Graduate Student Handbook
Department of Mathematics, University of Alabama

September 1, 2018

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1 Forward

This handbook is intended for graduate students in the Department of Mathematics at The University of Alabama. The Department wants their graduate study to be as smooth and pleasant as possible and hopes that this handbook will help make it so. This handbook will include a large amount of essential and useful information, including specific requirements, departmental policies and procedures, and the general philosophy of graduate work. There are many other sources of information about the University and its graduate programs. For example, further information can be found on the Graduate School website. This handbook was revised September 1, 2018.

2 Disclaimer

This handbook may not contain all the necessary information. However, every effort is made to ensure the accuracy of information contained herein at the time of publication. The Department of Mathematics reserves the right to make any change, revision or amendment to any part of this Handbook deemed necessary. The information contained herein is published solely for the convenience of students and to the extent permissible by law the university/math department expressly disclaims any liability which may otherwise be incurred.

Additional information can be found on the following websites:

- Graduate School: `http://graduate.ua.edu/`
- Mathematics Department: `http://math.ua.edu/`
- Graduate Catalog: `http://graduate.ua.edu/catalog/`
- Graduate Student Services: `http://gradservices.sa.ua.edu/`
- Housing and Residential Life: `http://housing.ua.edu/`

3 The Graduate Program Director

The Graduate Program Director, David Halpern, is the academic advisor for all incoming graduate students, with the exception of the Accelerated Masters Program students who are advised by Kabe Moen. Each semester, all students will meet with him to decide on what courses to take. He will also discuss overall objectives, and how well each student is progressing toward them. The Graduate Program Director is familiar with university and departmental regulations, but ultimately it is a student's responsibility to be aware of all the degree requirements. These are given below for the Masters and Ph.D. degrees.

The graduate advisor is available to help with any problems that may arise, for example: Trouble with particular courses; a change in the field of mathematics to concentrate in; problems with research advisor; visa difficulties for international students.

The majority of Ph.D. students are supported through Graduate Teaching Assistantships. Difficulties related to teaching duties concerning courses taught through the MTLC (i.e., courses below Calculus) should be initially discussed with Nathan Jackson, the Director of Introductory Mathematics. For other courses, such as Calculus, Linear Algebra and Differential Equations, speak to the individual course coordinator. For example, there could be issues of academic misconduct such as cheating in assignments, disruptive students in the classroom, or scheduling issues, such as how much time to spend on a particular topic in class.

4 Degree Requirements

The Mathematics Department offers a Master of Arts and a Doctorate of Philosophy. There is also a joint PhD program in Applied Mathematics with The University of Alabama system campuses at Birmingham and Huntsville.

The requirements listed below are all included in the Graduate Catalog. If University degree requirements change, students will be subject to the rules that were in force when they were first enrolled, not to the new rules.

Every graduate student must maintain a grade point average of 3.0 or better. A student, with more than 12 credit hours of coursework, whose grades drop below a 3.0 average will be placed on academic probation. During this period a student cannot hold an assistantship. According to University regulations, a probationary student who cannot return to a 3.0 average within the next twelve hours of graduate work will be dropped from the program. Furthermore, in order to graduate, at least 75% of the credit hours that are counted as part of the requirement for the degree must be completed with a grade of "B" or better. A complete list of courses offered by the university can be found in the Graduate Catalog, which is available on line at `https://catalog.ua.edu/graduate/`. For convenience, a list of graduate level courses in Mathematics appears in the handbook.

The Graduate School requires all students seeking an advanced degree to submit an "Admission to Candidacy" form. Master's students can only do this after receiving 12 hours of graduate credit, and PhD students only after passing the Qualifying Examination and having their dissertation proposal approved by their dissertation committee. All students must submit an "Application for Degree" form, which can be found on the Graduate Catalog website, and must be approved by the end of the registration period for the semester in which the student expects to graduate. If a student fails to graduate that semester, a new application for degree form must be submitted. Forms can be downloaded from the graduate school's website at `https://graduate.ua.edu/current-students/forms-students/`.

4.1 The Master of Arts Program in Mathematics

Candidates for the Master's degree in Mathematics can specialize in one of three focus areas of study: Pure or Applied Mathematics; Mathematics Finance; or Mathematics Education. A total of 30 hours of graduate work is required to obtain a Master's degree. Two distinct plans are offered:

Plan I requires successful completion of 24 semester hours of course work, and a thesis (6 hours of Math 599) supervised by a graduate faculty member in Mathematics. A student planning to graduate in the Spring semester ought to start thinking about the thesis topic as early as possible, and no later than in early Fall of the preceding year. The thesis must be defended in front of a committee, and then submitted electronically on line through ProQuest at `http://www.etdadmin.com/cgi-bin/school?siteId=176` once it has been approved by the committee. See http://services.graduate.ua.edu/etd/manual/index.html for a student guide on preparing electronic theses. Please note that a copy of the thesis or project must be available to each committee member at least two weeks prior to the presentation.

Plan II requires 27 semester hours of courses and 3 hours of work (Math 598) devoted to a project supervised by a member of the graduate faculty in Mathematics. The project does not have to be based on original work, and can be an extensive literature review of a particular field of Mathematics. The project can be started in the semester that a student plans to graduate. A copy of the project approved by a faculty member must be provided to Natalie Lau, in the main office. A pdf file should also be given to her. The project should be in 12pt font and single-spaced. Students are required to write their thesis in LaTeX, which they should have used in many of their courses. A skeleton template LaTeX file can be obtained from the UA Box to help students get started.

Although the Graduate Program Director can assist students in the selection of thesis or project advisors, students are in the end responsible for finding a thesis or project advisor.

The following courses do not count toward the Master's degree: Math 502, Math 504, Math 505, Math 508, Math 551, Math 552, and Math 570. For course descriptions, see Appendix C on page 26.

Students pursuing a PhD degree in Mathematics can be awarded a Master's degree after they pass their Qualifying Exams, complete 30 hours in graduate coursework and fulfill the core course requirements. A thesis, project, or oral exam is not required in this case.

A Master's degree specializing in Pure or Applied Mathematics requires at least 21 credit hours in Mathematics. Math 591 does not count toward this 21-hour requirement.

A Master's degree specializing in Mathematics Finance or Mathematics Education requires at least 18 hours in Mathematics. Math 591 does not count toward this 18-hour requirement but can count as part of the 24 (thesis) or 27 (project) hour requirement.

Master's degree students can submit an Admission to Candidacy form after completing at least 12 credit hours of approved courses. Students may fulfill the remaining credit hours by taking other Mathematics courses. With the approval of the Graduate Program Director, students may take courses in related areas such as Computer Science, Education, Finance, or Physics.

4.1.1 Core course requirements for Master's Degree in Mathematics

One course with grade of B or better from each of the following two categories, and one two-course sequence:

Category 1 (Pure)	Math 571, Math 573, Math 674, Math 587, Math 580, Math 681, Math 565, and Math 566
Category 2 (Applied)	Math 510, Math 511, Math 512, Math 520, Math 521, Math 522, Math 541, Math 542, Math 554, Math 555, and Math 585
Two-course sequences	Algebra - Math 571 and Math 573
	Real Analysis - Math 587 and Math 580 or Math 580 and Math 681
	Topology and Algebraic Topology - Math 565 and Math 566
	Numerical Methods - Math 510 and Math 511 or Numerical Analysis - Math511 and Math 512
	Optimization - Math 520 and Math 521
	Mathematical Statistics - Math 554 and Math 555
	Boundary Value Problems – Math 541 and PDEs - Math 642

4.1.2 Research requirements for a Master's Degree in Mathematics

- Plan I: Math 599 - Thesis Research, 6 credit hours
- Plan II: Math 598 – Non-Thesis Project, 3 credit hours

4.1.3 Focus area in Pure or Applied Mathematics

In addition to 21 credit hours in Mathematics, Plan I students may choose one elective course from outside Mathematics, subject to the approval of the Graduate Program Director. Plan II students may choose two elective courses from outside Mathematics, subject to the approval of the Graduate Program Director.

