Graduate Student Handbook
Department of Mathematics, University of Alabama

August 4, 2022

Contents

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 August 4, 2022.

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: https://catalog.ua.edu/graduate/
- Graduate Student Services: https://graduate.ua.edu/current-students/
- Housing and Residential Life: http://housing.ua.edu/

3 Advising of Graduate Students

Every incoming graduate student is assigned an initial advisor. Each semester, all students will meet with their advisors to decide on what courses to take. The advisors will also discuss overall objectives, and how well each student is progressing towards them. They are familiar with university and departmental regulations, but ultimately it is the students' responsibility to be aware of all the degree requirements. These are given below for the Masters and Ph.D. degrees.

The Graduate Program Director is available to help with any problems that are beyond the power of initial advisors or thesis/dissertation advisors, for example: course related problems; 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. For lower division courses, whether taught at the MTLC or not, GTAs should speak first to their course coordinators about academic related issues and then with the Director of Lower Division Instruction. For tutoring related issues, GTAs should speak to the Supervisor of Tutors and Proctors and the MTLC Lab Coordinator. Here are some examples of cases when a course coordinator should be consulted: 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 three graduate programs:

- Master of Arts (M.A.) in Mathematics;
- Doctorate of Philosophy (Ph.D.) in Mathematics;
- Doctorate of Philosophy (Ph.D.) in Applied Mathematics. This is a joint program with The University of Alabama system campuses at Birmingham and Huntsville.

Students admitted to either PhD in Mathematics or PhD in Applied Mathematics can request to switch to the other PhD program by the August after their first year of PhD studies in the Department of Mathematics at The University of Alabama. Switching programs does not reset the time of PhD studies. Due to the difference in coursework requirements, requests after the aforementioned date is discouraged. The requirements listed below are included in the Graduate Catalog which is updated yearly. 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 12 or more 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. See the Graduate Catalog https://catalog.ua.edu/graduate/ for details.

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

A total of 30 hours of graduate work is required to obtain a Master's degree in Mathematics. 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 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 hard copy and the pdf file of the project report approved by a faculty member must be provided to the Graduate Program Assistant in the main office. Students are required to write their project reports in LaTeX, in 12pt font and single-spaced. A workshop on how to use LaTeX and its derivatives is offered by the University Library (specifically for graduate students in mathematics) at the beginning of each academic year. 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.

For course descriptions, see the Graduate Catalog https://catalog.ua.edu/graduate/arts-sciences/mathematics/.

Note that students pursuing a PhD degree in Mathematics can be awarded a Master's degree after passing the PhD Qualifying Exams, completing 30 hours in graduate coursework and fulfilling the core course requirements.

4.1.1 Course requirements for Master's Degree in Mathematics

All students are required to take the Master's core sequences: MATH 572 Linear Algebra and MATH 586 Intro to Real Analysis I in their first semester, and MATH 510 Numerical Linear Algebra or MATH 570 Prin Modern Algebra I and MATH 587 Intro to Real Analysis II in their second semester, and one of the Ph.D. year-long core sequences in one of the following areas: Algebra; Real Analysis; Topology; Numerical Analysis; Optimization; Mathematical Statistics; and Partial Differential Equations. In addition, there is a breadth requirement under which students need to take at least one more graduate level course in mathematics at the 500-level or 600-level, with the exception of courses beginning with 50 and MATH 551 and 552. 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.

Students should consult the Director of Graduate Programs if they wish to place out of any of the above requirements. The list of requirements is given below.

