# DEPARTMENT OF MATHEMATICS (GRAD)

## Contact Information

**Department of Mathematics**
http://www.math.unc.edu

**Richard McLaughlin, Chair**

The Department of Mathematics offers graduate training leading to the degrees of master of arts, master of science, and doctor of philosophy. A master's degree may be included or bypassed in the doctoral program. All of a student's graduate work may be done within the department or, when appropriate, may be done under the direction of an approved advisor in an allied discipline. The Department of Mathematics is housed in Phillips Hall and Chapman Hall. The Department of Mathematics offers a number of teaching assistantships and teaching fellowships each year. Applicants for financial aid are also considered for several University fellowships awarded by The Graduate School in the Universitywide competition. Applications for admission and financial assistance may be obtained from The Graduate School. Applications filed by the posted deadline will receive full consideration.

The general regulations of The Graduate School govern the work for graduate degrees in mathematics. Specific requirements are explained below. In general, a graduate student in mathematics may receive credit only for mathematics courses numbered 600 and above.

These descriptions summarize the requirements for the master's and Ph.D. degrees. More detailed statements may be obtained from the department. The director of graduate studies must approve all aspects of a student's program. The purpose of the graduate programs is to develop mathematical skills appropriate for competition in academia or industry.

The course schedule for first-year students will depend upon each student's undergraduate training. The normal course load for a graduate student is three courses (nine credit hours) per semester. Graduate students must maintain full-time status in order to qualify for tuition and health insurance benefits. First-year students typically choose courses from five yearlong sequences in algebra (MATH 676, MATH 677), analysis (MATH 653, MATH 656), geometry-topology (MATH 680, MATH 681), scientific computation (MATH 661, MATH 662), and methods of applied mathematics (MATH 668, MATH 669).

The Ph.D. comprehensive exams are based on the content of the first-year sequences. These exams are offered in January and August of each year, just before the semester begins. A Ph.D. student can pass either the Pure Math option or the Applied Math option for the qualifying examination. To pass the Pure Math option a student must pass any three of the five qualifying exams. To pass the Applied Math option, a student is required to pass Methods of Applied Math and Scientific Computation.

During the second year a typical Ph.D. student will take the Ph.D. comprehensive exams and select courses from a list of 20 more advanced "second tier" courses. A typical master's student will complete that degree during the second year. The department considers two years to be the normal time needed to complete a master's degree.

A candidate for a master's degree must satisfy each of the following requirements:

1. Earn at least two semesters of residency credit and complete all requirements within five years
2. Demonstrate computer programming ability by passing an approved undergraduate or graduate course in programming, or by passing an exam administered by the Department of Mathematics
3. Perform satisfactorily in 30 hours of graduate work in a program approved by the director of graduate studies. At least 15 of these hours must be in Department of Mathematics courses numbered 600 or above
4. Complete a master's project or thesis for a master of science degree or a master's thesis for a master of arts degree
5. Pass an oral examination upon completion of the master's project or master's thesis. The exam will cover coursework as well as the project or thesis
6. A master's candidate must pass one of the written comprehensive exams given to doctoral students.

A candidate for a Ph.D. degree must satisfy each of the following requirements:

1. Earn at least four semesters of residency credit and complete all requirements within eight years
2. Satisfy the same computer programming requirement as a master's student
3. Demonstrate reading competence in one approved foreign language by passing an approved course or by passing a translation exam administered by the Department of Mathematics
4. Complete either the Pure Math option or the Applied Math option for qualifying examinations by the beginning of the sixth semester
5. Pass at least six courses from the following two lists: a) the second tier courses or b) first-year comprehensive courses that are not basic courses for any of the comprehensive exams passed by the student. Of these six courses at least three must be numbered over 700 and drawn from the second tier list.
6. Pass the Teaching Assistant Teaching Seminar and perform a minimum of two semesters of instructional service
7. Pass a preliminary oral exam on the chosen Ph.D. specialty area
8. Write a Ph.D. thesis and defend it successfully during a final oral exam chaired by the thesis advisor

The student/faculty ratio of about 2/1 makes it possible for graduate students to take reading courses from individual faculty members that are tailored to meet the student's needs.

## Minor in Mathematics

Graduate students in other departments who plan to offer mathematics as a (complete or partial) minor field for the Ph.D. should consult the director of graduate studies in mathematics for approval of their programs and for assignment of an advisor in the Department of Mathematics. This should be done at the earliest possible time in order to prevent disappointment for the student.

