Mathematics

The Department of Mathematics offers graduate programs of study leading to the M.S. degree in Mathematics or the Ph.D. in Applied Mathematics.

The master's program aims to give students the background to use mathematics in a variety of ways. We train students in mathematical rigor. This provides training in the ability to analyze and solve problems in all walks of life. We also emphasize the development of communication skills of our students (in the classes they take as well as in the classes they teach). Therefore the M.S. program prepares students not only for a career in secondary or junior college level teaching but provides also a very good preparation for students who go into business, industry, or government. In the past our students have been very successful in obtaining employment. Of course, the M.S. program will also prepare students who wish to pursue a Ph.D. in Mathematics but whose undergraduate education did not provide them with a sufficient background in advanced mathematics to directly enter a Ph.D. program.

The PhD program in Applied Mathematics prepares students interested in an academic career in a college or university as well as students interested in a career in business, industry, or government.

Mathematics

Prospective students that want to apply for admission have to provide academic records, three letters of recommendation, a CV, and an Essay. There are more requirements for international students. UAB charges an application fee, for details please see the admissions page of the Graduate School. The Graduate School requires that all applications are submitted online here via the TargetX application portal, required recommendation letters must also be submitted using this application portal.

Degree Offered	M.S.
Director	Dr. Roman Shterenberg
Phone	205-934-2154
E-mail	shterenb@uab.edu
Website	http://www.uab.edu/cas/mathematics

Program Information

The MS program in Mathematics requires 30 semester hours and prepares students for various careers in teaching, academia, industry, and government.

Deadline for Entry Term(s)	Each semester
Deadline for All Application Materials to be in the Graduate School Office	Six weeks before term begins
Number of Evaluation Forms Required	Three
Entrance Tests	English proficiency test is required for international applicants whose native language is not English.

Additional Information

For detailed information, contact Dr. Roman Shterenberg, Mathematics Graduate Program Director, UAB Department of Mathematics, UH 4005, 1402 10th Avenue South, Birmingham, Alabama 35294-1241.

Telephone 205-934-2154

E-mail **shterenb@uab.edu** **(karpeshi@uab.edu)**

Web http://www.uab.edu/cas/mathematics/

Master of Science in Mathematics

The program requires a total of 30 semester hours. All students in their first and second semester are required to take 5 courses (15 credit hours) as indicated below. Students must select 3-5 more courses at 500-level or above (15 credit hours) from courses listed below with options in Applied or Traditional Mathematics. Traditional electives pair well for students who are interested in pure mathematics. The applied mathematics electives are focused on preparing students for careers in data science and data analytics, actuarial science and other industrial mathematics applications. Students planning to continue in the Ph.D. program should take the 600-level versions of the required courses.

Plan I - 30 hours

Requirements		Hours
Required Courses:		15
MA 540	Advanced Calculus I	
or MA 640	MATHEMATICAL ANALYSIS I	
MA 541	Advanced Calculus II	
or MA 641	MATHEMATICAL ANALYSIS II	
MA 534	Algebra I: Linear	
or MA 631	Linear Algebra	
MA 568	Numerical Analysis I	
or MA 660	Numerical Linear Algebra	
MA 585	Intro to Probability	
or MA 685		
Elective courses (choose 3) [1,2]		9
MA 699	Research for Thesis	6
Total Hours		**30**

1. Applied Mathematics based Elective Options include: *Algebra:* MA 631, MA 637, MA 660, *Analysis*: MA 519, MA 544, MA 545, MA 553, MA 554, MA 555, MA 556, MA 561, MA 562, MA 566, MA 642, MA 650, MA 655, MA 661, *Numerical Analysis:* MA 560, MA 567, MA 569, MA 660, MA 665, MA 668, MA 669, *Probability/Statistics:* MA 562, MA 584, MA 586, MA 587, MA 588, MA 589, MA 687, MA 688
2. Traditional/Pure Mathematics based elective options include: *Algebra:* MA 535, MA 631, MA 632, MA 637, *Analysis*: MA 519, MA 544, MA 545, MA 553, MA 554, MA 555, MA 556, MA 642, MA 645, MA 646, MA 648, MA 650, *Geometry:* MA 570, MA 572, MA 573, MA 675, *Probability/Statistics*: MA 586, MA 587, MA 588, MA 687, MA 688, *Topology:* MA 574, MA 575, MA 670, MA 671.

Plan II - 30 hours

Requirements		Hours
Required Courses		15
MA 540	Advanced Calculus I	
or MA 640	MATHEMATICAL ANALYSIS I	

MA 541	Advanced Calculus II	
or MA 641	MATHEMATICAL ANALYSIS II	
MA 534	Algebra I: Linear	
or MA 631	Linear Algebra	
MA 568	Numerical Analysis I	
or MA 660	Numerical Linear Algebra	
MA 585	Intro to Probability	
or MA 685		
Elective Courses (choose 5) [1,2]		15
Total Hours		**30**

1 Applied Mathematics based Elective Options include: *Algebra:* MA 631, MA 637, MA 660, *Analysis*: MA 519, MA 544, MA 545, MA 553, MA 554, MA 555, MA 556, MA 561, MA 562, MA 566, MA 642, MA 650, MA 655, MA 661, *Numerical Analysis:* MA 560, MA 567, MA 569, MA 660, MA 665, MA 668, MA 669, *Probability/Statistics:* MA 562, MA 584, MA 586, MA 587, MA 588, MA 589, MA 687, MA 688

2 Traditional/Pure Mathematics based elective options include: *Algebra:* MA 535, MA 631, MA 632, MA 637, *Analysis:* MA 519, MA 544, MA 545, MA 553, MA 554, MA 555, MA 556, MA 642, MA 645, MA 646, MA 648, MA 650, *Geometry:* MA 570, MA 572, MA 573, MA 675, *Probability/Statistics*: MA 586, MA 587, MA 588, MA 687, MA 688, *Topology:* MA 574, MA 575, MA 670, MA 671.

