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.

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.

Entrance Tests
English proficiency test is required for international applicants whose native language is not English.

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
E-mail 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. Based on their chosen track (traditional/pure or applied mathematics), students must select 5 more courses at 500-level or above (15 credit hours). The traditional track is for students who are interested in pure mathematics. The applied mathematics track is 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 Applied Mathematics

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Required Courses:</td>
<td>15</td>
</tr>
<tr>
<td>MA 540 Advanced Calculus I or MA 640 MATHEMATICAL ANALYSIS I</td>
<td></td>
</tr>
<tr>
<td>MA 541 Advanced Calculus II or MA 641 MATHEMATICAL ANALYSIS II</td>
<td></td>
</tr>
<tr>
<td>MA 534 Algebra I: Linear or MA 631 Linear Algebra</td>
<td></td>
</tr>
<tr>
<td>MA 588 Numerical Analysis I or MA 660 Numerical Linear Algebra</td>
<td></td>
</tr>
<tr>
<td>MA 585 Intro to Probability</td>
<td></td>
</tr>
</tbody>
</table>

Elective courses (choose 3) 9

<table>
<thead>
<tr>
<th>Course</th>
<th>Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>MA 631 Linear Algebra</td>
<td></td>
</tr>
<tr>
<td>MA 637 Graph Theory and Combinatorics</td>
<td></td>
</tr>
<tr>
<td>MA 660 Numerical Linear Algebra</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Course</th>
<th>Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>MA 544 Vector Analysis</td>
<td></td>
</tr>
<tr>
<td>MA 545 Complex Analysis</td>
<td></td>
</tr>
<tr>
<td>MA 553 Fourier Analysis</td>
<td></td>
</tr>
<tr>
<td>MA 554 Intermediate Differential Equations</td>
<td></td>
</tr>
<tr>
<td>MA 555 Partial Differential Equations I</td>
<td></td>
</tr>
<tr>
<td>MA 556 Partial Differential Equations II</td>
<td></td>
</tr>
<tr>
<td>MA 561 Modeling with Partial Differential Equations</td>
<td></td>
</tr>
<tr>
<td>MA 562 Intro to Stochastic Differential Equations</td>
<td></td>
</tr>
<tr>
<td>MA 566 Introduction to Optimization</td>
<td></td>
</tr>
<tr>
<td>MA 642 Calculus of Several Variables</td>
<td></td>
</tr>
<tr>
<td>MA 650 Differential Equations</td>
<td></td>
</tr>
<tr>
<td>MA 655 Partial Differential Equations</td>
<td></td>
</tr>
<tr>
<td>MA 661 Modeling With PDE</td>
<td></td>
</tr>
</tbody>
</table>
Plan II - 30 hours Applied Mathematics

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Required Courses:</td>
<td>15</td>
</tr>
<tr>
<td>MA 540 Advanced Calculus I or MA 640MATHEMATICAL ANALYSIS I</td>
<td></td>
</tr>
<tr>
<td>MA 541 Advanced Calculus II or MA 641MATHEMATICAL ANALYSIS II</td>
<td></td>
</tr>
<tr>
<td>MA 534 Algebra I: Linear or MA 631Linear Algebra</td>
<td></td>
</tr>
<tr>
<td>MA 568 Numerical Analysis I or MA 660Numerical Linear Algebra</td>
<td></td>
</tr>
<tr>
<td>MA 585 Intro to Probability</td>
<td></td>
</tr>
<tr>
<td>Elective Courses (choose 5)</td>
<td>9</td>
</tr>
<tr>
<td>Algebra</td>
<td></td>
</tr>
<tr>
<td>MA 631 Linear Algebra</td>
<td></td>
</tr>
<tr>
<td>MA 637 Graph Theory and Combinatorics</td>
<td></td>
</tr>
<tr>
<td>MA 660 Numerical Linear Algebra</td>
<td></td>
</tr>
<tr>
<td>Analysis</td>
<td></td>
</tr>
<tr>
<td>MA 544 Vector Analysis</td>
<td></td>
</tr>
<tr>
<td>MA 545 Complex Analysis</td>
<td></td>
</tr>
<tr>
<td>MA 553 Fourier Analysis</td>
<td></td>
</tr>
<tr>
<td>MA 554 Intermediate Differential Equations</td>
<td></td>
</tr>
<tr>
<td>MA 555 Partial Differential Equations I</td>
<td></td>
</tr>
<tr>
<td>MA 556 Partial Differential Equations II</td>
<td></td>
</tr>
<tr>
<td>MA 561 Modeling with Partial Differential Equations</td>
<td></td>
</tr>
<tr>
<td>MA 562 Intro to Stochastic Differential Equations</td>
<td></td>
</tr>
<tr>
<td>MA 566 Introduction to Optimization</td>
<td></td>
</tr>
<tr>
<td>MA 642 Calculus of Several Variables</td>
<td></td>
</tr>
<tr>
<td>MA 650 Differential Equations</td>
<td></td>
</tr>
<tr>
<td>MA 655 Partial Differential Equations</td>
<td></td>
</tr>
<tr>
<td>MA 661 Modeling With PDE</td>
<td></td>
</tr>
<tr>
<td>Numerical Analysis</td>
<td></td>
</tr>
<tr>
<td>MA 560 Scientific Programming</td>
<td></td>
</tr>
<tr>
<td>MA 567 Gas Dynamics</td>
<td></td>
</tr>
<tr>
<td>MA 569 Numerical Analysis II</td>
<td></td>
</tr>
<tr>
<td>MA 660 Numerical Linear Algebra</td>
<td></td>
</tr>
<tr>
<td>MA 665 Partial Differential Equations: Finite Differential Methods</td>
<td></td>
</tr>
</tbody>
</table>