*Following the faculty member's name is a section number that students should use when registering for independent studies, reading, research, and thesis and dissertation courses with that particular professor.*

# Professors

**Idris Assani (45),** Dynamical Systems, Ergodic Theory of Operators
**Prakash Belkale (57),** Algebraic Geometry
**Roberto A. Camassa (16),** Mathematical Modeling, Nonlinear Waves, Propagation, Dynamical Systems
**Ivan V. Cherednik (48),** Representation Theory, Mathematical Physics, Algebraic Combinatorics
**M. Gregory Forest (7),** Nonlinear Waves, Solitons, Fiber Flows of Complex Liquids
**Jane M. Hawkins (38),** Ergodic Theory, Dynamical Systems
**Jingfang Huang (51),** Integral Equation Methods and Fast Algorithms
**Christopher K.R.T. Jones (55),** Applications of Dynamical Systems, Nonlinear Partial Differential Equations, Ocean Dynamics, Nonlinear Optics
**Shrawan Kumar (46),** Representation Theory, Geometry of Flag Varieties
**Richard McLaughlin (50),** Fluid Dynamics and Turbulent Transport
**Sorin Mitran (58),** Computational Methods for Partial Differential Equations, Continuum-Kinetic Methods, Fluid Dynamics, Biological Fluid Dynamics and Mechanics
**Peter J. Mucha (60),** Network Analysis, Fluid Dynamics, Computer-Generated Animation
**Robert A. Proctor (43),** Combinatorics, Representation Theory
**Richard Rimanyi (59),** Topology, Geometry, Singularities
**Lev Rozansky (52),** Three-Dimensional Topology
**Michael E. Taylor (40),** Partial Differential Equations, Harmonic Analysis, Operator Theory
**Alexandre N. Varchenko (47),** Geometry, Mathematical Physics
**Jonathan M. Wahl (28),** Algebraic Geometry
**Mark Williams (36),** Partial Differential Equations

# Associate Professors

**David Adalsteinsson (1),** Applied Mathematics and Scientific Computation
**Hans Christianson (8),** Semiclassical Analysis and Partial Differential Equations
**Jeremy Marzuola (9),** Partial Differential Equations
**Jason Metcalfe (61),** Partial Differential Equations
**Laura Miller (22),** Mathematical Biology, Biomechanics, and Fluid Dynamics
**Justin Sawon (64),** Differential Geometry

# Assistant Professors

**Yaiza Canzani (18),** Geometric Analysis, Semiclassical Analysis, Perturbation Theory
**Boyce Griffith (10),** Numerical Analysis, Mathematical Biology
**Jiuzu Hong (13),** Representation Theory
**Katie Newhall (12),** Applied Mathematics, Stochastic Differential Equations
**Nancy Rodriguez (15),** Partial Differential Equations, Stochastic Differential Equations
**David Rose (17),** Categorification, Low-Dimensional Topology, Representation Theory

# Professors Emeriti

**Joseph A. Cima**
**James N. Damon**
**Patrick Eberlein**
**Ladnor Gessinger**
**Sue E. Goodman**
**William H. Graves**
**Robert G. Heyneman**
**Norberto Kerzman**
**Ancel C. Mewborn**
**Karl Petersen**
**John Pfaltzgraff**
**Joseph Plante**
**Michael Schlessinger**
**William W. Smith**
**Johann Sonner**
**James Stasheff**
**Warren R. Wogen**

# MATH

## Advanced Undergraduate and Graduate-level Courses

**MATH 406. Mathematical Methods in Biostatistics. 1 Credit.**
Special mathematical techniques in the theory and methods of biostatistics as related to the life sciences and public health. Includes brief review of calculus, selected topics from intermediate calculus, and introductory matrix theory for applications in biostatistics.
**Requisites:** Prerequisite, MATH 232.
**Gen Ed:** QI.
**Grading status:** Letter grade.

**MATH 410. Teaching and Learning Mathematics. 4 Credits.**
Study of how people learn and understand mathematics, based on research in mathematics, mathematics education, psychology, and cognitive science. This course is designed to prepare undergraduate mathematics majors to become excellent high school mathematics teachers. It involves field work in both the high school and college environments.
**Gen Ed:** EE-Field Work.
**Grading status:** Letter grade.