4.1.4 Focus Area in Mathematics Finance

In addition to the 18 credit hours in Mathematics, Plan I students may choose two of the following courses offered by the Department of Economics and Finance. Plan II students may choose three of the following courses:

- EC 570 – Mathematical Economics
- EC 513 – Economic Forecast and Analysis
- EC 571– Econometrics or EC 670 - Econometrics
- FI 519 – Financial Engineering
- FI 520 – Advanced Financial Derivatives
- EC 660 – Game Theory
- EC 672 – Financial Econometric Modeling

At the student's request, other courses may be considered for approval by the Graduate Program Director.

4.1.5 Focus in Mathematics Education

In addition to 18 credit hours in Mathematics, Plan I students will take Math 591- Teaching College-Level Mathematics and one of the following courses offered by the College of Education. Plan II students will take Math 591 – Teaching College-Level Mathematics and two of the following courses:

- BER 500 – Introduction to Education
- BER 545 – Analysis of Variance in Education
- BER 546 – Regression Methods in Education
- BER 558 – Introduction to Psychometrics
- BER 603 – Survey Research in Education
- BER 631 – Inquiry as Interpretation: Qualitative I

4.2 The Doctor of Philosophy Degree in Mathematics

The Doctor of Philosophy degree in Mathematics is intended as a research degree and is awarded based on scholarly proficiency (as demonstrated by course work and the Qualifying Examination) and the ability to conduct independent, original research (demonstrated by the PhD dissertation). A successful student must:

A) Complete 48 hours of graduate-level courses with a minimum of 39 hours in Mathematics. (The following courses do not count toward this degree: Math 502, Math 504, Math 505, Math 508, Math 551, Math 552, Math 570, Math 586, Math 587, and Math 591 (except Math Education students).

B) Not take more than three courses from the following: Math 522, Math 532, Math 537, Math 585, Math 588, Math 574.

C) Pass the PhD Qualifying Examination in two areas of Mathematics (see below).

D) Fulfill PhD candidacy requirements.

E) Complete at least 24 semester hours of dissertation research.

F) Write and submit a dissertation based on original research in an area of Mathematics.

G) Give an oral defense of the dissertation results.

For university rules regarding transfer credit, residency requirements, and other policies and deadlines, refer to the Graduate Catalog, available at https://catalog.ua.edu/graduate/ or see the Graduate Program Director.

4.2.1 Course Work Requirement

Students must complete 48 credit hours in order to qualify for the PhD. Most of the courses required for a Master's Degree, but not all, are part of the approved collection. In consultation with the student's dissertation advisor, the Graduate Program Director must approve the student's program of study. Study plans for students wishing to focus in Algebra, Analysis, Scientific Computing/PDE, Topology, Math Education, or Optimization can be found in Appendix A of this handbook. The following core course requirements must be completed: One course with grade of B or better from each of the following two categories representing Pure and Applied areas respectively, and three two-course sequences.

Category 1 (Pure)	Math 571, Math 573, Math 674, Math 580, Math 681, Math 565, and Math 566
Category 2 (Applied)	Math 510, Math 511, Math 512, Math 520, Math 521, Math 541, Math 542, Math 554 and Math 555
Two-course sequences	Algebra - Math 571 and Math 573
	Real Analysis - Math 580 and Math 681
	Topology - Math 565 and Math 566
	Numerical Analysis - Math 511 and Math 512
	Optimization - Math 520 and Math 521
	Mathematical Statistics - Math 554 and Math 555
	Patial Differential Equations – Math 541 and Math 642

Additional courses are available to students that provide the foundation to do research at the PhD level. Students with an uneven preparation at the undergraduate level may be advised to take foundation courses before proceeding with the program above. For example, students in the Ph.D. program may be initially advised to take the Master's level analysis course, Math 587, before enrolling in Math 580. Only courses with numbers above 500 are accepted for graduate credit; however, some courses have dual numbers so that they can be taken for either undergraduate or graduate credit. For example, students cannot take both Math 465 and Math 565 for credit. This situation may apply to students who were undergraduates at UA. Also, be aware that some 500-level courses may count toward the Master's degree requirement but not for PhD.

Because a doctoral degree usually requires five years of full-time study, financial support is provided for five years, with the possibility of a sixth year of support. A typical course load is three courses per semester. If a student is employed as a Graduate Teaching Assistant (equivalent to a 6-hour teaching load), the minimum course load is 6 hours. However, the total course load plus teaching must be between 12 to 18 hours inclusive.

Students are expected to finish the required core courses listed above in the first two years of the program (or the first three years, if foundation courses are taken). The core course requirement makes up from 18 to 21 of the necessary 48 hours, so students can specialize and broaden their studies.

After their second or third year, students should be focusing in areas related to their dissertation. Students are advised to take at least 12 hours of coursework in their chosen research area. A minor concentration in an area such as Computer Science, Engineering, Finance, or Physics could be advisable for students in Applied Mathematics. These areas may also be beneficial to students who plan to work outside an academic setting. Up to three courses at the 500-level from outside the Mathematics Department may be taken subject to the Graduate Program Director's approval. Be aware that the fees for courses in the Graduate School of Business are considerably higher than those charged by the College of Arts and Sciences. (In the spring of 2017, they were $284.50 for a graduate course from the Business school compared to $73.50 for an A& S course.)

4.2.2 Acceptable Progress toward a PhD in Mathematics

- 1st Year – Maintain a 3.00 GPA or higher and take 3 courses per semester.
- 2nd Year – Complete three of the 2-course sequences and core courses with a satisfactory GPA and pass two qualifying exams.
- 3rd Year – Maintain a satisfactory GPA, find a dissertation advisor, possibly do a year-long independent study, and determine a potential dissertation topic. By the end of the third year, apply for candidacy and form a Supervisory Committee.
- 4th Year – Prepare dissertation proposal and defend it in front of the Supervisory Committee by the end of the fall semester. Contact Marcia Black to reserve a room for the presentation. Obtain approval of the research proposal from the Supervisory Committee and begin dissertation research. Also, complete the 48 hours with a satisfactory GPA, submit the Plan of Study to the graduate school (via Natalie Lau at klau@ua.edu), and form a Dissertation Committee by the end of the fourth year. Note that one of the Committee members must be from outside the Department of Mathematics.
- 5th Year – Check the student deadlines from the graduate school's website, at `https://graduate.ua.edu/current-students/student-deadlines/`. Students who plan to graduate in the Spring semester, for example, have to submit an on line application for degree at the beginning of that semester. At least one month before the deadline for submission of the dissertation to the graduate school, students must distribute a hard copy of their dissertation to committee members, and the defense needs to be scheduled to give students at least one week to make corrections. Contact Marcia Black at mblack@ua.edu to reserve a room for the defense. The last day to submit a defended dissertation at the Proquest website, including changes suggested by the committee, is usually the towards the end of October in the fall semester, and towards the end of March in the spring semester.
- Provided satisfactory progress towards the PhD is being made, a student's advisor may request an extension for a 6th year of support. This request must be made before the end of the semester before the last semester of funding.

Students required to take foundation courses will be given additional time to satisfy the milestones listed above.

4.2.3 The PhD Qualifying Examination

The qualifying examinations are offered the week before the fall semester starts in August, and the week before the start of the Spring semester in January.

PhD students are expected to take and pass the PhD qualifying examination by the end of their second year in the program. The qualifying exam attempts to test both the depth and breadth of the student's knowledge. With the approval of the Graduate Program Director, well-qualified graduate students, especially those with a Master's degree, may request to take the Qualifying Exam early. Students who take foundation courses may request to have their qualifying exams taken in their third year.

For the tests, students choose any two from five subjects (listed in the next section), and must pass both four-hour long tests; otherwise, a failure status will be reported to the Graduate School. Students who only pass one exam, only need to retake the failed exam. A student may not fail any qualifying exam more than once. If a student takes a given exam and fails, and then chooses a different exam (e.g., replacing the analysis exam with the PDEs exam), the first exam failure will still count, and the student must pass the new exam in order to remain in the program. If a dispute arises, the final interpretation of the exams will be made by the Graduate Program Committee.

Starting in the fall of 2018, students must pass two qualifying exams from five subjects (listed in the next section) by the beginning of their fifth semester in order to remain in the PhD program. Exams are given twice a year, during the week before the fall and spring semesters begin. Students may take one qualifying exam at a time, until they have passed two subject areas within the specified time limit.