Plan I - 30 hours Traditional/Pure Mathematics

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Required Courses:</td>
<td>15</td>
</tr>
<tr>
<td>MA 540 Advanced Calculus I or MA 640MATHEMATICAL ANALYSIS I</td>
<td></td>
</tr>
<tr>
<td>MA 541 Advanced Calculus II or MA 641MATHEMATICAL ANALYSIS II</td>
<td></td>
</tr>
<tr>
<td>MA 534 Algebra I: Linear or MA 631Linear Algebra</td>
<td></td>
</tr>
<tr>
<td>MA 568 Numerical Analysis I or MA 660Numerical Linear Algebra</td>
<td></td>
</tr>
<tr>
<td>MA 585 Intro to Probability</td>
<td></td>
</tr>
<tr>
<td>Elective Courses (choose 3)</td>
<td>9</td>
</tr>
<tr>
<td>Algebra</td>
<td></td>
</tr>
<tr>
<td>MA 535 Algebra II: Modern</td>
<td></td>
</tr>
<tr>
<td>MA 631 Linear Algebra</td>
<td></td>
</tr>
<tr>
<td>MA 632 Abstract Algebra</td>
<td></td>
</tr>
<tr>
<td>MA 637 Graph Theory and Combinatorics</td>
<td></td>
</tr>
<tr>
<td>Analysis</td>
<td></td>
</tr>
<tr>
<td>MA 544 Vector Analysis</td>
<td></td>
</tr>
<tr>
<td>MA 545 Complex Analysis</td>
<td></td>
</tr>
<tr>
<td>MA 554 Intermediate Differential Equations</td>
<td></td>
</tr>
<tr>
<td>MA 555 Partial Differential Equations I</td>
<td></td>
</tr>
<tr>
<td>MA 556 Partial Differential Equations II</td>
<td></td>
</tr>
<tr>
<td>MA 642 Calculus of Several Variables</td>
<td></td>
</tr>
<tr>
<td>MA 645 Real Analysis I</td>
<td></td>
</tr>
<tr>
<td>MA 646 Real Analysis II</td>
<td></td>
</tr>
<tr>
<td>MA 648 Complex Analysis</td>
<td></td>
</tr>
<tr>
<td>MA 650 Differential Equations</td>
<td></td>
</tr>
<tr>
<td>Geometry</td>
<td></td>
</tr>
<tr>
<td>MA 570 Differential Geometry</td>
<td></td>
</tr>
<tr>
<td>MA 572 Geometry I</td>
<td></td>
</tr>
<tr>
<td>MA 573 Geometry II</td>
<td></td>
</tr>
<tr>
<td>MA 675 Differential Geometry</td>
<td></td>
</tr>
<tr>
<td>Probability/Statistics</td>
<td></td>
</tr>
<tr>
<td>MA 586 Mathematical Statistics</td>
<td></td>
</tr>
<tr>
<td>MA 587 Advanced Probability</td>
<td></td>
</tr>
<tr>
<td>MA 588 Advanced Statistics</td>
<td></td>
</tr>
<tr>
<td>MA 687 Advanced Probability</td>
<td></td>
</tr>
<tr>
<td>MA 688 Advanced Statistics</td>
<td></td>
</tr>
<tr>
<td>Topology</td>
<td></td>
</tr>
<tr>
<td>MA 574 Intro to Topology I</td>
<td></td>
</tr>
</tbody>
</table>
Plan II - 30 hours Traditional/Pure Mathematics

Requirements

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Required Courses</td>
<td>15</td>
</tr>
<tr>
<td>MA 540 Advanced Calculus I or MA 641 Mathematical Analysis I</td>
<td></td>
</tr>
<tr>
<td>MA 541 Advanced Calculus II or MA 641 Mathematical Analysis II</td>
<td></td>
</tr>
<tr>
<td>MA 534 Algebra I: Linear or MA 631 Linear Algebra</td>
<td></td>
</tr>
<tr>
<td>MA 568 Numerical Analysis I or MA 660 Numerical Linear Algebra</td>
<td></td>
</tr>
<tr>
<td>MA 585 Intro to Probability</td>
<td></td>
</tr>
<tr>
<td>Elective Courses (choose 15)</td>
<td>15</td>
</tr>
</tbody>
</table>