**MATH 411. Developing Mathematical Concepts. 3 Credits.**
Permission of the instructor. An investigation of various ways elementary concepts in mathematics can be developed. Applications of the mathematics developed will be considered.
**Gen Ed:** QI.
**Grading status:** Letter grade.

**MATH 418. Basic Concepts of Analysis for High School Teachers. 3 Credits.**
An examination of high school mathematics from an advanced perspective, including number systems and the behavior of functions and equations. Designed primarily for prospective or practicing high school teachers.
**Requisites:** Prerequisites, MATH 233 and 381.
**Gen Ed:** QI.
**Grading status:** Letter grade.

**MATH 515. History of Mathematics. 3 Credits.**
A general survey of the history of mathematics with emphasis on elementary mathematics. Some special problems will be treated in depth.
**Requisites:** Prerequisite, MATH 381.
**Gen Ed:** QI.
**Grading status:** Letter grade.

**MATH 521. Advanced Calculus I. 3 Credits.**
A grade of A- or better in STOR 215 may substitute for MATH 381. The real numbers, continuity and differentiability of functions of one variable, infinite series, integration.
**Requisites:** Prerequisites, MATH 233 and 381.
**Gen Ed:** QI.
**Grading status:** Letter grade.

**MATH 521H. Advanced Calculus I. 3 Credits.**
A grade of A- or better in STOR 215 may substitute for MATH 381. The real numbers, continuity and differentiability of functions of one variable, infinite series, integration.
**Requisites:** Prerequisites, MATH 233 and 381.
**Gen Ed:** QI.
**Grading status:** Letter grade.

**MATH 522. Advanced Calculus II. 3 Credits.**
Functions of several variables, the derivative as a linear transformation, inverse and implicit function theorems, multiple integration.
**Requisites:** Prerequisites, MATH 383 and 521.
**Gen Ed:** QI.
**Grading status:** Letter grade.

**MATH 522H. Advanced Calculus II. 3 Credits.**
Functions of several variables, the derivative as a linear transformation, inverse and implicit function theorems, multiple integration.
**Requisites:** Prerequisites, MATH 383 and 521.
**Gen Ed:** QI.
**Grading status:** Letter grade.

**MATH 523. Functions of a Complex Variable with Applications. 3 Credits.**
The algebra of complex numbers, elementary functions and their mapping properties, complex limits, power series, analytic functions, contour integrals, Cauchy's theorem and formulae, Laurent series and residue calculus, elementary conformal mapping and boundary value problems, Poisson integral formula for the disk and the half plane.
**Requisites:** Prerequisite, MATH 383.
**Gen Ed:** QI.
**Grading status:** Letter grade.

**MATH 524. Elementary Differential Equations. 3 Credits.**
Linear differential equations, power series solutions, Laplace transforms, numerical methods.
**Requisites:** Prerequisite, MATH 383.
**Gen Ed:** QI.
**Grading status:** Letter grade.

**MATH 528. Mathematical Methods for the Physical Sciences I. 3 Credits.**
Theory and applications of Laplace transform, Fourier series and transform, Sturm-Liouville problems. Students will be expected to do some numerical calculations on either a programmable calculator or a computer. This course has an optional computer laboratory component: MATH 528L.
**Requisites:** Prerequisite, MATH 383.
**Gen Ed:** QI.
**Grading status:** Letter grade.

**MATH 528L. Laboratory for Mathematical Methods for the Physical Sciences I. 1 Credit.**
Training in the use of symbolic and numerical computing packages and their application to the MATH 528 lecture topics. Students will need a CCI-compatible computing device.
**Requisites:** Prerequisite, MATH 383; pre- or corequisite, MATH 528.
**Grading status:** Letter grade.

**MATH 529. Mathematical Methods for the Physical Sciences II. 3 Credits.**
Introduction to boundary value problems for the diffusion, Laplace and wave partial differential equations. Bessel functions and Legendre functions. Introduction to complex variables including the calculus of residues. This course has an optional computer laboratory component: MATH 529L.
**Requisites:** Prerequisite, MATH 521, 524, or 528.
**Gen Ed:** QI.
**Grading status:** Letter grade.