Applied Mathematics

Prospective students that want to apply for admission have to provide academic records, three letters of recommendation, a CV, an Essay, and scores of the Graduate Record Examination (GRE), General Test. There are more requirements for international students. UAB charges an application fee, for details please see the admissions page of the Graduate School. The Graduate School requires that all applications are submitted online here via the TargetX application portal, required recommendation letters must also be submitted using this application portal.

Program Information

Mathematics has always been divided into a pure and an applied branch. However, these have never been strictly separated. The Ph.D. program in applied mathematics stresses the interconnection between pure mathematics and its diverse applications.

Admission

Only students with a firm foundation in advanced calculus, algebra, and topology are considered for immediate admission to the Ph.D. program. A student lacking this background will be considered for admission to the M.S. program. Upon passing the qualifying examination, a student may transfer to the Ph.D. program. We expect at least a B average in a student's previous work and a score above 158 on each section of the Graduate Record Examination General Test.

Program of Study

Each student in the Ph.D. program has to take the following steps:

- Passing the Joint Program Exam (JPE), also called the Qualifying Exam. The Joint Program Examinations in Real Analysis and Linear Algebra are given during two periods each year (one in May and one in September). During each period a student may take one or both of the exams but subject to the following restrictions: (1) either exam may be attempted at most twice and (2) a student may participate in exams during no more than three periods.
- Completing 54 semester hours of graduate courses. The grade of each course has to be at least a B. The student's supervisory committee and the Joint Program Committee must approve the selection of courses. At least 18 hours must be in a major area of concentration, selected so that the student will be prepared to conduct research in an area of applied mathematics, while at least 12 hours have to be in a minor area of study, which is a subject outside mathematics. No courses counted towards an MS degree can be used. There are additional requirements by the UAB Graduate School, see "Minimum Course Requirements" in the Graduate Catalog.
- Passing a language or tool of research exam.
- Passing the Comprehensive Exam, which consists of a written part and an oral part.
- Preparing a dissertation, which must be a genuine contribution to mathematics.
- Passing the Final Examination (thesis defense).

Additional Information

For detailed information, contact Dr. Ioulia Karpechina, Mathematics Graduate Program Director, UAB Department of Mathematics, UH 4005, 1402 10th Avenue South, Birmingham, Alabama 35294-1241.

Telephone: 205-934-2154

Web http://www.uab.edu/cas/mathematics/

Courses

MA 501. History of Mathematics I. 3 Hours.
Development of mathematical principles and ideas from a historical viewpoint, and their cultural, educational and social significance; earliest origins through Newton and Leibnitz.
Prerequisites: MA 125 [Min Grade: C] or MA 225 [Min Grade: C]

MA 502. History of Mathematics II. 3 Hours.
Development of mathematical principles and ideas from a historical viewpoint, and their cultural, educational and social significance; Newton and Leibnitz through early 20th century.
Prerequisites: MA 501 [Min Grade: B] or MA 311 [Min Grade: B]

MA 511. Integrating Mathematical Ideas. 3 Hours.
This course will integrate ideas from algebra, geometry, probability, and statistics. Emphasis will be on using functions as mathematical models, becoming fluent with multiple representations of functions, and choosing the most appropriate representations for solving a specific problem. Students will be expected to communicate mathematics verbally and in writing through small group, whole group, and individual interactions.

MA 513. Mathematics for Elementary and Middle School Teachers. 3 Hours.
Problem solving experiences, inductive and deductive reasoning, patterns and functions, some concepts and applications of geometry for elementary and middle school teachers. Topics include linear and quadratic relations and functions and some cubic and exponential functions. Number sense with the rational number system including fractions, decimals and precents will be developed in problem contexts. An emphasis will be on developing algebriac thinking and reasoning.

MA 514. Mathematics for Elementary and Middle School Teachers. 3 Hours.
Problem solving experiences, inductive reasoning, concepts and applications of geometry and proportional reasoning for elementary and middle school teachers. Topics include analysis of one, two and three dimensional feature of real objects, ratio and proportionality, similarity and congruence, linear, area, and volume measurement, and the development of mathematically convincing arguments. An emphasis will be on developing thinking and reasoning.
Prerequisites: MA 313 [Min Grade: C] or MA 513 [Min Grade: C]

MA 515. Probabilistic & Stat Reasoning. 3 Hours.
Descriptive and inferential statistics, probability, estimation, hypothesis testing. Reasoning with probability and statistics is emphasized.
Prerequisites: MA 313 [Min Grade: C] or MA 513 [Min Grade: C]

MA 516. Numerical Reasoning. 3 Hours.
Develop understanding of number and improve numerical reasoning skills specifically with regard to place value, number relationship that build fluency with basis facts, and computational proficiency; developing a deep understanding of numerous diverse computational algorithms; mathematical models to represent fractions, decimals and percents, equivalencies and operations with fractions, decimals and percents; number theory including order of operations, counting as a big idea, properties of number, primes and composites, perfect, abundant and significant numbers, and figurate numbers; inductive and deductive reasoning with number.
Prerequisites: MA 313 [Min Grade: C] or MA 513 [Min Grade: C]

MA 517. Extending Algebraic Reasoning. 3 Hours.
Extending Algebraic Reasoning. Extending algebraic and functional reasoning to polynomials, rational, exponential, and logarithmic functions; problem-solving involving transfer among representations (equation, graph, table); proof via symbolic reasoning, contradiction, and algorithm; interpretation of key points on graphs (intercepts, slope, extrema); develop facility and efficiency in manipulating symbolic representations with understanding; appropriate use of technology and approximate versus exact solutions; functions as models.
Prerequisites: MA 313 [Min Grade: C] or MA 513 [Min Grade: C]