Algebra

| MA 535 Algebra II: Modern |       |
| MA 631 Linear Algebra |       |
| MA 632 Abstract Algebra |       |
| MA 637 Graph Theory and Combinatorics |       |

Analysis

| MA 544 Vector Analysis |       |
| MA 545 Complex Analysis |       |
| MA 554 Intermediate Differential Equations |       |
| MA 555 Partial Differential Equations I |       |
| MA 556 Partial Differential Equations II |       |
| MA 642 Calculus of Several Variables |       |
| MA 645 Real Analysis I |       |
| MA 646 Real Analysis II |       |
| MA 648 Complex Analysis |       |
| MA 650 Differential Equations |       |

Geometry

| MA 570 Differential Geometry |       |
| MA 572 Geometry I |       |
| MA 573 Geometry II |       |
| MA 675 Differential Geometry |       |

Probability/Statistics

| MA 586 Mathematical Statistics |       |
| MA 587 Advanced Probability |       |
| MA 588 Advanced Statistics |       |
| MA 687 Advanced Probability |       |
| MA 688 Advanced Statistics |       |

Topology

| MA 574 Intro to Topology I |       |
| MA 575 Intro to Topology II |       |
| MA 670 Topology I |       |
| MA 671 Topology II |       |

Total Hours 30

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 515. 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 513 [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 513 [Min Grade: B] or MA 513 [Min Grade: C]

MA 517. 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 532. 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 533. Algebra II: Modern. 3 Hours.
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 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 course 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 Cauchy’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 Fourier 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 Fourier series; 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 MATLAB
and its PDE Tool-box, and COMSOL using practical examples; an
overview of finite difference and finite element solution methods;
specialized modeling projects in topics such as groundwater modeling,
scattering of waves, medical and industrial imaging, 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 all
homework assignments. Quantitative Literacy and Writing are significant
components of this course.
Prerequisites: 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 Itô
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
to 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.
Programming for numerical calculations, round-off error, approximation
and interpolation, numerical quadrature, and solution of ordinary
differential equations. Practice on the computer.
Prerequisites: MA 252 [Min Grade: C] and MA 227 [Min Grade: C]

MA 569. Numerical Analysis II. 3 Hours.
Iterative solution of systems of nonlinear equations, evaluation of
eigenvalues and eigenvectors of matrices, applications to simple partial
differential equations, special topics in numerical linear algebra. 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.
Probability spaces, combinatorics, conditional probabilities and
independence, Bayes rule, discrete and continuous distributions, mean
value and variance, moment generation function, joint distributions,
correlation, Central Limit Theorem, Law of Large Numbers, random
walks, Poisson process.
Prerequisites: MA 227 [Min Grade: C] and MA 260 [Min Grade: C]

MA 586. Mathematical Statistics. 3 Hours.
Confidence intervals, hypothesis testing, analysis of variance and co-
variance, maximum likelihood estimates, linear regression, tests of
fit/robust estimates and tests.
Prerequisites: MA 485 [Min Grade: C] or MA 585 [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: B] or MA 585 [Min Grade: B]

MA 588. Advanced Statistics. 3 Hours.
Parameter estimations, maximum likelihood estimation, sufficient statistic,
hypothesis testing, Neyman-Pearson Lemma, p-value, 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 485 [Min Grade: B] or MA 585 [Min Grade: B] or
MA 587 [Min Grade: B] or MA 687 [Min Grade: B]

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 sup. 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 minimax 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 introduced. Classical results such as the mean value theorem, the Cauchy integral theorem and integral formula; power series; 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 541 [Min Grade: B]

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. Specifically, 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 differentiation and integration for series is developed, including properties of power series/real analytic functions. The course wishes with a short introduction to some basic topological objects. Specifically, 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 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; the singular value decomposition; stability, condition numbers, and error analysis; QR factorization; least squares problems; computation of eigenvalues and eigenvectors; iterative 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.

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 560 [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.

Prerequisites: MA 670 [Min Grade: B]

MA 669. Numerical Analysis II. 3 Hours.

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 Reimann curvature tensor; the second variation of arc length; selected topics in the global theory of surfaces.

Prerequisites: MA 642 [Min Grade: C]

MA 687. 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: B] or MA 585 [Min Grade: B]
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. Linear Operators in Hilbert Space. 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 Transforms. 3 Hours.
Fourier transform and inverse transform to tempered distributions; applications to partial differential equations.
Prerequisites: MA 645 [Min Grade: B] and MA 655 [Min Grade: B]  

MA 749. Theory of Distribution. 3 Hours.
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 viewpoint: 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.
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