**MATH 529L. Laboratory for Mathematical Methods for the Physical Sciences II. 1 Credit.**
Training in the use of symbolic and numerical computing packages and their application to the MATH 529 lecture topics. Students will need a CCI-compatible computing device.
**Requisites:** Prerequisite, MATH 383; pre- or corequisite, MATH 529.
**Grading status:** Letter grade.

**MATH 533. Elementary Theory of Numbers. 3 Credits.**
A grade of A- or better in STOR 215 may substitute for MATH 381. Divisibility, Euclidean algorithm, congruences, residue classes, Euler's function, primitive roots, Chinese remainder theorem, quadratic residues, number-theoretic functions, Farey and continued fractions, Gaussian integers.
**Requisites:** Prerequisite, MATH 381.
**Gen Ed:** QI.
**Grading status:** Letter grade.

**MATH 534. Elements of Modern Algebra. 3 Credits.**
A grade of A- or better in STOR 215 may substitute for MATH 381. Binary operations, groups, subgroups, cosets, quotient groups, rings, polynomials.
**Requisites:** Prerequisite, MATH 381.
**Gen Ed:** QI.
**Grading status:** Letter grade.

**MATH 535. Introduction to Probability. 3 Credits.**
Introduction to mathematical theory of probability covering random variables; moments; binomial, Poisson, normal and related distributions; generating functions; sums and sequences of random variables; and statistical applications.
**Requisites:** Prerequisite, MATH 233.
**Gen Ed:** QI.
**Grading status:** Letter grade
**Same as:** STOR 435.

**MATH 547. Linear Algebra for Applications. 3 Credits.**
Algebra of matrices with applications: determinants, solution of linear systems by Gaussian elimination, Gram-Schmidt procedure, eigenvalues. MATH 416 may not be taken for credit after credit has been granted for MATH 547.
**Requisites:** Prerequisite, MATH 233 or 283.
**Gen Ed:** QI.
**Grading status:** Letter grade.

**MATH 548. Combinatorial Mathematics. 3 Credits.**
Counting selections, binomial identities, inclusion-exclusion, recurrences, Catalan numbers. Selected topics from algorithmic and structural combinatorics, or from applications to physics and cryptography.
**Requisites:** Prerequisite, MATH 381 or STOR 215.
**Gen Ed:** QI.
**Grading status:** Letter grade.

**MATH 550. Topology. 3 Credits.**
Introduction to topics in topology, particularly surface topology, including classification of compact surfaces, Euler characteristic, orientability, vector fields on surfaces, tessellations, and fundamental group.
**Requisites:** Prerequisites, MATH 233 and 381; co-requisite, MATH 383; A grade of A- or better in STOR 215 may substitute for MATH 381.
**Gen Ed:** QI.
**Grading status:** Letter grade.

**MATH 551. Euclidean and Non-Euclidean Geometries. 3 Credits.**
A grade of A- or better in STOR 215 may substitute for MATH 381. Critical study of basic notions and models of Euclidean and non-Euclidean geometries: order, congruence, and distance.
**Requisites:** Prerequisite, MATH 381.
**Gen Ed:** QI.
**Grading status:** Letter grade.

**MATH 553. Mathematical and Computational Models in Biology. 3 Credits.**
This course introduces analytical, computational, and statistical techniques, such as discrete models, numerical integration of ordinary differential equations, and likelihood functions, to explore various fields of biology.
**Requisites:** Prerequisites, BIOL 201 and 202, MATH 231, and either MATH 232 or STOR 155; Co-requisite, BIOL 553L/MATH 553L; permission of the instructor for students lacking the requisites.
**Gen Ed:** QI.
**Grading status:** Letter grade
**Same as:** BIOL 553.

**MATH 553L. Mathematical and Computational Models in Biology Laboratory. 1 Credit.**
This lab introduces analytical, computational, and statistical techniques, such as discrete models, numerical integration of ordinary differential equations, and likelihood functions, to explore various fields of biology.
**Requisites:** Prerequisites, BIOL 201 and 202, MATH 231, and either MATH 232 or STOR 155; Co-requisite, BIOL 553/MATH 553; Permission of the instructor for students lacking the prerequisites.
**Grading status:** Letter grade
**Same as:** BIOL 553L.

**MATH 555. Introduction to Dynamics. 3 Credits.**
Topics will vary and may include iteration of maps, orbits, periodic points, attractors, symbolic dynamics, bifurcations, fractal sets, chaotic systems, systems arising from differential equations, iterated function systems, and applications.
**Requisites:** Prerequisite, MATH 383.
**Gen Ed:** QI.
**Grading status:** Letter grade.