MA 519. Special Topics for Teachers. 1-4 Hour.
With permission of instructor, may be used as continuation of any of MA 513 through 518. May be repeated for credit when topics vary.
Prerequisites: MA 125 [Min Grade: C] or MA 225 [Min Grade: C]

MA 534. Algebra I: Linear. 3 Hours.
Abstract vector spaces, subspaces, dimension, bases, linear transformation, matrix algebra, matrix representations of linear transformations, determinants.
Prerequisites: MA 124 [Min Grade: C] or MA 126 [Min Grade: C] or MA 226 [Min Grade: C]

MA 535. Algebra II: Modern. 3 Hours.
Rings, including the rings of integers and of polynomials, integral domains, fields and groups. Homomorphism, isomorphism. As time permits, Galois theory, semi-groups, quotient groups, models, or other areas of algebra may be included. Students present proofs from a list of pre-assigned theorems to the class. Logical correctness and proper mathematical proof-writing style are assessed.
Prerequisites: MA 434 [Min Grade: C] or MA 534 [Min Grade: C]

MA 540. Advanced Calculus I. 3 Hours.
This class covers sequences and series of real numbers, supremum and infimum limits for subsets of the real numbers, the theorem of Bolzano-Weierstrass, Cauchy sequences, continuous functions, intermediate value theorem, uniform continuity, monotone functions. In addition, derivatives - mean value theorem, Taylor's theorem for real functions on a real interval, Riemann integration for functions on a real interval, improper integrals.

MA 541. Advanced Calculus II. 3 Hours.
This class covers sequences of functions, including pointwise and uniform convergence and the specifics of interchanging limits. Series of functions, including the M-test, differentiation/integration and real analytic functions will be studied. We introduce metric spaces and develop the notions of 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.
Prerequisites: MA 540 [Min Grade: C]

MA 544. Vector Analysis. 3 Hours.
Review and applications of multiple integrals, Jacobians and change of variables in multiple integrals; line and surface integrals; theorems of Green, Gauss, and Stokes with application to the physical sciences; computation in spherical and cylindrical coordinates.
Prerequisites: MA 227 [Min Grade: C]

MA 545. Complex Analysis. 3 Hours.
Analytic functions, complex integration and Cauvchy’s theorem, Taylor and Laurent series, calculus of residues and applications, conformal mappings.
Prerequisites: MA 227 [Min Grade: C]

MA 553. Fourier Analysis. 3 Hours.
Fourier series, including odd/even functions expansions, complex power series, generalized Fourier series. Convergence, applications to partial differential equations. Fourier transform: basic properties, inversion of the FT, windowing, relation to the Laplace transform. Applications to partial differential equations. Wavelets and signal processing basic functions, transforming wavelets, short time Fourier transform.
Prerequisites: MA 252 [Min Grade: C]

MA 554. Intermediate Differential Equations. 3 Hours.
Topics from among Frobenius series solutions, Sturm-Liouville systems, nonlinear equations, and stability theory.
Prerequisites: MA 252 [Min Grade: C]

MA 555. Partial Differential Equations I. 3 Hours.
Classification of second order partial differential equations; background on eigenfunction expansions and Fourirer series; integrals and transforms; solution of the wave equation, reflection of waves; solution of the heat equation in bounded and unbounded media; Laplace s equations, Dirichlet and Neumann problems.
Prerequisites: MA 252 [Min Grade: C]

MA 556. Partial Differential Equations II. 3 Hours.
Classification of second order partial differential equations; background on eigenfunction expansions and Fourirer seriers; integrals and transforms; solutions of the wave equations, reflection of waves; solution of heat equation in bounded and unbounded media; Laplace s equations, Dirichlet and Neumann problems.
Prerequisites: MA 252 [Min Grade: C]

MA 560. Scientific Programming. 3 Hours.
Programming and mathematical problem solving using Matlab, Python, FORTRAN or C++. Emphasizes the systematic development of algorithms and numerical methods. Topics include computers, floating point arithmetic, iteration, functions, arrays, Matlab graphics, image processing, robotics, GNU/Linux operating system, solving linear systems and differential equation arising from practical situations, use of debuggers and other debugging techniques, and profiling; use of callable subroutine packages like LAPACK and differential equation routines; parallel programming. Assignments and projects are designed to give students a computational sense through complexity, dimension, inexact arithmetic, randomness, simulation and the role of approximation.
Prerequisites: MA 126 [Min Grade: C] or MA 226 [Min Grade: C]

MA 561. Modeling with Partial Differential Equations. 3 Hours.
Practical examples of partial differential equations; derivation of partial differential equations from physical laws; introduction to COMSOL Multiphysics using practical examples; specialized modeling projects selected from topics such as groundwater modeling, scattering of waves, medical and industrial imaging, traffic flows, continuum mechanics and deformation of solids, Fluid mechanics including the class boat race, financial derivative modeling, and acoustic and electromagnetic wave applications. Written project reports required for homework assignments in addition to online quizzes. Quantitative Literacy and Writing are significant components of this course.
Prerequisites: MA 227 [Min Grade: C] or MA 252 [Min Grade: C]

MA 562. Intro to Stochastic Differential Equations. 3 Hours.
Stochastic differential equations arise when random effects are introduced into the modeling of physical systems. Topics include Brownian motion and Wiener processes, stochastic integrals and the Ito calculus, stochastic differential equations, and applications to financial modeling, including option pricing.
Prerequisites: MA 485 [Min Grade: C] or MA 585 [Min Grade: C]