Each exam is written and graded by a committee consisting of at least two faculty members selected by the Chair in consultation with the graduate program committee (GPC) in the subject area of the exam. After the qualifying exam is graded, the exam committee makes a recommendation of a grade of Fail, Weak Pass, Pass, or Strong Pass to the GPC and the Graduate Director. The GPC will have the final authority to assign the grade, which is then conveyed to each student by the Graduate Director, who will also inform the Graduate School in a shortened form (Pass or Fail). The full grade will also be available to potential advisors.

4.2.4 The Qualifying Examination in Mathematics

- **Algebra**: Properties of rings: Fundamental aspects of ring and module theory are covered, Euclidean rings, Principal Ideal Domains, Unique Factorization Domains, fields, field extensions, finite extensions, algebraic extensions, algebraically closed fields, Descending chain condition and Artinian rings, polynomial rings, matrix rings, ascending chain condition and Noetherian rings, finitely generated modules, direct sums of modules, free modules, invariant basis number. Properties of groups: Elementary theory of groups, automorphisms, split extensions, Sylow theorems, examples including dihedral groups, quaternion groups and other groups of small order, p-groups, nilpotent groups, solvable groups and simple properties of such groups, abelian groups, quasi-cyclic groups, finitely generated groups, free groups and their construction, wreath products, groups with the maximum condition or the minimum condition, simple groups.

  The Algebra Qualifying Exam is based on Math 571 and Math 573. The material covered in Math 571 may vary depending upon the interests of the professor who teaches the course. Part II of Dummit and Foote will be covered in Math 571 together with additional topics from Parts III, IV and V. The Qualifying Exam will have enough problems on it to satisfy the needs of all students, irrespective of who taught the course. The material covered on the Algebra Qualifying Exam can be found in the books of D. S. Dummit and R. M. Foote, Abstract Algebra, and J. J. Rotman, An Introduction to the Theory of Groups. The algebra exam usually includes definitions, statements and proofs of theorems, examples, and standard exercises.

- **Analysis**: Sigma algebras and Lebesgue measure, measurable functions; Lebesgue integration; monotone convergence theorem, Fatou's lemma, dominated convergence theorem; Product measures, Tonelli's theorem and Fubini's theorem; Abstract measures, signed measures, Jordan decomposition theorem, Radon-Nikodym theorem; L_p spaces, Holder's and Minkowski's inequality, dual spaces; Differentiation theory, bounded variation, absolute continuity, Lebesgue differentiation theorem; Hilbert spaces, bounded operators and their adjoints; Elementary properties of Banach spaces, dual spaces, Hahn-Banach theorem, open mapping theorem, closed graph theorem, uniform boundedness property.

  The courses preparatory to the analysis exam are Math 580 and Math 681. Most of the above material can be found in Royden's book, Real Analysis. Students should be familiar with a substantial collection of examples and counterexamples, and with the proofs of standard theorems.

- **Numerical Analysis**: The material covered in the qualifying exam in numerical analysis is based on the core courses MA511-MA512, and includes: Error analysis, solution of linear and nonlinear systems of equations, eigenvalues, interpolation and approximation, least squares problems, numerical differentiation, integration and Richardson extrapolation, initial and boundary value problems for ordinary differential equations, finite difference methods for solving partial differential equations, stability analysis of numerical schemes, basic iterative methods needed for solving elliptic equations, and finite element methods for solving elliptic problems. Background material on linear algebra is assumed: This includes Gaussian elimination and matrix factorization, vector spaces, linear dependence and independence and bases.

  The book Numerical Analysis by Richard L. Burden and J. Douglas Faires, Brooks-Cole, Cengage Learning, August 2010, (chapters 2-8, and chapters 10-12) is often used in Math 511-Math 512. It covers in sufficient detail all the material listed above.

- **Partial Differential Equations**: The first part of the exam is concerned with solutions for the heat, wave, and Laplace's equations in bounded domains. Topics include the L^2 theory of Fourier series, the formal differentiation and integration of Fourier series, the eigenvalues and eigenfunctions for elliptic operators (specifically the Laplace operator) with Dirichlet and Neumann boundary conditions, orthogonality of eigenfunctions, orthogonal expansions, solutions of both homogeneous and nonhomogeneous boundary value problems in Cartesian and polar coordinates, existence and uniqueness of solutions for the heat, wave, and Laplace's and Poisson's equations, Fredholm alternative. The pertinent topics for the second part of the exam are: First-order equations (The Cauchy problem for quasilinear equations; Method of characteristics; Semi-linear equations; Weak solutions; Conservation laws, jump conditions, fans and rarefaction waves; General nonlinear equations); Second-order equations (Classification by characteristics; Canonical forms and general solutions; First-order systems; Well-posedness and Cauchy problems; Cauchy-Kovalevski theorem; Adjoints and weak solutions; Transmission conditions, delta distributions, convolution and fundamental solutions); The wave equation (Initial value problems; Weak solutions; Duhamel's principle; Spherical means; Hadamard method of descent; Domains of dependence and influence; Huygen's principle; Energy methods; Traveling wave solutions); Laplace equation (Green's formulas; Separation of variables; Spherical Laplacian in R^3 and R^n for radial functions; Mean value theorem; Maximum principle; The fundamental solution; Green's functions and the Poisson kernel; Properties of Harmonic functions; Eigenvalues of the Laplacian; Method of eigenfunctions expansion; Dirichlet problem on a half-space; Dirichlet problem on a ball; Helmholtz decomposition); Heat equation (The pure initial value problem; Fourier transforms; Non-homogeneous equations; Similarity solutions; Regularity; Energy methods; Maximum principle, uniqueness and fundamental solution).

  Currently, the two recommended books used in MATH 541 and MATH 642 are Partial Differential

Equations and Boundary-Value Problems with Applications: Third Edition by Mark Pinsky and Partial Differential Equations, Methods and Applications, 2nd ed., by Robert C. McOwen.

- **Topology**: Topological spaces, metric spaces, Baire Category Theorem, separation and countability axioms, compactness and related concepts, connectedness and related concepts, continuous functions, Urysohn's Lemma, Tietze's Extension Theorem, spaces of functions, Tychonoff's Theorem, quotient spaces, CW-complexes, homotopy of continuous functions, fundamental group, covering spaces and lifting criteria, singular homology, Hurewitz Theorem, exact sequences, Euler Characteristic, and computations of certain fundamental and homology groups.

  Courses preparatory to the topology exam are Math 565 and Math 566. Most of the material can be found in the book of Fred H. Croom, Principles of Topology or of James R. Munkres, Topology First Course; the first 21 sections in Greenberg-Harper, Algebraic Topology First Course, or Chapters 1 and 2 in Hatcher, Algebraic Topology.

  Normally, the relevant two-course sequences are designed to help students prepare for the Qualifying Exam. However, students are responsible for all listed topics although some topics may not be covered in class because of time constraints. The test on each subject is written and graded by a committee consisting of at least two faculty members in the area. The committee will report their assessment to the Graduate Program Director.

4.2.5 PhD Candidacy Requirements

Advancing to candidacy requires the passing of the qualifying examination, the completion of all the coursework as listed on the approved plan of study, and the approval of the dissertation subject by the supervisory dissertation committee. After passing the qualifying exam and successfully finishing the core course requirements, students need to decide on a major area of specialization, and find an advisor in that area. This should happen no later than the third year. A list of faculty members and their research interests can be found in Appendix B on page 25. Their major area of specialization should typically be in an area related to one of the subjects of their Qualifying Exam. The Graduate Program Director will assist students in choosing a dissertation advisor. Students must form a supervisory dissertation committee that consists of at least three Mathematics faculty members, with one member being their advisor. In a formal meeting, students present their dissertation research proposal to the committee in which students should demonstrate they have meaningful directions of research to pursue and a good foundation for research. The committee will assess the worthiness of the research proposal and approve or disapprove it. Under normal circumstances, students should fulfill all PhD candidacy requirements by their fourth year.