**MATH 564. Mathematical Modeling in the Life Sciences. 3 Credits.**
Requires some knowledge of computer programming. Model validation and numerical simulations using ordinary, partial, stochastic, and delay differential equations. Applications to the life sciences may include muscle physiology, biological fluid dynamics, neurobiology, molecular regulatory networks, and cell biology.
**Requisites:** Prerequisite, MATH 383.
**Gen Ed:** QI.
**Grading status:** Letter grade
**Same as:** BIOL 534.

**MATH 565. Computer-Assisted Mathematical Problem Solving. 3 Credits.**
Personal computer as tool in solving a variety of mathematical problems, e.g., finding roots of equations and approximate solutions to differential equations. Introduction to appropriate programming language; emphasis on graphics.
**Requisites:** Prerequisite, MATH 383.
**Gen Ed:** QI.
**Grading status:** Letter grade.

**MATH 566. Introduction to Numerical Analysis. 3 Credits.**
Requires some knowledge of computer programming. Iterative methods, interpolation, polynomial and spline approximations, numerical differentiation and integration, numerical solution of ordinary and partial differential equations.
**Requisites:** Prerequisite, MATH 383.
**Gen Ed:** QI.
**Grading status:** Letter grade.

**MATH 577. Linear Algebra. 3 Credits.**
Vector spaces, linear transformations, duality, diagonalization, primary and cyclic decomposition, Jordan canonical form, inner product spaces, orthogonal reduction of symmetric matrices, spectral theorem, bilinear forms, multilinear functions. A much more abstract course than MATH 416 or 547.
**Requisites:** Prerequisites, MATH 381 and 383; A grade of A- or better in STOR 215 may substitute for MATH 381.
**Gen Ed:** QI.
**Grading status:** Letter grade.

**MATH 578. Algebraic Structures. 3 Credits.**
Permutation groups, matrix groups, groups of linear transformations, symmetry groups; finite abelian groups. Residue class rings, algebra of matrices, linear maps, and polynomials. Real and complex numbers, rational functions, quadratic fields, finite fields.
**Requisites:** Prerequisite, MATH 547 or 577.
**Gen Ed:** QI.
**Grading status:** Letter grade.

**MATH 590. Topics in Mathematics. 3 Credits.**
Permission of the instructor. Topics may focus on matrix theory, analysis, algebra, geometry, or applied and computational mathematics.
**Repeat rules:** May be repeated for credit; may be repeated in the same term for different topics; 12 total credits. 4 total completions.
**Grading status:** Letter grade.

**MATH 594. Nonlinear Dynamics. 3 Credits.**
Interdisciplinary introduction to nonlinear dynamics and chaos. Fixed points, bifurcations, strange attractors, with applications to physics, biology, chemistry, finance.
**Requisites:** Prerequisite, MATH 383; permission of the instructor for students lacking the prerequisite.
**Grading status:** Letter grade
**Same as:** PHYS 594.

**MATH 635. Probability. 3 Credits.**
Foundations of probability. Basic classical theorems. Modes of probabilistic convergence. Central limit problem. Generating functions, characteristic functions. Conditional probability and expectation.
**Requisites:** Prerequisite, STOR 634; permission of the instructor for students lacking the prerequisite.
**Grading status:** Letter grade
**Same as:** STOR 635.

**MATH 641. Enumerative Combinatorics. 3 Credits.**
Basic counting; partitions; recursions and generating functions; signed enumeration; counting with respect to symmetry, plane partitions, and tableaux.
**Requisites:** Prerequisite, MATH 578.
**Grading status:** Letter grade.

**MATH 643. Combinatorial Structures. 3 Credits.**
Graph theory, matchings, Ramsey theory, extremal set theory, network flows, lattices, Moebius inversion, q-analogs, combinatorial and projective geometries, codes, and designs.
**Requisites:** Prerequisite, MATH 578.
**Grading status:** Letter grade.

**MATH 653. Introductory Analysis. 3 Credits.**
Requires knowledge of advanced calculus. Elementary metric space topology, continuous functions, differentiation of vector-valued functions, implicit and inverse function theorems. Topics from Weierstrass theorem, existence and uniqueness theorems for differential equations, series of functions.
**Grading status:** Letter grade.