MA 566. Introduction to Optimization. 3 Hours.
Optimization is important in many decision making problems in various areas like engineering, economics and machine learning. Optimization theory deals with finding the best solution(s) or variables of a given objective function. Recently, the area of optimization has received much attention due to the development of highly efficient computational methods for data analysis. The scope of this course covers linear algebra, unconstrained optimization, linear programming, and nonlinear constrained optimization. The topics include linear algebra, linear program, duality, network flows, simplex method, non-simplex method, gradient and conjugate methods, neural network, genetic algorithm and convex optimization. The course will also introduce optimization algorithms and codes via python and matlab.
Prerequisites: MA 126 [Min Grade: C] or MA 226 [Min Grade: C]

MA 567. Gas Dynamics. 3 Hours.
Euler s equations for inviscid flows, rotation and vorticity, Navier-Stok.
Prerequisites: MA 252 [Min Grade: C] and (MA 360 [Min Grade: C] or MA 560 [Min Grade: C])

MA 568. Numerical Analysis I. 3 Hours.
Sources of error and conditioning. Solution of algebraic equations in one variable: Bisection method, Fixed point iteration method, Newton's method and its variants, and their conver-gence. Approximation and interpolation: Monomial and Lagrange interpolations, Newton's divided difference form, Hermite interpolation, and Cubic spline. Numerical differentiation: Deriving formulas using Taylor series, Truncation error, and Richardson extrapolation. Nu-merical integration: Open and closed Newton-Cotes formulas, Composite numerical inte-gration, Romberg integration, and Gaussian quadrature. Solution of Ordinary Differential Equations (ODEs): Initial value ODEs, Euler's method, Runge-Kutta methods, Multi-step methods, and Boundary value ODEs. Practice on the computer.
Prerequisites: MA 252 [Min Grade: C] and MA 227 [Min Grade: C]

MA 569. Numerical Analysis II. 3 Hours.
Direct methods for linear systems: Gaussian elimination and back substitution, Pivoting strategies, Matrix factorization: LU and Cholesky decomposition, and Estimating errors and the condition number. Iterative solution of systems of nonlinear equations: Fixed points for functions of several variables, Newton's method, Quasi-Newton methods, Steep-est Descent method. Evaluation of eigenvalues and eigenvectors of matrices: Existence and uniqueness, Orthogonal matrices and similarity transformations, Power method and vari-ants, Generalized eigenvalue problems, Householder's Method, QR algorithm, and Singular Value Decomposition (SVD). Practice on the computer.
Prerequisites: MA 568 [Min Grade: C]

MA 570. Differential Geometry. 3 Hours.
Theory of curves and surfaces: Frenet formulas for curves, first and second fundamental forms of surfaces. Global theory; abstract surfaces, manifolds, Riemannian geometry.
Prerequisites: MA 126 [Min Grade: C] or MA 226 [Min Grade: C]

MA 572. Geometry I. 3 Hours.
The axiomatic method; Euclidean geometry including Euclidean constructions, basic analytic geometry, transformational geometry, and Klein's Erlangen Program. Students present proofs from a list of pre-assigned theorems to the class. Logical correctness and proper mathematical proof-writing style are assessed.
Prerequisites: MA 125 [Min Grade: C] or MA 225 [Min Grade: C]

MA 573. Geometry II. 3 Hours.
Analytical geometry, Birkhoff s axioms, and the complex plane; structure and representation of Euclidean isometries; plane symmetries; non-Euclidean (hyperbolic) geometry and non-Euclidean transformations; fractal geometry; algorithmic geometry. Course integrates intuition/exploration and proof/explanation. Project and report or oral presentation required.
Prerequisites: MA 472 [Min Grade: C] or MA 572 [Min Grade: C]

MA 574. Intro to Topology I. 3 Hours.
Separable metric spaces, basis and sub-basis, continuity, compactness, completeness, Baire category theorem, countable products, general topological spaces, Tychonov theorem.
Prerequisites: MA 126 [Min Grade: C] or MA 226 [Min Grade: C]

MA 575. Intro to Topology II. 3 Hours.
Separable metric spaces, basis and sub-basis, continuity, compactness, completeness, Baire category theorem, countable products, general topological spaces, Tychonov theorem.
Prerequisites: MA 574 [Min Grade: C]

MA 584. Mathematical Finance. 3 Hours.
The notion of no arbitrage. Interest, compounding, bonds. Review of mean, variance, and covariance. Portfolio management: risk and return. Forwards and Futures. Put-call parity. Martingales and conditional expectation. The binomial model. Fundamental theorems of asset pricing. Brownian motion (heuristics). Ito's formula and Girsanov's theorem (heuristics). The Black-Scholes-Merton formula. Interest rates. The binomial model for stochastic interest rates.
Prerequisites: (MA 260 [Min Grade: C] or MA 434 [Min Grade: C] or MA 435 [Min Grade: C]) and (MA 485 [Min Grade: C] or MA 585 [Min Grade: C])

MA 585. Intro to Probability. 3 Hours.
Combinatorics, probability spaces, combinatorics, conditional probabilities and independence, Bayes rule, discrete and continuous distributions, mean value and variance, random variables, joint distributions, correlation, Law of Large Numbers, Central Limit Theorem.
Prerequisites: MA 227 [Min Grade: C] and MA 260 [Min Grade: C]

MA 586. Mathematical Statistics I. 3 Hours.
Sampling techniques and data analysis, Describing data distributions, Point estimation, Statistical inference, Confidence intervals, Tests for binomials, Tests for normals, Hypothesis testing, Two-factor analysis, Goodness-of-Fit test, Contingency tables.
Prerequisites: MA 485 [Min Grade: C] or MA 585 [Min Grade: C] or MA 685 [Min Grade: C]