Course requirements for Plan I	Hours
Core courses MATH 572 Linear Algebra MATH 510 Numerical Linear Algebra or MATH 570 Prin Modern Algebra I MATH 586 Intro Real Analysis I MATH 587 Intro Real Analysis II	 3 3 3 3
Select one of the following sequences **Algebra** MATH 571 Prin Modern Algebra II MATH 573 Abstract Algebra I **Real Analysis** MATH 580 Real Analysis I MATH 681 Real Analysis II **Topology** MATH 565 Intro General Topology MATH 566 Intro Algebraic Topology **Numerical Analysis** MATH 511 Numerical Analysis I MATH 512 Numerical Analysis II **Optimization** MATH 520 Linear Optimization Theory MATH 521 Non-Linear Optimization Theory **Mathematical Statistics** MATH 554 Math Statistics I MATH 555 Math Statistics II **Partial Differential Equations** MATH 541 Boundary Value Problems MATH 642 Partial Differential Equations	6
Breadth Requirement One additional 3 hour course in mathematics at the 500-level or 600-level with the exception of courses beginning with 50 and MATH 551 and 552. Examples include MATH 510, MATH 511, MATH 520, MATH 532, MATH 554, MATH 557, MATH 565, MATH 571, MATH 580, MATH 585, MATH 574, MATH 588, MATH 591 or MATH 674.	3
Research Requirements MATH 599 Thesis Research	 6
Elective Courses Elective courses of approved graduate level coursework	 3
	Credit Hours Subtotal: 30

Course requirements for Plan II	Hours
Core courses MATH 572 Linear Algebra MATH 510 Numerical Linear Algebra or MATH 570 Prin Modern Algebra I MATH 586 Intro Real Analysis I MATH 587 Intro Real Analysis II	 3 3 3 3
Select one of the following sequences **Algebra** MATH 571 Prin Modern Algebra II MATH 573 Abstract Algebra I **Real Analysis** MATH 580 Real Analysis I MATH 681 Real Analysis II **Topology** MATH 565 Intro General Topology MATH 566 Intro Algebraic Topology **Numerical Analysis** MATH 511 Numerical Analysis I MATH 512 Numerical Analysis II **Optimization** MATH 520 Linear Optimization Theory MATH 521 Non-Linear Optimization Theory **Mathematical Statistics** MATH 554 Math Statistics I MATH 555 Math Statistics II **Partial Differential Equations** MATH 541 Boundary Value Problems MATH 642 Partial Differential Equations	6
Breadth Requirement One additional 3 hour course in mathematics at the 500-level or 600-level with the exception of courses beginning with 50 and MATH 551 and 552. Examples include MATH 510, MATH 511, MATH 520, MATH 532, MATH 554, MATH 557, MATH 565, MATH 571, MATH 580, MATH 585, MATH 574, MATH 588, MATH 591 or MATH 674.	3
Research Requirements MATH 598 Non-Thesis Research	 3
Elective Courses Elective courses of approved graduate level coursework	 6
	Credit Hours Subtotal: 30

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).

4.2.1 Preliminary Examination

All first year PhD students are required to take two preliminary tests (PT), one in Real Analysis and the other in Linear Algebra. These tests take place in the week before the start of the fall semester. Each test is either assigned a passing or a failing grade. A comprehensive description of all possible outcomes is given below.

- Passing both PTs allows students to take any of the PhD core sequences provided the course prerequisites are satisfied. See the graduate catalog for the latter.
- If students fail the Linear Algebra PT, they must take the MATH 572 Linear Algebra course in the fall and MATH 510 or Math 570 in the spring, and obtain at least a grade of B in Math 572. Otherwise, the Linear Algebra PT must be retaken the following August.
- If students fail the Real Analysis PT, they must take the MATH 586 Intro Real Analysis I course in the fall and MATH 587 Intro to Real Analysis II course in the spring, and obtain at least a grade of B in both courses. Otherwise, the Real Analysis PT must be retaken the following August.
- If students fail one of the PTs for a second time, they will not be able to continue in the PhD program and would have to transfer to the Master's program.

Note that students entering the PhD program in the spring will have to take the preliminary tests in August.

The level of difficulty is similar to advanced senior level courses in analysis (such as the sequence Math 486/ Math 487) and in linear algebra (such as Math 371). A list of exam topics is given below.

Linear Algebra Topics include: vector spaces; linear transformations and matrices; determinants; systems of linear equations and Gaussian elimination; eigenvalues, eigenvectors and diagonalization; generalized eigenvectors and Jordan Canonical Form; minimal polynomials, Cayley-Hamilton theorem; inner product spaces; self-adjoint and normal operators, orthogonal and unitary operators, the spectral theorem.

Recommended textbook: Linear Algebra by Friedberg, Insel and Spence.