**MATH 656. Complex Analysis. 3 Credits.**
A rigorous treatment of complex integration, including the Cauchy theory. Elementary special functions, power series, local behavior of analytic functions.
**Requisites:** Prerequisite, MATH 653.
**Grading status:** Letter grade.

**MATH 657. Qualitative Theory of Differential Equations. 3 Credits.**
Requires knowledge of linear algebra. Existence and uniqueness theorems, linear and nonlinear systems, differential equations in the plane and on surfaces, Poincare-Bendixson theory, Lyapunov stability and structural stability, critical point analysis.
**Requisites:** Prerequisite, MATH 653.
**Grading status:** Letter grade.

**MATH 661. Scientific Computation I. 3 Credits.**
Requires some programming experience and basic numerical analysis. Error in computation, solutions of nonlinear equations, interpolation, approximation of functions, Fourier methods, numerical integration and differentiation, introduction to numerical solution of ODEs, Gaussian elimination.
**Grading status:** Letter grade
**Same as:** ENVR 661.

**MATH 662. Scientific Computation II. 3 Credits.**
Theory and practical issues arising in linear algebra problems derived from physical applications, e.g., discretization of ODEs and PDEs. Linear systems, linear least squares, eigenvalue problems, singular value decomposition.
**Requisites:** Prerequisite, MATH 661.
**Grading status:** Letter grade
**Same as:** COMP 662, ENVR 662.

**MATH 668. Methods of Applied Mathematics I. 3 Credits.**
Requires an undergraduate course in differential equations. Contour integration, asymptotic expansions, steepest descent/stationary phase methods, special functions arising in physical applications, elliptic and theta functions, elementary bifurcation theory.
**Grading status:** Letter grade
**Same as:** ENVR 668.

**MATH 669. Methods of Applied Mathematics II. 3 Credits.**
Perturbation methods for ODEs and PDEs, WKBJ method, averaging and modulation theory for linear and nonlinear wave equations, long-time asymptotics of Fourier integral representations of PDEs, Green's functions, dynamical systems tools.
**Requisites:** Prerequisite, MATH 668.
**Grading status:** Letter grade
**Same as:** ENVR 669.

**MATH 676. Modules, Linear Algebra, and Groups. 3 Credits.**
Requires knowledge of linear algebra and algebraic structures. Modules over rings, canonical forms for linear operators and bilinear forms, multilinear algebra, groups and group actions.
**Repeat rules:** May be repeated for credit. 6 total credits. 2 total completions.
**Grading status:** Letter grade.

**MATH 677. Groups, Representations, and Fields. 3 Credits.**
Internal structure of groups, Sylow theorems, generators and relations, group representations, fields, Galois theory, category theory.
**Requisites:** Prerequisite, MATH 676.
**Grading status:** Letter grade.

**MATH 680. Geometry of Curves and Surfaces. 3 Credits.**
Topics include (curves) Frenet formulas, isoperimetric inequality, theorems of Crofton, Fenchel, Fary-Milnor; (surfaces) fundamental forms, Gaussian and mean curvature, special surfaces, geodesics, Gauss-Bonnet theorem.
**Requisites:** Prerequisite, advanced calculus.
**Grading status:** Letter grade.

**MATH 681. Introductory Topology. 3 Credits.**
Topological spaces, connectedness, separation axioms, product spaces, extension theorems. Classification of surfaces, fundamental group, covering spaces.
**Requisites:** Prerequisites, MATH 653 and 680.
**Grading status:** Letter grade.

**MATH 690. Topics In Mathematics. 3 Credits.**
Permission of the department. Directed study of an advanced topic in mathematics. Topics will vary.
**Repeat rules:** May be repeated for credit; may be repeated in the same term for different topics; 12 total credits. 4 total completions.
**Grading status:** Letter grade.

**MATH 691H. Honors Research in Mathematics. 3 Credits.**
Permission of the director of undergraduate studies. Readings in mathematics and the beginning of directed research on an honors thesis.
**Gen Ed:** EE-Mentored Research.
**Grading status:** Letter grade.

**MATH 692H. Honors Thesis in Mathematics. 3 Credits.**
Permission of the director of undergraduate studies. Completion of an honors thesis under the direction of a member of the faculty. Required of all candidates for graduation with honors in mathematics.
**Gen Ed:** EE-Mentored Research.
**Grading status:** Letter grade.