MA 587. Advanced Probability. 3 Hours.
Foundation of probability, conditional probabilities, and independence, Bayes theorem, discrete and continuous distributions, joint distributions, conditional and marginal distributions, convolution, moments and moment generation function, multivariable normal distribution and sums of normal random variables, Markov chains.
Prerequisites: MA 485 [Min Grade: C] or MA 585 [Min Grade: C] or MA 685 [Min Grade: C]

MA 588. Mathematical Statistics II. 3 Hours.
The course is designed as a continuation of MA586 for Master students (both mathematics and non-mathematics majors) interested in Statistics and looking to gain the skills necessary for a wide variety of professions like actuaries, analytics, banking etc. Topics to be covered: Association and prediction: general linear models (GLM), multiple regression: testing hypothesis and correlations, polynomial regression, one-way and two-way ANOVA for multiple regression, GLM assumption diagnostics, polynomial regression, best model selection, checking model adequacy.
Prerequisites: MA 485 [Min Grade: C] or MA 486 [Min Grade: C] or MA 585 [Min Grade: C] or MA 586 [Min Grade: C] or MA 587 [Min Grade: C] or MA 685 [Min Grade: C] or MA 687 [Min Grade: C]

MA 589. STATISTICAL TECHNIQUES FOR MACHINE LEARNING AND BIG DATA. 3 Hours.
Topics of statistical learning and how to implement these methods by using R/Python. The course will cover major statistical learning methods and concepts for both supervised and unsupervised learning, such as sampling algorithms; nonparametric tests; model assessment and selection; classification, clustering; and big data analysis.
Prerequisites: MA 486 [Min Grade: B] or MA 586 [Min Grade: B]

MA 590. Mathematics Seminar. 1-3 Hour.
This course covers special topics in mathematics and the applications of mathematics. May be repeated for credit when topics vary. Prerequisites vary with topics.

MA 591. Mathematics Seminar. 1-3 Hour.
This course covers special topics in mathematics and the applications of mathematics. May be repeated for credit when topics vary. Prerequisites vary with topics.

MA 592. Special Topics in Mathematics. 1-3 Hour.
This course covers special topics in mathematics and the applications of mathematics. May be repeated for credit when topics vary. Prerequisites vary with topics.

MA 593. Special Topics in Mathematics. 1-3 Hour.
This course covers special topics in mathematics and the applications of mathematics. May be repeated for credit when topics vary. Prerequisites vary with topics.

MA 594. Special Topics in Mathematics. 1-6 Hour.
This course covers special topics in mathematics and the applications of mathematics. May be repeated for credit when topics vary. Prerequisites vary with topics.

MA 595. Special Topics in Mathematics. 1-6 Hour.
This course covers special topics in mathematics and the applications of mathematics. May be repeated for credit when topics vary. Prerequisites vary with topics.

MA 596. Special Topics in Mathematics. 1-12 Hour.
This course covers special topics in mathematics and the applications of mathematics. May be repeated for credit when topics vary. Prerequisites vary with topics.

MA 597. Special Topics in Mathematics. 1-12 Hour.
This course covers special topics in mathematics and the applications of mathematics. May be repeated for credit when topics vary. Prerequisites vary with topics.

MA 598. Research in Mathematics. 1-12 Hour.
This course covers special topics in mathematics and the applications of mathematics. May be repeated for credit when topics vary. Prerequisites vary with topics.

MA 599. Research in Mathematics. 1-12 Hour.
This course covers special topics in mathematics and the applications of mathematics. May be repeated for credit when topics vary. Prerequisites vary with topics.

MA 610. Intro to Set Theory. 3 Hours.
Set theory, products, relations, orders and functions, cardinal and ordinal numbers, transfinite induction, axiom of choice, equivalent statements.

MA 631. Linear Algebra. 3 Hours.
Vector spaces and their bases; linear transformations; eigenvalues and eigenvectors: Jordan canonical form; multilinear algebra and determinants; norms and inner products.

MA 632. Abstract Algebra. 3 Hours.
Propositional and predicate logic; set, relations, and functions; the induction principle; Groups, in particular symmetry groups, permutations groups, and cyclic groups; cosets and quotient groups; group homomorphisms; rings, integral domains, and fields; ideals and rings homomorphisms; factorization; polynomial rings.
Prerequisites: MA 534 [Min Grade: B] or MA 631 [Min Grade: B]

MA 637. Graph Theory and Combinatorics. 3 Hours.
Topics covered include specialized terminology and notation; eulerian and hamiltonian graphs; matrices of graphs and information about graphs obtained from matrices; topological graph theory, including planarity theorems of Kuratowski, Whitney and MacLane and also embeddings of graphs in surfaces of higher genus and in nonorientable surfaces; Menger's theorem and network flows; the graph reconstruction problem; counting techniques, including the Pigeonhole Principle and the use of generating functions; Dilworth's theorem; Sperner's lemma; finite and infinite Ramsey theory; matching theory and the classical theorem of Philip Hall; and, if time permits, the Polya/Redfield theory of enumerations.

MA 640. MATHEMATICAL ANALYSIS I. 3 Hours.
The course introduces basic objects in analysis, such as the structure of the real numbers, the rationals, sequences of real numbers, the concepts of lim, lim inf; lim inf Further on, the Bolzano-Weierstrass theorem and the Cauchy sequences are discussed in detail. The relevant material is in Sections 2.1, 2.2, 2.3, 2.4, [1]. Next, another basic object, continuous functions is introduced and analyzed. In particular, the min-max theorem, the intermediate value theorem, uniform continuity for continuous functions and its relation with continuity, Sections 3.2, 3.3, 3.4, 3.5, 3.6 [1]. Another classical object, the derivative of a function of one variable is introduced. Classical results such as the mean value theorem, the Taylor's theorem for real functions on a real interval are covered along with applications, Sections 4.1, 4.2, 4.3 [1]. Finally, the theory of the Riemann integration for functions on a real interval is build. The relevant material is contained in Sections 5.1, 5.2, 5.3, 5.5, [1].