Real Analysis Topics include: sequences and their limits, limits of functions of a real variable, continuity, derivatives, basic topology, advanced topics in differentiation theory, the Riemann integral, the fundamental theorem of calculus, numerical series, absolute and conditional convergences, convergence tests, pointwise and uniform convergence of sequences and series of functions, topological properties of the space of continuous functions: Weierstrass approximation theorem and the Arzela-Ascoli theorem.

Recommended textbooks:

- Understanding Analysis, Stephan Abbott (Has almost everything except the Weierstrass approximation theorem and the Arzela-Ascoli theorem);
- Real Analysis and Foundations, 3rd Ed., Steven G. Krantz (The 4th edition has the Arzela-Ascoli theorem missing);
- Principles of Mathematical Analysis, Walter Rudin (Covers the topics that the other two books miss out but is more sophisticated than is necessary).

Students may request access to old preliminary exams.

4.2.2 General Requirements

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 503, Math 504, Math 505, Math 508, Math 509, Math 551, Math 552, Math 570, Math 572, Math 586, Math 587, and Math 591 (except Math Education students).
- For students who fail both preliminary tests, they need to take either $48+9$ (Math 586, 587, 572) = 57 hours if they choose Math 510 in the spring; or $48+12$ (Math 586, 587, 572, 570) = 60 hours if they choose Math 570 in the spring.

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

C) Fulfill PhD candidacy requirements. Presentation of dissertation research proposal in front of student's advisory committee. The goals are

- To verify that the student has a suitable topic for thesis research.
- To evaluate student's depth of knowledge in a chosen area of specialization.
- To evaluate the student's ability to start research.

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

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

F) 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 (https://catalog.ua.edu/graduate/) or see the Graduate Program Director.

4.2.3 Course Work Requirement

Students must complete 48 credit hours in order to qualify for the PhD. 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 642, Math 554, Math 555, and Math 585
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. Only courses with numbers above 500 are accepted for graduate credit. As noted above, however, there are certain 500-level courses that may count only for the Master's degree and even some that do not count

towards a graduate degree in Mathematics. Some courses have dual numbers, either starting with a four or a five, 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.

Financial support is usually provided for five years, with the possibility of an extension for a sixth year. 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.

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 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 fall of 2019, they were $286 for a graduate course from the Business school compared to $81 for an A& S course.)

4.2.4 Acceptable Progress toward a PhD in Mathematics

- 1st Year – Satisfy the Preliminary Test Requirements, 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 attempt at least one of the two required qualifying exams.
- 3rd Year – Maintain a satisfactory GPA, pass both qualifying exams no later than the August after their third year, find a dissertation advisor, possibly do a year-long independent study, and determine a potential dissertation topic.
- 4th Year – Prepare dissertation proposal and defend it in front of the Supervisory Committee by the end of the fourth year. Obtain approval of the research proposal from the Supervisory Committee and begin dissertation research. Although optional, it is recommended that one of the Committee members be from outside the Department of Mathematics.

  Also, complete the 48 hours with a satisfactory GPA. Request the Plan of Study form and the Admission to Candidacy form by contacting the Graduate Program Assistant. Also, initiate the Dissertation Committee formation process online at https://graduate.ua.edu/current-students/forms-students/td-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 online 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. 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, towards the end of March in the spring semester, and in June for summer graduation. Note that graduate school offers a final semester minimum registration concession; see deadlines webpage mentioned above.

- 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.

4.2.5 The PhD Qualifying Examination

PhD students must pass two qualifying exams from five subjects (listed in the next section) no later than the August after their third year of PhD studies in the Department of Mathematics at The University of Alabama; those who do not will be dropped from the program. Exams are given twice a year, in January and August respectively, lasting four hours each. Students may take no more than two qualifying exams at a time, and they have at most three attempts in each qualifying exam. Although not recommended, it is allowed for students to take different subjects in different testing periods. However, doing so will not extend the deadline of passing two exams beyond the August after their third year. If a dispute arises, the final interpretation of the exam rules and scores will be made by the Graduate Program Committee.

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 High 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.

4.2.6 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 Math 511-Math 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: An Introduction, 2nd ed., by Walter Strauss and Partial Differential Equations, 2nd ed., by Lawrence C. Evans.

- **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.

4.2.7 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. 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.