## Graduate-level Courses

**MATH 751. Introduction to Partial Differential Equations. 3 Credits.**
Basic methods in partial differential equations. Topics may include: Cauchy-Kowalewski Theorem, Holmgren's Uniqueness Theorem, Laplace's equation, Maximum Principle, Dirichlet problem, harmonic functions, wave equation, heat equation.
**Requisites:** Prerequisite, MATH 653.

**MATH 753. Measure and Integration. 3 Credits.**
Lebesgue and abstract measure and integration, convergence theorems, differentiation, Radon-Nikodym theorem, product measures, Fubini theorem, Lebesgue spaces, invariance under transformations, Haar measure and convolution.
**Requisites:** Prerequisite, MATH 653; permission of the instructor for students lacking the prerequisite.

**MATH 754. Introductory Functional Analysis. 3 Credits.**
Hahn-Banach and separation theorems. Normed and locally convex spaces, duals of spaces and maps, weak topologies; closed graph and open mapping theorems, uniform boundedness theorem, linear operators. Spring.
**Requisites:** Prerequisite, MATH 753.

**MATH 755. Advanced Complex Analysis. 3 Credits.**
Laurent series; Mittag-Leffler and Weierstrass Theorems; Riemann mapping theorem; Runge's theorem; additional topics chosen from: harmonic, elliptic, univalent, entire, meromorphic functions; Dirichlet problem; Riemann surfaces.
**Requisites:** Prerequisite, MATH 656.

**MATH 756. Several Complex Variables. 3 Credits.**
Elementary theory, the Cousin problems, domains of holomorphy, Runge domains and polynomial approximation, local theory, complex analytic structures, coherent analytic sheaves and Stein manifolds, Cartan's theorems.
**Requisites:** Prerequisite, MATH 656.

**MATH 761. Numerical ODE/PDE, I. 3 Credits.**
Single, multistep methods for ODEs: stability regions, the root condition; stiff systems, backward difference formulas; two-point BVPs; stability theory; finite difference methods for linear advection diffusion equations.
**Requisites:** Prerequisites, MATH 661 and 662.
**Same as:** ENVR 761, MASC 781.

**MATH 762. Numerical ODE/PDE, II. 3 Credits.**
Elliptic equation methods (finite differences, elements, integral equations); hyperbolic conservation law methods (Lax-Fiedrich, characteristics, entropy condition, shock tracking/capturing); spectral, pseudo-spectral methods; particle methods, fast summation, fast multipole/vortex methods.
**Requisites:** Prerequisite, MATH 761.
**Same as:** ENVR 762, MASC 782.

**MATH 768. Mathematical Modeling I. 3 Credits.**
Nondimensionalization and identification of leading order physical effects with respect to relevant scales and phenomena; derivation of classical models of fluid mechanics (lubrication, slender filament, thin films, Stokes flow); derivation of weakly nonlinear envelope equations. Fall.
**Requisites:** Prerequisites, MATH 661, 662, 668, and 669.
**Same as:** ENVR 763, MASC 783.

**MATH 769. Mathematical Modeling II. 3 Credits.**
Current models in science and technology: topics ranging from material science applications (e.g., flow of polymers and LCPs); geophysical applications (e.g., ocean circulation, quasi-geostrophic models, atmospheric vortices).
**Requisites:** Prerequisites, MATH 661, 662, 668, and 669.
**Same as:** ENVR 764, MASC 784.

**MATH 771. Commutative Algebra. 3 Credits.**
Field extensions, integral ring extensions, Nullstellensatz and normalization theorem, derivations and separability, local rings, valuations, completions, filtrations and graded rings, dimension theory.
**Requisites:** Prerequisite, MATH 677.

**MATH 773. Lie Groups. 3 Credits.**
Lie groups, closed subgroups, Lie algebra of a Lie group, exponential map, compact groups, Haar measure, orthogonality relations, Peter-Weyl theorem, maximal torus, representations, Weyl character formula, homogeneous spaces.
**Requisites:** Prerequisites, MATH 676 and 781.

**MATH 774. Lie Algebras. 3 Credits.**
Nilpotent, solvable, and semisimple Lie algebras, structure theorems, root systems, Weyl groups, weights, classification of semisimple Lie algebras and their finite dimensional representations, character formulas.
**Requisites:** Prerequisite, MATH 676.