4.2.6 The PhD Dissertation

After completing the above requirements, students are admitted to candidacy for the PhD degree. Each student must demonstrate a broad knowledge of Mathematics. The Qualifying Exam and the required-curriculum listed courses represent very basic Mathematics. The main objective of a Mathematics PhD student is to become a creative and independent mathematician. Students may still be required to do course work. Much of this should be completed in their main area of specialization, although other courses can be taken in related areas. Initially, the admitted candidates are advised by the Graduate Program Director. Eventually, they will be directed by their advisor. The 24 hours of dissertation research required by the Graduate Catalog represent only a minimum, and there is no guarantee that a dissertation is finished once this minimum is achieved. Good results are required before one has a dissertation. It is imperative that the dissertation represents original work that can be published in a recognized research journal.

4.2.7 The Dissertation Defense

Each student is required to have a dissertation defense committee consisting of five faculty members. One committee member must be chosen from outside the Department of Mathematics, possibly from another university. Note that they all need to be graduate faculty. See Michele Farley about requesting temporary graduate faculty membership for non UA faculty. The committee's purpose is two-fold: first, to make useful suggestions about the dissertation; second, to administer a final oral examination; the dissertation defense. Because of the first purpose, the committee should be kept closely informed of the student's progress as he or she works on his or her dissertation research.

Once the dissertation is written, the candidate must provide copies to his or her committee members to review at least one month before the deadline for submission of the dissertation to the graduate school, and the defense needs to be scheduled to give the candidate at least one week to make corrections. The oral defense consists of a presentation concerning the work and a Q&A session with the committee. The committee's questions are not necessarily confined to the dissertation's topic, but may involve related topics. After corrections have been made, the candidate submits his/her dissertation to the Graduate School electronically. LaTeX is the preferred format for mathematics dissertations, and a template can be obtained from UA Box (permission is required).

Exclusion: Each student is expected to make "acceptable progress" toward the intended degree. In the period preceding the Qualifying Exam, "acceptable progress" is determined solely by the courses taken and the grade point average. At the beginning of the fall and spring semesters, the academic committee will review the progress of each graduate student.

A student will be dropped out of the PhD program in any one of the following cases:

- The student fails to maintain good standing in the graduate program.
- The student does not attempt the Qualifying Exam by the end of their second year.
- The student fails the Qualifying Exam twice.
- The student fails to pass the Qualifying Exam by the end of their third year.
- The student does not advance to candidacy by the end of the their fourth year.

4.3 The Doctor of Philosophy Degree in Applied Mathematics

The PhD program in Applied Mathematics is a joint endeavor, conducted with the Mathematics Departments at the University of Alabama campuses in Birmingham and Huntsville. Even if you are not interested in Pure Mathematics, we suggest that you read Section II describing the PhD dissertation. That section discusses some of the philosophy of the PhD degree that is common to both programs. The following are the minimum requirements for the PhD in Applied Mathematics:

A. Complete 54 hours of graduate-level Mathematics courses.

B. Pass the Joint Program Examination.

C. Satisfy the residency requirement of one continuous full-time academic year after passing the Joint Program Examination.

D. Satisfy the language requirement.

E. Complete an acceptable Program of Study which includes at least four graduate-level courses in a minor area of concentration outside the department.

F. Pass a Comprehensive Qualifying Examination associated with the Plan of Study.

G. Complete at least 24 semester hours of dissertation research and defend a research dissertation, the results of which are publishable in a nationally recognized journal.

4.3.1 Joint Program Examination

Students will take the Joint Program Examination after the first year of graduate studies. This examination will cover topics from graduate courses in Numerical Linear Algebra; and Real Analysis I and II, and will be administered in two parts: Linear Algebra and Numerical Linear Algebra and Real Analysis.

Topics on which the Joint Program Examination is based:

- Numerical/Linear Algebra: Vector spaces over a field. Subspaces. Quotient spaces. Complementary subspaces. Bases as maximal linearly independent subsets. Finite dimensional vector spaces. Linear transformations. Null spaces. Ranges. Invariant subspaces. Vector space isomorphisms. Matrix of a linear transformation. Rank and nullity of linear transformations and matrices. Change of basis. Equivalence and similarity of matrices. Dual spaces and bases. Diagonalization of linear operators and matrices. Cayley-Hamilton theorem and minimal polynomials. Jordon canonical forms. Real and complex normed and inner product spaces. Cauchy- Schwartz and triangle inequalities. Orthogonal complements. Orthonormal sets. Fourier coefficients and the Bessel inequality. Adjoint of a linear operator. Positive definite operators and matrices. Unitary diagonalization of normal operators and matrices. Orthogonal diagonalization of real symmetric matrices. Bilinear and quadratic forms over a field. Triangular matrices and systems. Gaussian elimination. Triangular decomposition. The solution of linear systems. The effects of rounding error. Norms and limits. Matrix norms. Inverses of perturbed matrices. The accuracy of solutions of linear systems. Orthogonality. The linear least squares problem. Orthogonal triangularization. The iterative refinement of least squares solutions. The space C^n. Eigenvalues and eigenvectors. Reduction of matrices by similarity transformations. The sensitivity of eigenvalues and eigenvectors. Hermitian matrices. The singular value decomposition. Reduction to Hessenberg and tridiagonal forms. The power and inverse power methods. The explicitly shifted QR algorithm. The implicitly shifted QR algorithm. Computing singular values and vectors. The generalized eigenvalue problem.
- Real Analysis: Lebesgue measure on R1 : Outer measure, measurable sets and Lebesgue measure, non-measurable sets, measurable functions. Positive functions and general functions. Comparison with the proper and improper Riemann integral. Differentiation and integration: Monotone functions, functions of bounded variation, absolute continuity, the fundamental theorem of calculus. Definition of a positive measure. Measure spaces. Measurable functions. The integral with respect to a positive measure. Convergence theorems for positive measures. Monotone and dominated convergence. L^p-spaces for positive measures with $p = 1, 2, \infty$, definition, completeness. Product measures, Lebesgue measure on R^k, Fubini's theorem.

The examination may be taken at most twice. On either the first or second attempt, students must pass both parts of the Joint Program Examination by the end of their second year of full-time graduate studies; those who do not will be dropped from the program.

4.3.2 Program of Study

Each Program of Study will stress breadth, depth, and research competence, as well as an understanding of the relationship of the major area to its applications, and will be individualized to meet the student's needs and requirements of the joint PhD program. It will be permissible for a student to complete a Program of Study at one campus, but students will be encouraged to visit campuses other than their own.

Programs of study require prior approval by the Joint Program Committee. A Program of Study will consist of at least 54 semester hours at the graduate level, including

A. Courses required to prepare for the common core portion of the Joint Program Examination;

B. A major area of concentration consisting of at least six courses in addition to those taken in A., selected so that the student will be prepared to conduct research in an area of Applied Mathematics;

C. A body of support courses giving breadth to the major area of study;

D. An outside minor that is designed to support the major area of concentration and that consists of at least four related graduate courses in an area of science, engineering, operations research, or applied statistics.

Students will take the Comprehensive Qualifying Examination after three years of graduate studies. The examination will cover the program of study, with a written and an oral component, and will be jointly prepared and graded by the student's Graduate Study Supervisory Committee. This will consist of six faculty members: the student's advisor serves as Committee Chairman; two others from the student's home department; one faculty member from each of the Mathematics departments at UAB and UAH; and one from outside the department in the student's minor area. The written component will consist of three parts; two parts will be devoted to the student's major area, and one part will be devoted to his minor area. Three hours will be allowed for each part. The oral portion will cover the entire program of study. Copies of old exams are available on the department's website.

If the judgment of the Supervisory Committee is that the student's performance on the test is not satisfactory, then they may, at their discretion, and without obligation, elect to give the test at most one additional time. The second test, if given, will conform to the above policies for the first test. Students must pass both the written and oral component by the end of their fourth year of full-time graduate studies; those who do not will be dropped from the program.

4.3.3 Language Requirements

The language requirement for each student will be set by the Joint Program Committee with the approval of the appropriate Graduate Dean.

4.3.4 Dissertation Defense

The Graduate Study Supervisory Committee serves as the student's PhD committee. The committee's purpose is two-fold: first, to make useful suggestions about your dissertation; second, to administer a final oral examination the dissertation defense. Because of the first purpose, the committee should be kept closely informed of your progress as you work toward a degree. Once your dissertation is written, you must provide copies to your committee, giving them at least a month to read your work before your dissertation defense. The defense will be oral and may involve both a general presentation from you concerning your work and questions from the committee. The committee's questions are not necessarily restricted to the dissertation, but may involve related topics. Your advisor can help you to prepare for the defense.