4.2.8 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. The admitted candidates 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.

4.2.9 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, giving them at least one month to read the work before the dissertation defense. The defense need to be scheduled at least two weeks before the deadline for submission of the dissertation to the graduate school, so that the candidate has enough time 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).

4.2.10 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 fails to fulfill the requirements on QE as described in Section 4.2.5.
- The student fails to advance to candidacy by the end of the their fifth 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. The following are the minimum requirements for the PhD in Applied Mathematics:

A. Complete 54 hours of graduate 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 Preliminary Examination

All first year PhD students are required to take two preliminary tests, and are subject to the rules described in Section 4.2.1.

4.3.2 Joint Program Examination

The Joint Program Examination[1] consists of two written examinations which cover topics from Math 586, Math 587, Math 572, and Math 510. The names of these examinations are as follows:

[1]The Joint Program Examination was revised in March 2022 and the new version applies to all students matriculated in Fall 2022 or later. Students who matriculated before Fall 2022 can request to use the new examination, and will be considered case by case. Contact the Graduate Program Director for more information.

1. Linear and Numerical Linear Algebra;
2. Real Analysis.

Topics for the Joint Program Exam include:

- *Linear and 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. Jordan 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:*[2] (1) sup and inf for subsets of R, limsup, liminf for real sequences, Bolzano-Weierstrass theorem, Cauchy sequences. (2) Continuous functions: min-max, intermediate value theorem, uniform continuity, monotone functions. (3) Derivative: mean value theorem, Taylor's theorem for real functions on an interval. (4) Riemann integration for functions on an interval. Improper integrals. Integrals depending on parameters. (5) Sequences of functions: pointwise and uniform convergence, interchange of limits. (6) Series of functions: M-test, differentiation/integration, real analytic functions. (7) Metric spaces: open and closed sets, completeness and compactness, Cauchy sequences, continuous functions between metric spaces, uniform continuity, Heine-Borel and related theorems, contraction mapping theorem, Arzela-Ascoli theorem.

The examination for each part is 3.5 hours long. These examinations are held on different days of the same week in May and September of each year. During each administration, a student may take one or both of the exams. A single exam may be attempted at most twice. Students need to pass both exams no later than the September after their second year of PhD studies in the Department of Mathematics at The University of Alabama; those who do not will be dropped from the program.

4.3.3 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

[2]This is the new version that will come into effect starting September 2023. Contact the Graduate Program Director if any student is interested in knowing more about the old version.

A. Courses required to prepare for the Joint Program Examination, i.e., Math 586, Math 587, Math 572, Math 510, unless the student passes the preliminary exams. However, the preliminary exams do not replace the Joint Program Exams.

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. The following courses do not count toward this degree: MATH 502, Math 503, Math 504, Math 505, Math 508, Math 509, Math 551, Math 552, Math 570, Math 591.

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.

4.3.4 Language Requirements

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

4.3.5 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 need to be scheduled at least two weeks before the deadline for submission of the dissertation to the graduate school, so that the candidate has enough time to make corrections. 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 late August for fall proposals, late January for spring proposals, and late April 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 the Graduate Program Assistant 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 the Graduate Program Assistant for additional information.

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 20 hours each week is said to be assigned a 0.5 Full Time Equivalency (FTE), while a student working for 10 hours each week has a 0.25 FTE. Most employed graduate students are assigned a 0.5 FTE, which allows for half of the time to be spent working, and half studying.

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 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, grade homework and exams for professors, or carry out other duties.

Students must earn 18 credit hours of graduate level Mathematics to teach. MTLC courses are assigned by the Director of Lower Division Instruction and the Departmental Chair. For teaching duties, the Director of Lower Division Instruction is the immediate supervisor for the MTLC courses. Otherwise, the supervisor is the course coordinator. 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.

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 Exams by the deadlines described in Section 4.2 and 4.3.
3. Students must have a dissertation proposal that is approved by their supervisory committee by the midpoint of their fourth year (or fifth year for those who took the foundation courses).

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 3.0 GPA or better throughout the 5-year program.