MA 641. MATHEMATICAL ANALYSIS II. 3 Hours.
The course is a continuation of MA 640 and provides a necessary prerequisite to a number of standard higher Ph.D. level courses, such as Topology, Measure theory, Numerical Analysis, Functional Analysis etc. Speci#cally, sequences of functions are introduced, and of particular interest will be pointwise and uniform convergence, interchange of limits to name a few. This is mostly a prerequisite to-ward an important object in the theory, namely series of functions. Various convergence tests are discussed and analyzed: comparison test, M - test, Dirichlet test, integral test. Finally, the theory of di#erentiation and integration for series is developed, including properties of power series/real analytic functions. The course #nishes with a short introduction to some basic topological objects. Speci#cally, metric spaces are introduced. Important concepts in this context include open and closed sets, completeness and compactness, Cauchy sequences. Continuous functions between metric spaces and uniform continuity of such functions are discussed, together with various applications. Finally, the Heine-Borel and related theorems, the contraction mapping theorem, and the Arzela-Ascoli theorem are proved in detail, together with relevant applications.
Prerequisites: MA 640 [Min Grade: B]

MA 642. Calculus of Several Variables. 3 Hours.
Functions of several variables; total and partial derivatives; the Implicit Function Theorem; integration of differential forms; Stokes's Theorem.
Prerequisites: MA 541 [Min Grade: B]

MA 645. Real Analysis I. 3 Hours.
Abstract measures and integration; positive Borel measures; Lp-spaces.
Prerequisites: MA 642 [Min Grade: B] and MA 670 [Min Grade: B]

MA 646. Real Analysis II. 3 Hours.
Complex measures and the Radon-Nikodym theorem; differentiation; integration on product spaces and Fubini s theorem.
Prerequisites: MA 645 [Min Grade: B]

MA 648. Complex Analysis. 3 Hours.
The algebraic and topological structure of the complex plane; analytic functions; Cauchy's integral theorem and integral formula; power series; elementary functions; and their Riemann surfaces; isolated singularities and residues; the Laurent expansion; the Riemann mapping theorem.
Prerequisites: MA 642 [Min Grade: B]

MA 650. Differential Equations. 3 Hours.
Separable, linear, and exact first order equations; existence and uniqueness theorems; continuous dependence of solutions on data and initial conditions; first order systems and higher order equations; stability for two-dimensional linear systems; higher order linear systems; boundary value problems; stability theory.
Prerequisites: MA 642 [Min Grade: B]

MA 655. Partial Differential Equations. 3 Hours.
This course covers first order partial differential equations, elliptic equations, parabolic equations, and hyperbolic equations.
Prerequisites: MA 642 [Min Grade: C] or MA 650 [Min Grade: C]

MA 660. Numerical Linear Algebra. 3 Hours.
Vector and matrix norms. Singular Value Decomposition (SVD). Stability, condition num-bers, and error analysis. QR factorization. Least squares problems; Computation of eigen-values and eigenvectors: Power method and variants. Iterative methods for linear systems: Stationary iteration and relaxation methods, Convergence of stationary methods, Conju-gate gradient method, Krylov subspace methods, and Multigrid methods.
Prerequisites: MA 631 [Min Grade: B]

MA 661. Modeling With PDE. 3 Hours.
Practical examples of partial differential equations; derivation of partial differential equations from physical laws; introduction to MATLAB and its PDE Toolbox, and other PDE packages such as FEMLAB using practical examples; brief discussion of finite difference and finite element solution methods; introduction to continuum mechanics and classical electrodynamics; parallel programming using MPI and the mathematics department Beowulf system; specialized modeling projects in topics such as groundwater modeling, scattering of waves, medical and industrial imaging, fluid mechanics, and acoustic and electromagnetic applications.

MA 665. Partial Differential Equations: Finite Differential Methods. 3 Hours.
Review of difference methods for ordinary differential equations including Runge-Kutta, multi-step, adaptive step-sizing, and stiffness; finite difference versus finite element; elliptic boundary value problems; iterative solution methods, self-adjoint elliptic problems; parabolic equations including consistency, stability, and convergence, Crank-Nicolson method, method, method of lines; first order hyperbolic systems and characteristics Lax-Wendroff schemes, methods of lines for hyperbolic equations.
Prerequisites: MA 360 [Min Grade: C] or MA 560 [Min Grade: C] or MA 455 [Min Grade: C] or MA 555 [Min Grade: C]

MA 668. Numerical Analysis I. 3 Hours.
Iterative solution of algebraic equations in one variable: Bisection method, Fixed point iter-ation method, and Newton’s method and it variants. Review of linear algebra background: Basic concept of linear algebra, Vector and matrix norms, Special classes of matrices: Sym-metric positive definite matrices, Orthogonal vectors and matrices, and Singular values. Direct methods for solving linear systems: Gaussian elimination, LU decomposition, Piv-oting strategies, Cholesky decomposition, Computational complexity, Sparse matrix, Per-mutation and ordering strategies, Estimating errors and condition number. Linear least squares problems: Normal equations. Polynomial interpolation: General approximation and interpolation, Monomial, Lagrange, and Newton’s divided difference polynomial in-terpolations, Chebyshev interpolation, Piecewise polynomial interpolation and their error analysis. Numerical integration: Basic quadrature algorithms, Composite numerical inte-gration, Gaussian and Adaptive quadrature, and their error analysis. Numerical solution of ordinary differential equations: Euler’s method, Multistep methods, stability and stiffness, Explicit vs. implicit methods, Truncation error, and Order of convergence.
Prerequisites: MA 670 [Min Grade: B]