Once the dissertation is written, and assuming that all goes well and you are deemed to have passed the oral defense, all requirements for the PhD degree will have been satisfied. After the defense, your dissertation is to be presented to the University through electronic submission. You should take careful note of the endless regulations involving official copies of PhD dissertations. The type of paper is specified; the size of the margins; the work must be bound; etcetera. Please check with the Graduate School for publications regarding the preparation of dissertations. You should be aware that typing and preparing an official copy of a dissertation is not a short-term project; you should probably allow your typist at least two months for the job.

If finances permit, there will be an external examiner who is a faculty member in a mathematics department other than those in the University of Alabama system. This examiner, to be approved by the Joint Program Committee, will have experience in a well-established PhD program, and will have expertise in the area of the dissertation. The examiner will attend the dissertation defense, will advise the Graduate Study Supervisory Committee as to the quality of the dissertation, and will file a report with the Joint Program Committee.

5 Travel

The department of Mathematics encourages all graduate students to actively participate in regional, national and international conferences and workshops. The graduate school provides some funding for graduate students to present their work at conferences. This funding is reserved for students whose expenses have been approved by the department, and who are also receiving some partial support by funds from the department or their advisor. The graduate school provides 1:1 matching funds. For conference awards, the graduate school's match is up to $500 for travel within North America/Caribbean, and $800 for travel beyond North America/Caribbean, and for research awards (such as participating in a workshop), the match is capped at $300 for expenses within North America, $600 if involving travel beyond North America. Departmental funding for conference attendance, without an accompanying presentation, will not be eligible for graduate school match. Students are limited to a maximum of one conference award and one research award per year (Fall/Spring/Summer). Requests are initiated either by the faculty advisor or by the student, and must be submitted on line to the graduate school. The request must include a budget, confirmation about cost sharing, and, for conferences, a confirmation that the student will be personally presenting her or his own work. Application deadlines are August 31 for fall proposals, January 31 for spring proposals, and April 30 for summer proposals.

Graduate students should also approach their advisers to find out about funding through their advisers' grant. The Department of Mathematics may be able to provide partial funding support for graduate students to attend a second conference or workshop. A travel request should consist of one page, supporting documents, and a budget.

Other sources of funding include:

- The conference or conference organizers;
- The College of Arts and Sciences. See Natalie Lau for the application form;
- The graduate student association research and travel fund.

Students must fill out a travel form whenever they attend a conference or are going out of town for any reason, even during the summer months. Students working as GTAs must get approval from their supervisors. Please see Natalie Lau to receive the appropriate form.

6 Employment and Financial Aid

Financial assistance is available to all graduate students on a competitive basis. The College of Arts & Sciences and the Graduate School have additional merit-based fellowships. See http://graduate.ua.edu/students/financial-support/ for more information. All additional money, above and beyond the regular graduate stipend is subject to availability of funding, continued good progress towards obtaining a degree and a good employment record. Because a PhD usually requires five years of full-time study, financial support is ordinarily provided for a maximum of five years.A sixth year of funding is made available on a case by case basis.

Each GTA with a 0.5 FTE must be enrolled in a minimum of six and a maximum of twelve credit hours in graduate-level courses (two to four three-hour courses) each semester. A GTA with a 0.25 FTE must be enrolled in a minimum of nine and a maximum of twelve credit hours of graduate-level courses each semester. All GTAs must successfully complete at least six credit hours in each semester to be eligible for the continuation of financial support.

GTAs are paid monthly on the last working day of the month. All prospective employees must complete a Department of Homeland Security I9 form regardless of citizenship.

The University of Alabama has instituted a mandatory policy that requires a satisfactory background check as a condition of employment. The background check will include the results of a criminal history search, governmental identification number trace (to verify name and address), and a national sex offender registry search. This is not a credit check; the report will only be used to evaluate you for employment purposes. Please complete and sign the enclosed Standard release Form for Graduate Employees-Authorization and Release for the Procurement of a Consumer and/or Investigative Consumer Report and return it to us immediately. The report and its contents will be kept strictly private and confidential. This check is done once unless there is a change in status, for example from GTA to GRA and then back to GTA.

GTAs are required to work in addition to taking courses. The University measures the amount of work expected of students in terms of a 40-hour work per week. A student who is expected to work for 40 hours each week is said to be assigned a 1.0 Full Time Equivalency (FTE); a student working for 20 hours each week has a 0.5 FTE, and so on. In the Mathematics Department, most employed graduate students are assigned a 0.5 FTE, which allows for half of the time to be spent working, and half studying. Workloads vary during the semester, and you may find yourself working 25 hours some weeks and 15 during others.

Any student with a Teaching Assistantship of 0.5 FTE or greater is awarded a full tuition grant, which pays the full amount of that student's tuition. GTAs will never see this money; it just means that they won't have to pay their tuition at the beginning of each semester. GTAs are eligible for a variety of other benefits, including health services, single coverage health insurance provided by the Graduate School, textbooks provided by the Department of Mathematics, and membership in the Alabama Credit Union. For a list of all benefits, refer to the Graduate Assistant Guide.

In the first year, GTAs may tutor, conduct problem sessions for courses taught in large lecture sections or grade homework and exams for professors.

For GTAs teaching their own sections, the normal load is one or two 3- credit hour courses, or one 4-credit hour course with some additional tutoring assignments per semester.

Students must earn 18 credit hours of graduate- level Mathematics to teach. MTLC courses are assigned by the Director of Introductory Mathematics, Nathan Jackson, and the Departmental Chair, David Cruz-Uribe. For teaching duties, the Director of Introductory Mathematics is the immediate supervisor for the MTLC courses. Otherwise, the supervisor is the course coordinator.

Sometimes, however, teaching duties may interfere with GTA's own studies. This can happen, for example, at the end of the semester, when many exams are assignments. It is important for GTAs to learn how to divide their time between their duties as students and as teachers.

6.1 Steps to Continuing Financial Support

1. Students who were advised to take foundation courses must successfully complete these courses during their first year.
2. Students must complete their core course requirements and pass the Qualifying Exam by the end of their second year.
3. Students must have a dissertation proposal that is approved by their supervisory committee by the midpoint of their fourth year.

4. Students must report substantial progress in their dissertation research work to their committee by the end of the fourth year.

5. Students must maintain a 3.4 GPA or better throughout the 5-year program.

7 International Students

International students often face different challenges than their American counterparts. For example, visa difficulties can sometimes arise. There are many different ways that this problem can occur, and students should immediately contact the Graduate Program Director.

International students whose native language is not English may have the added burden of taking courses and perhaps teaching courses in an unaccustomed language. The university has established certain guidelines and procedures to ease the problems of non-native English speakers. All international students are required to take the Test of English as a Foreign Language TOEFL before being admitted; the Graduate School has established a minimum of 550 pBT or 79 iBT or 6.5 IELTS on the TOEFL or equivalent for admission. These guidelines are not intended as roadblocks or filters for graduate students, but are primarily to protect prospective students

The English Language Institute (ELI) was established at the University of Alabama to help international students master English, and to certify their proficiency in the language. Before being permitted to teach, every non-native English speaker must take and pass the International Teaching Assistant Program (ITAP) test given by the ELI. The program focuses on three main areas of study: pronunciation, teaching methods, and U.S. culture.

The ELI gives three grades: "full pass" (with a score in the range 52-60),"conditional pass"(46-51) and "no pass" (0-45). A student who receives a full pass can be assigned to teach a lecture-type class after having completed 18 hours of graduate mathematics. A conditional pass allows a student to lead problem sessions and tutor undergraduate students. With a "no pass", a student may only be assigned grading. The assistantship is contingent upon the completion of the ITAP course and the appropriate grade on the Proficiency Examination. International students are required to obtain a "full pass" by the end of their second year of their teaching assistantship. Those who initially fail or receive a conditional pass in the ELI examination are required by this department to take courses at ELI and retake the examination at the next opportunity. Failure to do so may result in the loss of the teaching assistantship.