7 Other Requirements

Every graduate student need not only to make satisfactory progress in their studies and research, but also to carry out the teaching and/or other duties assigned to them by the department and the university. Failing to carry out their duties will result in prorated stipend, the termination of their assistantships, or the suspension from the graduate program.

Examples of failing to carry out duties include, but not limited to

- Failure to teach assigned classes or perform assigned duties in the MTLC.
- Failure to consult with course coordinator or the Director of Lower Division Instruction about changes to their courses.
- Failure to consult with the Supervisor of Tutors and Proctors or the MTLC Lab Coordinator about changes to MTLC schedules or duties.
- Leaving before the end of the semester (defined as the date grades are due) or returning after the Monday before classes start without permission of MTLC and graduate director.

8 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 Sample PhD Study Plans

This appendix contains sample PhD study plans for students wanting to focus in one of the following areas: Algebra, Analysis, Scientific Computing, Partial Differential Equations, Topology, Math Education and Optimization. Students who pass one or both of the preliminary exams before the start of their first fall semester can skip the corresponding Master's core courses, and follow the plans for Year 2 and on. Please keep in mind that these are just sample plans. Each student need to work with their advisor to design a plan that best suits them.

A.1 Sample Study Plan for Algebra

Year 1

Fall		Spring	
Course	Units	Course	Units
MATH 586 Introduction to Analysis I	3	MATH 587 Introduction to Analysis II	3
MATH 572 Linear Algebra	3	MATH 570 Prin. Modern Algebra I	3
Elective[2]	3	Elective[2]	3
		GTA training	3

[2] The elective course can be any MATH 500-level course subject to the approval of a student's academic advisor, provided the prerequisites are satisfied.

Year 2

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

Year 3

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	MATH 560 Introduction to Differential Geometry	3
Elective[3]	3	MATH 598 Non-Thesis Research or MATH 698 Non-Dissertation Research	3

Fourth/Fifth/Sixth Years

Electives[3] and MATH 699 Dissertation Research.

[3] Preferred electives: MATH 684 Complex Analysis II; MATH 686 Functional Analysis. MATH 677 Topics in Algebra may be taken more than once. There is an applied math requirement which can be satisfied by taking MATH 510 Numerical Linear Algebra; MATH 554 Mathematical Statistics I or other applied PhD courses.

A.2 Sample Study Plan for Analysis

Year 1

Fall		Spring	
Course	Units	Course	Units
MATH 586 Introduction to Analysis I	3	MATH 587 Introduction to Analysis II	3
MATH 572 Linear Algebra	3	MATH 570 Prin. Modern Algebra I	3
Elective[2]	3	Elective[2]	3
		GTA training	3

[2] The elective course can be any MATH 500-level course subject to the approval of a student's academic advisor, provided the prerequisites are satisfied.

Year 2

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 642 Partial Differential Equations	3
MATH 565 Intro General Topology	3	MATH 560 Intro Diff Geom or MATH 566 Intro Alg Topology	3

Year 3

Fall		Spring	
Course	Units	Course	Units
MATH 583 Complex Analysis I	3	MATH 566 Intro Algebraic Topology	3
MATH 571 Modern Algebra II	3	MATH 573 Abstract Algebra I	3
MATH 686 Functional Analysis I	3	MATH 598 Non-Thesis Research or MATH 698 Non-Dissertation Research	3

Fourth/Fifth/Sixth Years

Electives[3] and MATH 699 Dissertation Research.

[3] Preferred electives: MATH 510 Numerical Linear Algebra; MATH 511 Numerical Analysis; MATH 688 Topics in Analysis; MATH 554 Mathematical Statistics I; MATH 557 Stochastic Processes I; MATH 588 Theory of Differential Equations.

A.3 Sample Study Plan for Scientific computing

Year 1

Fall		Spring	
Course	Units	Course	Units
MATH 586 Introduction to Analysis I	3	MATH 587 Introduction to Analysis II	3
MATH 572 Linear Algebra	3	MATH 510 Numerical Linear Algebra	3
MATH 537 Applied Math Topics I	3	Elective[2]	3
		GTA training	3

[2] The elective course can be any MATH 500-level course subject to the approval of a student's academic advisor, provided the prerequisites are satisfied.