**MATH 775. Algebraic Geometry. 3 Credits.**
Topics may include: algebraic varieties, algebraic functions, abelian varieties, projective and complete varieties, algebraic groups, schemes and the Grothendieck theory, Riemann-Roch theorem.
**Requisites:** Prerequisite, MATH 771.

**MATH 776. Algebraic Topology. 3 Credits.**
Homotopy and homology; simplicial complexes and singular homology; other topics may include cohomology, universal coefficient theorems, higher homotopy groups, fibre spaces.
**Requisites:** Prerequisites, MATH 676 and 681.

**MATH 781. Differentiable Manifolds. 3 Credits.**
Calculus on manifolds, vector bundles, vector fields and differential equations, Lie Groups, connections, de Rham cohomology.
**Requisites:** Prerequisites, MATH 653, 676, and 681.

**MATH 782. Differential Geometry. 3 Credits.**
Riemannian geometry, first and second variation of area and applications, effect of curvature on homology and homotopy, Chern-Weil theory of characteristic classes, Chern-Gauss-Bonnet theorem.
**Requisites:** Prerequisite, MATH 781.

**MATH 853. Harmonic Analysis. 3 Credits.**
Permission of the instructor. Subjects may include topological groups, abstract harmonic analysis, Fourier analysis, noncommutative harmonic analysis and group representation, automorphic forms, and analytic number theory.

**MATH 854. Advanced Functional Analysis. 3 Credits.**
Permission of the instructor. Subjects may include operator theory on Hilbert space, operators on Banach spaces, locally convex spaces, vector measures, Banach algebras.

**MATH 857. Theory of Dynamical Systems. 3 Credits.**
Permission of the instructor. Topics may include: ergodic theory, topological dynamics, stability theory of differential equations, classical dynamical systems, differentiable dynamics.

**MATH 891. Special Topics. 1-3 Credits.**
Advance topics in current research in statistics and operations research.
**Repeat rules:** May be repeated for credit; may be repeated in the same term for different topics.
**Same as:** GNET 891, BCB 891.

**MATH 892. Topics in Computational Mathematics. 3 Credits.**
Topics may include: finite element method; numerical methods for hyperbolic conservation laws, infinite dimensional optimization problems, variational inequalities, inverse problems.
**Requisites:** Prerequisites, MATH 661 and 662.

**MATH 893. Topics in Algebra. 3 Credits.**
Topics from the theory of rings, theory of bialgebras, homological algebra, algebraic number theory, categories and functions.
**Requisites:** Prerequisite, MATH 677.

**MATH 894. Topics in Combinatorial Mathematics. 3 Credits.**
Topics may include: combinatorial geometries, coloring and the critical problem, the bracket algebra, reduced incidence algebras and generating functions, binomial enumeration, designs, valuation module of a lattice, lattice theory.
**Requisites:** Prerequisite, MATH 641; permission of the instructor for students lacking the prerequisite.

**MATH 895. Special Topics in Geometry. 3 Credits.**
Topics may include elliptic operators, complex manifolds, exterior differential systems, homogeneous spaces, integral geometry, submanifolds of Euclidean space, geometrical aspects of mathematical physics.
**Requisites:** Prerequisite, MATH 781.

**MATH 896. Topics in Algebraic Topology. 3 Credits.**
Topics primarily from algebraic or differential topology, such as cohomology operations, homotopy groups, fibre bundles, spectral sequences, K-theory, cobordism, Morse Theory, surgery, topology of singularities.
**Requisites:** Prerequisite, MATH 776; permission of the instructor for students lacking the prerequisite.

**MATH 920. Seminar and Directed Readings. 1-3 Credits.**

**MATH 921. Seminar. 3 Credits.**

**MATH 925. Practical Training Course in Mathematics. 3-5 Credits.**
Required preparation, passed Ph.D. written comprehensive exam. An opportunity for the practical training of a graduate student interested in mathematics is identified. Typically this opportunity is expected to take the form of a summer internship.
**Repeat rules:** May be repeated for credit.

**MATH 992. Master's (Non-Thesis). 3 Credits.**

**MATH 993. Master's Research and Thesis. 3 Credits.**
This should not be taken by students electing non-thesis master's projects.
**Repeat rules:** May be repeated for credit.

**MATH 994. Doctoral Research and Dissertation. 3 Credits.**