In addition to required courses, ELI also offers a number of non-required short courses that help international students improve their spoken English, writing skills, and cultural knowledge.

More information can be found at the following links:

- English Language Institute; http://www.eli.ua.edu/
- International Student Life: http://gobama.ua.edu/international/student-life/

Appendix A Proposed Study Plans

This appendix contains study plans for students wanting to focus in one of the following areas: Algebra, Analysis, Scientific Computing/PDE, Topology, Math Education and Optimization.

A.1 Proposed Study Plan for Algebra

First Year

Fall		Spring	
Course	Units	Course	Units
Math 571 Modern Algebra II	3	Math 573 Abstract Algebra I	3
Math 565 Intro General Topology	3	Math 566 Intro Algebraic Topology	3
Math 580 Real Analysis I	3	Math 681 Real Analysis II	3

Second Year

Fall		Spring	
Course	Units	Course	Units
Math 583 Complex Analysis I	3	Math 677 Topics in Algebra I	3
Math 674 Abstract Algebra II	3	Elective	3

Third Year

Course	Units
Math 686 Functional Analysis I / Math 661 Algebraic Topology I/ other elective	3
Math 677 Topics in Algebra (Fall and/or Spring)	3-6
Math 687 Functional Analysis II/Math 669 Topics in Topology/other elective	3

Fourth Year

Course	Units
Math 677 Topics in Algebra (Fall and/or Spring)	3-6
Math 688 Topics in Analysis/669 Topics in Topology/other elective	3
Math 699 Dissertation Research	3-6

Fifth/Sixth Years

Math 699 Dissertation Research.

A.2 Proposed Study Plan for Analysis

First Year

Fall		Spring	
Course	Units	Course	Units
Math 565 Intro General Topology	3	Math 566 Intro Algebraic Topology	3
Math 571 Modern Algebra II	3	Math 573 Abstract Algebra I	3
Math 580 Real Analysis I	3	Math 681 Real Analysis II	3

Second Year

Fall		Spring	
Course	Units	Course	Units
Math 583 Complex Analysis I	3	Math 566 Intro Algebraic Topology	3
Math 686 Functional Analysis I	3	Other elective	3
Math 541 Applied PDE I	3	Math 642 Applied PDE II	3

Third Year

Course	Units
Math 688 Topics in Analysis	3
Math 566 Intro Algebraic Topology/other elective	3
Math 661 Algebraic Topology/Math 699 Dissertation Research/other elective	3-6

Fourth Year

Course	Units
Math 688 Topics in Analysis	3
Math 677 Topics in Algebra /Math 669 Topics in Topology/other elective	3-6
Math 699 Dissertation Research	3-6

Fifth/Sixth Years

Math 699 Dissertation Research.

Math electives can be any of the following courses: Math 510 Numerical Linear Algebra; Math 511 Numerical Analysis; Math 522 Mathematics for Finance I; Math 588 Theory of Differential Equations I. General electives can be any 500 or 600 courses from another department (if the student is interested in a particular area of application). Note that course fees charged by the Business School are much higher than those by the College of Arts and Sciences.

A.3 Proposed Study Plan for Scientific computing/ PDEs

First Year

Fall		Spring
Course	Units	Course
MA511 Numerical Analysis I	3	MA512 Numerical Analysis II
MA541 Boundary Value Problems	3	MA642 Partial Differential Equations
MA586 Introduction to Analysis I(*) or MA520 Optimization I	3	MA587 Introduction to Analysis II or MA510 N

Second Year

Fall		Spring
Course	Units	Course
MA580 Real Analysis I or MA520 Optimization I	3	MA510 Numerical Linear Algebra or MA681
MA610 Iterative Methods or MA611 Numerical Methods for PDEs	3	MA521 Optimization II or MA555 Stats II
MA 537 Topics in Applied Math	3	MA538 Topics in Applied Math

Third Year

Course	Units
Math 583 Complex Analysis I/Math 585 Introduction to Complex Calculus	3
Math 557 Stochastic Processes/other elective	3-6
Math 699 Dissertation Research	3 -6

Fourth Year

Course	Units
Math 537 Topics in Applied Mathematics	3
Other elective	3
Math 699 Dissertation Research	3-6

Fifth/Sixth Years

Math 699 Dissertation Research.

(*) Students with limited exposure to Analysis should consider taking the 586/587 sequence during their first year.

Math electives can be any of the following courses: Math 522 Mathematics for Finance I; Math 588 Theory of Differential Equations I; Math 686 Functional Analysis I. General electives can be any 500 or 600 courses from another department (if the student is interested in a particular area of application). Note that course fees charged by the Business School are much higher than those by the College of Arts and Sciences.

A.4 Proposed Study Plan for Topology

First Year

Fall		Spring	
Course	Units	Course	Units
Math 565 Intro General Topology	3	Math 566 Intro Algebraic Topology	3
Math 571 Modern Algebra II	3	Math 573 Abstract Algebra I	3
Math 580 Real Analysis I	3	Math 681 Real Analysis II	3

Second Year

Fall		Spring	
Course	Units	Course	Units
Math 583 Complex Analysis I	3	Math 684 Complex Analysis II	3
Math 661 Algebraic Topology	3	Math 560 Intro Differential Geometry	3

Third Year

Course	Units
Math 669 Topics in Topology	3
Math 674 Abstract Algebra II/Math 698 Non-Dissertation Research	3-6
Math 677 Topics in Algebra/other elective	3-6

Fourth Year

Course	Units
Math 669 Topics in Topology/other elective	3-6
Math 699 Dissertation Research	3-6

Fifth/Sixth Years

Math 699 Dissertation Research.

Notes: If possible, students can take a second course in Differential Geometry to replace one of 669/677/698); Students can substitute some courses by courses in Applied Mathematics, such as Math 541 Boundary Value Problems; Math 642 Applied PDEs.

A.5 Proposed Study Plan for Mathematics Education

This program is designed so that students have a strong background in all major areas of mathematics in order to be prepared to teach any undergraduate mathematics course or research the teaching and learning of undergraduate mathematics. Note that some students may need to take prerequisite coursework for the first year of study.

First Year

Fall		Spring	
Course	Units	Course	Units
Math 571 Modern Algebra II	3	Math 573 Abstract Algebra I	3
Math 554 Mathematical Statistics I	3	Math 555 Mathematical Statistics II	3
Math 565 Intro General Topology	3	Math 566 Intro Algebraic Topology	3

Second Year

Fall		Spring	
Course	Units	Course	Units
Math 580 Real Analysis I	3	Math 681 Real Analysis II	3
Math 511 Numerical Analysis I	3	Math 512 Numerical Analysis II	3
Mathematics Elective	3	Mathematics Elective	3

Third Year

Fall		Spring	
Course	Units	Course	Units
Mathematics Elective	3	Educational Research Course	3
Educational Research Course	3	Educational Research Course	3
Mathematics Education Course	3	Mathematics Education Course	3

Courses in Educational Research and Mathematics Education will be selective from courses offered by the College of Education based upon student interest and advisor recommendation in preparation for research in mathematics education.

Fourth Year

During this year, the student will work with an advisor to determine an appropriate dissertation topic, create a dissertation proposal, and to successfully defend the proposal during the fall semester and will begin work on the dissertation no later than the spring semester.

Fifth/Sixth Years

During this period, students take Math 699, complete and defend the dissertation.

A.6 Proposed Study Plan for Optimization

First Year

Fall		Spring	
Course	Units	Course	Units
Math 520 Linear Optimization	3	Math 521 Optimization Theory II	3
Math 511 Numerical Analysis I	3	Math 512 Numerical Analysis II	3
Math 580 Real Analysis I	3	Math 681 Real Analysis II	3

Second Year

Fall		Spring	
Course	Units	Course	Units
Math 554 Mathematical Statistics I	3	Math 555 Mathematical Statistics II	3
Math 541 Boundary Value Problems	3	Math 510 Numerical Linear Algebra	3
Math 557 Stochastic Processes I	3	Math 559 Stochastics Processes II	3

Third Year

Fall		Spring	
Course	Units	Course	Units
Mathematics Elective	3	Mathematics Elective	3
Mathematics Elective	3	Mathematics Elective	3
General Elective	3	General Elective	3

Fourth Year

Course	Units
Math 537 Topics in Applied Mathematics	3
Other elective	3
Math 699 Dissertation Research	3-6

Fifth/Sixth Years

Math 699 Dissertation Research.