Year 2

Fall		Spring	
Course	Units	Course	Units
MATH 511 Numerical Analysis I	3	MATH 512 Numerical Analysis II	3
MATH 541 Boundary Value Problems	3	MATH 642 Partial Differential Equations	3
MATH 520 Linear Optimization Theory	3	MATH 521 Non-linear Optimization Theory	3

Year 3

Fall		Spring	
Course	Units	Course	Units
MATH 610 Iterative Methods	3	MATH 611 Numerical PDEs	3
MATH 554 Mathematical Statistics I	3	MATH 555 Mathematical Statistics II	3
Elective[3]	3	MATH 598 Non-Thesis Research or MATH 698 Non-Dissertation Research	3

Fourth/Fifth/Sixth Years

Electives[3] and MATH 699 Dissertation Research.

[3] Preferred electives: MATH 554 Mathematical Statistics I; MATH 555 Mathematical Statistics II; MATH 588 Theory of Differential Equations I; MATH 580 Real Analysis I; MATH 681 Real Analysis II; MATH 686 Functional Analysis I.

A.4 Sample Study Plan for Partial Differential Equations

Year 1

Fall		Spring	
Course	Units	Course	Units
MATH 586 Introduction to Analysis I	3	MATH 587 Introduction to Analysis II	3
MATH 572 Linear Algebra	3	MATH 510 Numerical Linear Algebra or MATH 570 Prin. Modern Algebra I	3
Elective[2]	3	Elective[2]	3
		GTA training	3

[2] The elective course can be any MATH 500-level course subject to the approval of a student's academic advisor, provided the prerequisites are satisfied.

Year 2

Fall		Spring	
Course	Units	Course	Units
MATH 541 Boundary Value Problems	3	MATH 642 Partial Differential Equations	3
MATH 580 Real Analysis I	3	MATH 681 Real Analysis II	3
MATH 511 Numerical Analysis I	3	MATH 512 Numerical Analysis II	3

Year 3

Fall		Spring	
Course	Units	Course	Units
MATH 565 Intro General Topology	3	MATH 688 Topics in Analysis	3
MATH 686 Functional Analysis	3	Elective[3]	3
Elective[3]	3	MATH 598 Non-Thesis Research or MATH 698 Non-Dissertation Research	3

Fourth/Fifth/Sixth Years

Electives[3] and MATH 699 Dissertation Research.

[3]Preferred electives: MATH 520 Linear Optimization Theory; MATH 521 Nonlinear Optimization Theory; MATH 588 Theory of Differential Equations I; MATH 557 Stochastic Processes I; MATH 554 MATH Statistics I; MATH 555 Math Statistics II; MATH 611 Numerical Methods for PDEs.

A.5 Sample Study Plan for Topology

Year 1

Fall		Spring	
Course	Units	Course	Units
MATH 586 Introduction to Analysis I	3	MATH 587 Introduction to Analysis II	3
MATH 572 Linear Algebra	3	MATH 570 Prin. Modern Algebra I	3
MATH Elective[2]	3	Elective[2]	3
		GTA training	3

[2] The elective course can be any MATH 500-level course subject to the approval of a student's academic advisor, provided the prerequisites are satisfied.

Year 2

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

Year 3

Fall		Spring	
Course	Units	Course	Units
MATH 583 Complex Analysis I	3	MATH 560 Intro Differential Geometry	3
MATH 661 Algebraic Topology	3	Elective[3]	3
Elective[3]	3	MATH 598 Non-Thesis Research or MATH 698 Non-Dissertation Research	3

Fourth/Fifth/Sixth Years

Electives[3] and MATH 699 Dissertation Research.

[3] Preferred electives: MATH 510 Numerical Linear Algebra; MATH 541 Boundary Value Problems; MATH 642 Partial Differential Equations; MATH 688 Topics in Analysis; MATH 684 Complex Analysis II.

A.6 Sample 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.

Year 1

Fall		Spring	
Course	Units	Course	Units
MATH 586 Introduction to Analysis I	3	MATH 587 Introduction to Analysis II	3
MATH 572 Linear Algebra	3	MATH 570 Prin. Modern Algebra I	3
MATH Elective[2]	3	Elective[2]	3
		GTA training	3

[2] The elective course can be any MATH 500-level course subject to the approval of a student's academic advisor, provided the prerequisites are satisfied.

