the first covering the content of M600 and M602 (Advanced Calculus), and second comprising the content of M672 (Linear Algebra).

The syllabus to be covered by each examination is included in the following. Please obtain copies of past examinations and a more detailed syllabus from the Graduate Program Secretary in 301 Ewing Hall. Note also that the references cited on the following pages are intended to indicate the material to be covered. It is not necessarily intended that the student study all the references.

6.1 Advanced Calculus

Topology of Euclidean spaces. Bolzano–Weierstrass and Heine–Borel Theorems. Continuity and uniform continuity. Differentiability, Mean value theorems, Taylor's theorem. Sequences and series of real numbers and power series. Pointwise and uniform convergence of sequences and series of functions. Riemann–Stieltjes Integral.

Differentiability of functions of several variables. Inverse function theorem. Implicit function theorem. Multiple integrals. Line and surface integrals. Green's Theorem, Stokes' Theorem, Divergence Theorem.

References:

1. Walter Rudin, *Principles of Mathematical Analysis*
2. Tom M. Apostol, *Mathematical Analysis.*
3. R. Creighton Buck, *Advanced Calculus.*

6.2   Linear Algebra

Subspaces, bases, dimension, Linear transformations and matrix representations, Linear functionals, adjoints, and dual spaces, Scalar products and orthogonality, Symmetric, hermitian, and unitary operators, Eigenvectors and eigenvalues (spectral theorem),Jordan canonical form

References:

1. Sh. Axler, *Linear Algebra Done Right*, Springer-Verlag.
2. M. L. Curtis, *Abstract Linear Algebra*, (skip Chapter 2 (B) and Chapter 5), (Springer-Verlag).
3. K. Huffman and R. Kunze, *Linear Algebra*, (skip Chapters 4, 5, Sections 6.5, 7.2, 7.6, 7.5, 9.4, 9.6, 10.6), (Prentice-Hall).
4. S. Lang, *Linear Algebra*, Third Edition, (Springer-Verlag).

Note: Material skipped in one of these references might be found in other references, but presented in a more elementary form.

6.3   Numerical Linear Algebra

Direct and iterative methods for the solution of linear systems, LU factorization, row pivoting, stable QR factorization, solution of linear least squares problems by normal equations and QR, stability and conditioning issues, power and inverse iterations, QR iteration, singular value decomposition, simple iterations for sparse matrices, conjugate gradients and other Krylov subspace iterations.

Suggested References:
1. L.N.Trefethen and D. Bau, III, *Numerical Linear Algebra*, SIAM (see e.g., I, II, III.)
2. J.W. Demmel, *Applied Numerical Linear Algebra*, SIAM (Sections 2.1, 2.2, 2.3, 2.4, 3.1-3.3, 4.4, 6.5, 6.6.)
3. A. Quarteroni, R. Sacco and F. Saleri, *Numerical Mathematics*, Springer-Verlag (Sections 3.1, 3.3, 4.1, 4.2, 4.3, 5.2, 5.3, 5.4, 5.5, 5.8.)