MA 669. Numerical Analysis II. 3 Hours.
Numerical solution of partial differential equations using Finite Element Methods (FEM) which includes, Finite element spaces, Sobolev spaces, Interpolating theory, Variational for-mulation, Lax-Milgram Theorem, Stability analysis, Error estimation, and implementation of FEM library in one and higher dimensions problems.
Prerequisites: MA 668 [Min Grade: B]

MA 670. Topology I. 3 Hours.
Definition of topologies; closure; continuity; finite product topology; metric spaces; connectedness; completeness and compactness (in particular, in metric spaces).
Prerequisites: MA 631 [Min Grade: B] or MA 540 [Min Grade: B] or MA 440 [Min Grade: B]

MA 671. Topology II. 3 Hours.
Product topology; quotient spaces; countability and separation axioms; Tychonoff's theorem; homotopy; manifolds; partitions of unity.
Prerequisites: MA 670 [Min Grade: B]

MA 675. Differential Geometry. 3 Hours.
Local and global theory of curves and surfaces; Fenchel s theorem; the first and second fundamental forms; surface area; Bernstein s theorem; Gauss theorema egregium; local intrinsic geometry of surfaces; Riemannian surfaces; Lie derivatives; covariant differentiation; geodesics; the Reimanncurvature tensor; the second variation of arc length; selected topics in the global theory of surfaces.
Prerequisites: MA 642 [Min Grade: C]

MA 685. Probability Theory. 3 Hours.
Combinatorics, probability spaces, conditional probabilities and independence, Bayes rule, discrete and continuous distributions, mean value and variance, moment generation function, joint distributions, correlation, Law of Large Numbers, Central Limit Theorem, random walks, Poisson process.

MA 687. Advanced Probability. 3 Hours.
Probability space, random variables, expected value, variance, joint distribution of a sequence of random variables, weak and strong Law of Large Numbers, Fourier transform of a distribution, Central Limit Theorem, elements of Martingale Theory.
Prerequisites: (MA 585 [Min Grade: C] or MA 685 [Min Grade: C]) and MA 646 [Min Grade: B]

MA 688. Advanced Statistics. 3 Hours.
Parameter estimations, Maximum likelihood estimation, Sufficient statistic, Rao-Cramer bound, Hypothesis testing, Neyman-Pearson Lemma, p-value, Regression, Order statistics, Nonparametric methods: Wilcoxon test, Run test, and Kolmogorov-Smirnov test, Anderson-Darling test, P-P plot, Q-Q plot, testing for distribution type, location and scale parameters, mean squared error.
Prerequisites: MA 585 [Min Grade: C] or MA 586 [Min Grade: C] or MA 587 [Min Grade: C] or MA 685 [Min Grade: C] or MA 687 [Min Grade: C]

MA 690. Mathematics Seminar. 1-3 Hour.
This course covers special topics in mathematics and the applications of the mathematics. May be repeated for credit when topics vary. Prerequisites vary with topics.

MA 691. Mathematics Seminar. 1-3 Hour.
This course covers special topics in mathematics and the applications of mathematics. May be repeated for credit when topics vary. Prerequisites vary with topics.

MA 692. Special Topics in Mathematics. 1-3 Hour.
This course covers special topics in mathematics and the applications of the mathematics. May be repeated for credit when topics vary. Prerequisites vary with topics.

MA 693. Special Topics in Mathematics. 1-3 Hour.
This course covers special topics in mathematics and the applications of the mathematics. May be repeated for credit when topics vary. Prerequisites vary with topics.

MA 694. Special Topics in Mathematics. 1-6 Hour.
This course covers special topics in mathematics and the applications of the mathematics. May be repeated for credit when topics vary. Prerequisites vary with topics.

MA 695. Special Topics in Mathematics. 1-6 Hour.
This course covers special topics in mathematics and the applications of the mathematics. May be repeated for credit when topics vary. Prerequisites vary with topics.

MA 696. Special Topics in Mathematics. 1-12 Hour.
This course covers special topics in mathematics and the applications of the mathematics. May be repeated for credit when topics vary. Prerequisites vary with topics.

MA 697. Special Topics in Mathematics. 1-12 Hour.
This course covers special topics in mathematics and the applications of the mathematics. May be repeated for credit when topics vary. Prerequisites vary with topics.

MA 698. M Lev Non-Thesis Res. 1-12 Hour.
This course covers special topics in mathematics and the applications of the mathematics. May be repeated for credit when topics vary. Prerequisites vary with topics.

MA 699. Research for Thesis. 1-12 Hour.
This course covers special topics in mathematics and the applications of the mathematics. May be repeated for credit when topics vary. Prerequisites vary with topics.
Prerequisites: GAC M

MA 740. Advanced Complex Analysis. 3 Hours.
This course covers special topics in mathematics and the applications of mathematics. May be repeated for credit when topics vary. Prerequisites: Having passed the Qualifying Exam or permission of instructor.

MA 745. Functional Analysis I. 3 Hours.
Normed and Banach spaces; inner product and Hilbert spaces; linear functionals and dual spaces; operators in Hilbert spaces; theory of unbounded sesquilinear forms; Hahn-Banach, open mapping and closed graph theorems; spectral theory.
Prerequisites: MA 646 [Min Grade: B]

MA 746. Functional Analysis II. 3 Hours.
This course covers special topics in mathematics and the applications of mathematics. May be repeated for credit when topics vary. Prerequisites vary with topics.