Math electives can be any of the following courses: Math 522 Mathematics for Finance I; Math 585 Introduction to Complex Calculus. Or Math 583 Complex Analysis I; Math 588 Theory of Differential Equations I; Math 610 Iterative Methods for Linear Systems; Math 686 Functional Analysis I. General electives can be any 500 or 600 courses from another department (if the student is interested in a particular area of application). Note that course fees charged by the Business School are much higher than those by the College of Arts and Sciences.

A.7 Proposed Study Plan for Statistics

First Year

Fall		Spring	
Course	Units	Course	Units
Math 554 Mathematical Statistics I	3	Math 555 Mathematical Statistics II	3
Math 520 Linear Optimization	3	Math 521 Optimization Theory II	3
Math 511 Numerical Analysis I	3	Math 512 Numerical Analysis II	3

Second Year

Fall		Spring	
Course	Units	Course	Units
Math 580 Real Analysis I	3	Math 681 Real Analysis II	3
Math 541 Boundary Value Problems	3	Math 510 Numerical Linear Algebra	3
Math 557 Stochastic Processes I	3	Math 559 Stochastics Processes II	3

Third Year

Fall		Spring	
Course	Units	Course	Units
General Elective	3	General Elective	3
MATH 537 Topics in Applied Mathematics	3	General Elective	3

Fourth Year

Math 699 Dissertation Research.

Fifth/Sixth Years

Math 699 Dissertation Research.

General Elective can be any of the following courses: Applied Multivariate Analysis (ST 553), Applied Design Experiments (ST 561), Statistical Quality Control (ST 575), Nonparametric Statistics (ST 635), Advanced Data Mining II (ST 532). Note that course fees charged by the Business School are much higher than those by the College of Arts and Sciences.

Appendix B Faculty research interests by specialty

Algebra

- Paul Allen, Group theory, ring theory
- Jon Corson, Geometric group theory
- Martyn Dixon, Infinite group theory
- Martin Evans, Infinite group theory

Analysis

- Oleksandra Beznosova, Harmonic analysis
- David Cruz-Uribe, Harmonic analysis
- Tim Ferguson, Complex analysis, operator theory, harmonic analysis
- Kabe Moen, Harmonic analysis, PDEs

Applied & Computational Mathematics

- Brendan Ames, Optimization, machine learning
- Stavros Belbas, Optimal control, game theory
- Shibin Dai, Nonlinear PDEs, applied analysis, and numerical analysis
- Layachi Hadji, Fluid dynamics, materials science
- David Halpern, Fluid dynamics, mathematics in the life sciences, scientific computing
- Dang Nguyen: Stochastic Analysis
- Mojdeh Rasoulzadeh, Homogenization method, flow and transport in heterogeneous porous media
- Roger Sidje, Numerical methods for ODEs, numerical linear algebra, computational biology
- Min Sun, Modeling, simulation, global optimization, game theory
- Chuntian Wang: Stochastic Analysis
- Shan Zhao, Numerical methods for PDEs, mathematical methods for molecular biology
- Wei Zhu, Image processing, numerical methods for PDE's

Math Education

- Jim Gleason, Mathematical knowledge for teaching, educational measurement
- Martha Makowski, Math education, developmental math, STEM access, quantitative and mixed methods

Statistics

- Yuhui Chen, Big data analysis, Bayesian nonparametric modeling, survival models, statistical computing

Topology

- Jon Corson, Low dimensional topology
- Vo Liem, Geometric topology
- Lawrence Roberts, Low dimensional topology, homology theory, knot theory
- Bulent Tosun, Low dimensional topology, contact and symplectic geometry
- Bruce Trace, Geometric topology

Appendix C Course Descriptions

The course descriptions are identical to those listed in the graduate catalog, 2018-2019.

- **Math 502 History of Mathematics**. Three hours. Prerequisite: Permission of the department. Designed to increase awareness of the historical roots of the subject and its universal applications in a variety of settings, showing how mathematics has played a critical role in the evolution of cultures over both time and space.
- Math 504 Topics in Modern Mathematics for Teachers. Three hours. Prerequisite: Permission of the department. Diverse mathematical topics designed to enhance skills and broaden knowledge in mathematics for secondary mathematics teachers.
- **Math 505 Geometry for Teachers**. Three hours. Prerequisite: Math 125 or permission of the department. A survey of the main features of Euclidean geometry, including the axiomatic structure of geometry and the historical development of the subject. Some elements of projective and non-Euclidean geometry are also discussed.
- **Math 508 Topics in Algebra**. Three hours. Prerequisite: Permission of the department. Content changes from semester to semester to meet the needs of students. Designed for graduate students not majoring in mathematics.
- **Math 510 Numerical Linear Algebra**. Three hours. Prerequisites: Math 237 (or Math 257) or equivalent. Direct solution of linear algebraic systems, analysis of errors in numerical methods for solutions of linear systems, linear least-squares problems, orthogonal and unitary transformations, eigenvalues and eigenvectors, and singular value decomposition.
- **Math 511 Numerical Analysis I**. Three hours. Prerequisites: Math 237, Math 238, and CS 226; or equivalent. Numerical methods for solving nonlinear equations; iterative methods for solving linear systems of equations; approximations and interpolations; numerical differentiation and integration; and numerical methods for solving initial-value problems for ordinary differential equations.
- **Math 512 Numerical Analysis II**. Three hours. Prerequisite: Math 511. Continuation of Math 511 with emphasis on numerical methods for solving partial differential equations. Also covers least-squares problems, Rayleigh-Ritz method, and numerical methods for boundary-value problems.

- **Math 520 Linear Optimization**. Three hours. Prerequisite: C- or higher in Math 237.

  Topics include formulation of linear programs, simplex methods and duality, sensitivity analysis, transportation and networks, and various geometric concepts.

- **Math 521 Optimization Theory II**. Three hours. Prerequisite: Math 321 or Math 520. Corequisite: Math 510 or permission of the instructor. Emphasis on traditional constrained and unconstrained nonlinear programming methods, with an introduction to modern search algorithms.

- **Math 522 Mathematics for Finance I**. Three hours. Prerequisites: Math 227 and Math 355 or with permission of the instructor. An introduction to financial engineering and mathematical model in finance. This course covers basic no-arbitrage principle, binomial model, time value of money, money market, risky assets such as stocks, portfolio management, forward and future contracts and interest rates.

- **Math 532 Graph Theory and Applications**. Three hours. Prerequisites: Math 237 or Math 257, and Math 382 or permission of the instructor. Survey of several of the main ideas of general graph theory with applications to network theory. Topics include oriented and nonoriented linear graphs, spanning trees, branchings and connectivity, accessibility, planar graphs, networks and flows, matchings, and applications. 257 and 382 no longer taught?

- **Math 537 Special Topics in Applied Mathematics I**. Three hours. Prerequisite: Permission of the department.

- **Math 538 Special Topics in Applied Mathematics II**. Three hours. Prerequisite: Permission of the department.

- **Math 541 Boundary Value Problems**. Three hours. Prerequisites: C- or higher in Math 343. Emphasis on boundary-value problems for classical partial differential equations of physical sciences and engineering. Other topics include boundary-value problems for ordinary differential equations and for systems of partial differential equations.

- **Math 542 Integral Transforms and Asymptotics**. Three hours. Prerequisite: Math 441, Math 541, or permission of the instructor. Introduction to complex variable methods, integral transforms, asymptotic expansions, WKB method, matched asymptotics, and boundary layers.

- **Math 551 Mathematical Statistics with Applications I**. Three hours. Prerequisites: Math 237 and Math 355. Introduction to mathematical statistics. Topics include bivariate and multivariate probability distributions; functions of random variables; sampling distributions and the central limit theorem; concepts and properties of point estimators; various methods of point estimation; interval estimation; tests of hypotheses; and Neyman-Pearson lemma with some applications. Credit for this course will not be counted toward an advanced degree in mathematics.