Year 2

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 Alg. Top or MATH 681 Real Analysis II	3
MATH 580 Real Analysis I	3	MATH 591 or 593	3

Year 3

Fall		Spring	
Course	Units	Course	Units
MATH 554 Mathematical Statistics I	3	MATH 555 Mathematical Statistics II	3
BER 600 or BER 631	3	BER 600 or BER 631	3
MATH elective[3]	3	MATH elective[3]	3

Year 4

Fall		Spring	
Course	Units	Course	Units
MATH elective[3]	3	Education elective[2]	3
Education elective[2]	3	MATH 699 Dissertation Research	3-6
MATH 699 Dissertation Research	3		

Fifth/Sixth Years

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

[2] Courses in Educational Research and Mathematics Education will be selected from courses offered by the College of Education to reflect a balance between research methods and educational theory. Choices will be made to reflect student interest and advisor recommendation in preparation for research in mathematics education.

[3] Preferred Math electives: MATH 510 Numerical Linear Algebra; MATHH 511 Numerical Analysis I; MATH 512 Numerical Analysis II; MAATH 557 Stochastic Processes ; MATH 585 Introduction to Complex Variables.

A.7 Sample Study Plan for Optimization

Year 1

Fall		Spring	
Course	Units	Course	Units
MATH 586 Introduction to Analysis I	3	MATH 587 Introduction to Analysis II	3
MATH 572 Linear Algebra	3	MATH 510 Numerical Linear Algebra	3
MATH Elective[2]	3	Elective[2]	3
		GTA training	3

[2] The elective course can be any MATH 500-level course subject to the approval of a student's academic advisor, provided the prerequisites are satisfied.

Year 2

Fall		Spring	
Course	Units	Course	Units
MATH 520 Linear Optimization Theory	3	MATH 521 Non-linear Optimization Theory	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

Year 3

Fall		Spring	
Course	Units	Course	Units
MATH 554 Mathematical Statistics I	3	MATH 555 Mathematical Statistics II	3
MATH 541 Boundary Value Problems	3	Elective[3]	3
MATH 557 Stochastic Processes I	3	MATH 598 Non-Thesis Research or MATH 698 Non-Dissertation Research	3

Fourth/Fifth/Sixth Years

Electives[3] and MATH 699 Dissertation Research.

[3] Preferred electives: MATH 583 Complex Analysis I; MATH 588 Theory of Differential Equations I; MATH 610 Iterative Methods for Linear Systems; MATH 642 Partial Differential Equations; 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).

A.8 Sample Study Plan for Statistics

Year 1

Fall		Spring	
Course	Units	Course	Units
MATH 586 Introduction to Analysis I	3	MATH 587 Introduction to Analysis II	3
MATH 572 Linear Algebra	3	MATH 510 Numerical Linear Algebra	3
MATH Elective[2]	3	Elective[2]	3
		GTA training	3

[2] The elective course can be any MATH 500-level course subject to the approval of a student's academic advisor, provided the prerequisites are satisfied.

Year 2

Fall		Spring	
Course	Units	Course	Units
MATH 554 Mathematical Statistics I	3	MATH 555 Mathematical Statistics 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

Year 3

Fall		Spring	
Course	Units	Course	Units
MATH 520 Linear Optimization Theory	3	MATH 521 Non-linear Optimization Theory	3
MATH 557 Stochastic Processes I	3	Elective[3]	3
Elective[3]	3	MATH 598 Non-Thesis Research or MATH 698 Non-Dissertation Research	3

Fourth/Fifth/Sixth Years

Electives[3] and MATH 699 Dissertation Research.

[3] Preferred electives: MATH 541 Boundary Value Problems; MATH 583 Complex Analysis I; MATH 588 Theory of Differential Equations I; MATH 559 Stochastic Processes II; MATH 610 Iterative Methods for Linear Systems; MATH 642 Partial Differential Equations; MATH 686 Functional Analysis I. Non-math electives can be any three 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).

Appendix B Other Useful Information and Links

- For faculty research interests by specialty, see the Department Webpage on Research.
- For course descriptions, see the Graduate Catalog.