MA 747. Spectral Theory. 3 Hours.
Hilbert space; Bessel's inequality; Parseval's formula; bounded and un-bounded linear operators; representation theorems; the Friedrichs extension; the spectral theorem for self-adjoint operators; spectral theory for Schrodinger operators.
Prerequisites: MA 646 [Min Grade: B]

MA 748. Fourier Analysis. 3 Hours.
Lp spaces, Real and complex interpolation, Fourier Transform and applications. Singular integrals and Littlewood-Paley theory. Method of stationary phase, Strichartz estimates. Applications to the heat equation, the Schroedinger equation.
Prerequisites: MA 645 [Min Grade: B] and MA 648 [Min Grade: B] and MA 655 [Min Grade: B]

MA 749. Theory of Distribution. 3 Hours.
The space of test functions. The space of distributions. Main properties of distributions. Completeness of the space of distributions. Support of a distribution. Sochotzki formula. Derivatives of distributions and their properties. The structure of a distribution with a point support. Direct products and convolutions of distributions and their properties. Regularization of distributions. The space of test functions of rapid decay. The space of distributions of slow growth and their properties. Fourier transform of test functions of rapid decay and its properties. Parseval's identity. Fourier transform of distributions of slow growth. Fourier transform of direct products and convolutions of distributions of slow growth. Applications of distributions to partial differential equations. Fundamental solutions of partial differential equations.
Prerequisites: MA 645 [Min Grade: B]

MA 750. Advanced Ordinary Differential Equations. 3 Hours.
This course covers special topics in mathematics and the applications of mathematics. May be repeated for credit when topics vary. Prerequisites vary with topics.

MA 753. Nonlinear Analysis. 3 Hours.
Selected topics including degree theory, bifurcation theory, and topological methods.

MA 755. Advanced Partial Differential Equations. 3 Hours.
This course covers special topics in mathematics and the applications of mathematics. May be repeated for credit when topics vary. Prerequisites vary with topics.
Prerequisites: MA 645 [Min Grade: B]

MA 760. Dynamical Systems I. 3 Hours.
Continuous dynamical systems; limit sets; centers of attraction; recurrence; stable and wandering points; flow boxes, and monotone sequences in planar dynamical systems; Poincare-Bendixson theorem.

MA 761. Dynamical Systems II. 3 Hours.
Discrete dynamical systems; hyperbolicity; symbolic dynamics; chaos; homoclinic orbits; bifurcations; attractors(theory and examples).

MA 770. Continuum Theory. 3 Hours.
Pathology of compact connected metric spaces; inverse limits; boundary bumping theorem; Hahn-Muzukiewicz theorem; composants; chainable and circle-like continua; irreducibility; separation; unicoherence; indecomposability.

MA 772. Complex Analytic Dynamics. 3 Hours.
Riemann surfaces; polynomial dynamics, rational functions and entire functions; fixed point theory; Mandelbrot set; Julia sets; prime ends; conformal mappings.

MA 774. Algebraic Topology. 3 Hours.
Covering spaces; introduction to homotopy theory; singular homology, cohomology.

MA 776. Advanced Differential Geometry. 3 Hours.
This course covers special topics in mathematics and the applications of mathematics. May be repeated for credit when topics vary. Prerequisites vary with topics.

MA 781. Differential Topology I. 3 Hours.
A study of differentiable structures on manifolds, primarily from a global viewport: smooth mappings including diffeomorphisms, immersions and submersions; submanifolds and transversality.
Prerequisites: MA 645 [Min Grade: B] and MA 675 [Min Grade: B]

MA 782. Differential Topology II. 3 Hours.
A continuation of MA 781, with further applications such as Morse Theory.

MA 790. Mathematics Seminar. 1-3 Hour.
This course covers special topics in mathematics and the applications of mathematics. May be repeated for credit when topics vary. Prerequisites vary with topics.

MA 791. Mathematics Seminar. 1-3 Hour.
This course covers special topics in mathematics and the applications of mathematics. May be repeated for credit when topics vary. Prerequisites vary with topics.

MA 792. Special Topics in Mathematics. 1-3 Hour.
This course covers special topics in mathematics and the applications of mathematics. May be repeated for credit when topics vary. Prerequisites vary with topics.

MA 793. Special Topics in Mathematics. 1-3 Hour.
This course covers special topics in mathematics and the applications of mathematics. May be repeated for credit when topics vary. Prerequisites vary with topics.

MA 794. Special Topics in Mathematics. 1-6 Hour.
This course covers special topics in mathematics and the applications of mathematics. May be repeated for credit when topics vary. Prerequisites vary with topics.

MA 795. Special Topics in Mathematics. 1-6 Hour.
This course covers special topics in mathematics and the applications of mathematics. May be repeated for credit when topics vary. Prerequisites vary with topics.

MA 796. Special Topics in Mathematics. 1-12 Hour.
This course covers special topics in mathematics and the applications of mathematics. May be repeated for credit when topics vary. Prerequisites vary with topics.

MA 797. Special Topics in Mathematics. 1-12 Hour.
This course covers special topics in mathematics and the applications of mathematics. May be repeated for credit when topics vary. Prerequisites vary with topics.

MA 798. Non-Dissertation Research and Preparation for Comp. 1-12 Hour.
This course covers special topics in mathematics and the applications of the mathematics. May be repeated for credit when topics vary. Prerequisites vary with topics.

MA 799. Dissertation Research. 1-12 Hour.
This course covers special topics in mathematics and the applications of the mathematics. May be repeated for credit when topics vary. Prerequisites vary with topics.
Prerequisites: GAC Z