- **Math 552 Mathematical Statistics with Applications II**. Three hours. Prerequisite: Math 551. Considers further applications of the Neyman-Pearson lemma, likelihood ratio tests, chi-square test for goodness of fit, estimation and test of hypothesis for linear statistical models, the analysis of variance, analysis of enumerative data, and some topics in nonparametric statistics. Credit for this course will not be counted toward an advanced degree in mathematics.

- **Math 554 Mathematical Statistics I**. Three hours. Prerequisites: Math 237 and Math 486 or Math 586. Distributions of random variables, moments of random variables, probability distributions, joint distributions, and change of variable techniques.

- **Math 555 Mathematical Statistics II**. Three hours. Prerequisite: Math 554. Order statistics, asymptotic distributions, point estimation, interval estimation, and hypothesis testing.

- **Math 557 Stochastic Processes with Applications I**. Three hours. Prerequisite: Math 554 or ST 554. Introduction to the basic concepts and applications of stochastic processes. Markov chains, continuous- time Markov processes, Poisson and renewal processes, and Brownian motion. Applications of stochastic processes including queueing theory and probabilistic analysis of computational algorithms.

- **Math 559 Stochastic Processes with Applications II**. Three hours. Prerequisite: Math 355 and Math 557, or permission of the department. Continuation of Math 557. Advanced topics of stochastic processes including Martingales, Brownian motion and diffusion processes, advanced queueing theory, stochastic simulation, and probabilistic search algorithms (simulated annealing).
- **Math 560 Introduction to Differential Geometry**. Three hours. Prerequisites: Math 486 or Math 586 or equivalent. Introduction to basic classical notions in differential geometry: curvature, torsion, geodesic curves, geodesic parallelism, differential manifold, tangent space, vector field, Lie derivative, Lie algebra, Lie group, exponential map, and representation of a Lie group.
- **Math 565 Introduction to General Topology**. Three hours. Prerequisite: Prerequisites: Math 486 or Math 586 or equivalent. Basic notions in topology that can be used in other disciplines in mathematics. Topics include topological spaces, open sets, closed sets, basis for a topology, continuous functions, separation axioms, compactness, connectedness, product spaces, quotient spaces, and metric spaces.
- **Math 566 Introduction to Algebraic Topology**. Three hours. 29

  Prerequisites: Math 565 and a course in abstract algebra. Homotopy, fundamental groups, covering spaces, covering maps, and basic homology theory, including the Eilenberg Steenrod axioms.
- **Math 570 Principles of Modern Algebra I**. Three hours. Prerequisite: Math 257. Designed for graduate students not majoring in mathematics. A first course in abstract algebra. Topics include groups, permutations groups, Cayley's theorem, finite Abelian groups, isomorphism theorems, rings, polynomial rings, ideals, integral domains, and unique factorization domains. Credit for this course will not be counted toward an advanced degree in mathematics.
- **Math 571 Principles of Modern Algebra II**. Three hours. Prerequisite: Math 470 or equivalent. This course begins with an overview of rings, including polynomial rings, Euclidean rings, Principal Ideal Domains, Unique Factorization Domains and matrix rings. Much of this material can be found in Part II of Dummit and Foote. An introduction is also given to modules, field extensions, group representations, and other topics from Parts III-VI of Dummit and Foote as time permits.
- **Math 573 Abstract Algebra I**. Three hours. Prerequisite: Math 470 or equivalent. Fundamental aspects of group theory are covered. Topics include Sylow theorems, semi-direct products, free groups, composition series, nilpotent and solvable groups, and infinite groups.
- **Math 574 Cryptography**. Three hours. Prerequisite: Math 307, Math 470/Math 570, or permission of department. Introduction to the rapidly growing area of cryptography, an application of algebra, especially number theory.
- **Math 580 Real Analysis I**. Three hours. Prerequisites: Math 486 (formally 380). Topics covered include measure theory, Lebesgue integration, convergence theorems, Fubini's theorem, and LP spaces.
- **Math 583 Complex Analysis I**. Three hours. Prerequisites: Math 380 and permission of the department. The basic principles of complex variable theory are discussed. Topics include Cauchy-Riemann equations, Cauchy's integral formula, Goursat's theorem, the theory of residues, the maximum principle, and Schwarz's lemma.
- **Math 585 Introduction to Complex Variables**. Three hours. Prerequisite: Math 227. Some basic notions in complex analysis. Topics include analytic functions, complex integration, infinite series, contour integration, and conformal mappings. Credit for this course will not be counted if it is taken after Math 583.

- **Math 586 – Introduction to Real Analysis I**. Three hours.

  Prerequisites: Math 237

- **Math 587 – Introduction to Real Analysis II**. Three hours. Prerequisites: Math 486 or Math 586.

- **Math 588 Theory of Differential Equations I**. Three hours. Prerequisites: Math 238 and Math 486 or Math 586. Topics covered include existence and uniqueness of solutions, Picard theorem, homogenous linear equations, Floquet theory, properties of autonomous systems, Poincare-Bendixson theory, stability, and bifurcations.

- **Math 591 Teaching College-Level Mathematics**. Three hours. Prerequisite: Permission of the instructor or the department. Provides a basic foundation for teaching college-level mathematics; to be taken by graduate students being considered to teach undergraduate-level mathematics courses.

- **Math 598 Research Not Related to Thesis**. Three to nine hours. Math 599 Thesis Research. One to six hours.

- **Math 610 Iterative Methods for Linear Systems**. Three hours. Prerequisite: Math 511. Corequisite: Math 512. Describes some of the best iterative techniques for solving large sparse linear systems.

- **Math 642 Partial Differential Equations**. Three hours. Prerequisite(s): Math 238, Math 486 and Math 541. This is an introductory course in partial differential equations. It covers the theory, methods of solution as well as applications related to the three main equations of mathematical physics, namely the Laplace's equation, the heat equation and the wave equation. This course serves as the first part of the sequence for the qualifying exam in partial differential equations.

- **Math 644 Singular Perturbations**. Three hours. Prerequisites: None. This is an introductory course in perturbation methods. It covers both the theory and the methods of solution for a variety of equations ranging from algebraic, ordinary differential equations, to partial differential equations containing either small or large parameters. This course serves as the second part of the sequence for the qualifying exam in partial differential equations.

- **Math 661 Algebraic Topology I**. Three hours. Prerequisite: Math 566 or equivalent. In-depth study of homotopy and homology. The theory of cohomology is also introduced as are characteristic classes.

- **Math 669 Seminar: Topics in Topology**. One to three hours.

- **Math 674 Abstract Algebra II**. Three hours. Prerequisite: Math 573 or equivalent. Fundamental aspects of ring theory are covered. Topics include Artinian rings, Wedderburn's theorem, idempotents, polynomial rings, matrix rings, Noetherian rings, free and projective modules, and invariant basis number.

- **Math 677 Topics in Algebra** I. Three hours. Prerequisite: Permission of the department. Content decided by instructor. Recent topics covered include linear groups, representation theory, commutative algebra and algebraic geometry, algebraic K-theory, and theory of polycyclic groups.

- **Math 681 Real Analysis II**. Three hours. Prerequisite: Math 580 or permission of the department. Topics covered include basic theory of LP spaces, convolutions, Hahn decomposition, the Radon-Nikodym theorem, Riesz representation theorem, and introduction to Banach spaces.

- **Math 684 Complex Analysis II**. Three hours. Prerequisite: Math 583 or permission of the department. Typical topics covered include analytic functions, the Riemann mapping theorem, harmonic and subharmonic functions, the Dirichlet problem, Bloch's theorem, Schottley's theorem, and Picard's theorems.

- **Math 686 Functional Analysis I**. Three hours. Prerequisites: Math 681 and a course in complex analysis. Topics covered in recent courses include Hilbert spaces, Riesz theorem, orthonormal bases, Banach spaces, Hahn-Banach theorem, open-mapping theorem, bounded operators, and locally convex spaces.
- **Math 687 Functional Analysis II**. Three hours. Prerequisite: Math 686. Topics covered in recent courses include spectral theory, Banach algebras, C* algebras, nest algebras, Sobolev spaces, linear p.d.e.'s, interpolation theory, and approximation theory.
- **Math 688 Seminar: Topics in Analysis**. One to three hours.
- **Math 698 Research Not Related to Dissertation**. One to nine hours.
- **Math 699 Dissertation Research**. One to twelve hours.